Stair Climbing Multifunctional Walking Robot

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Abstract. China has the largest number of elderly people in the world, and many of them have the problem of mobility. At present, there are some problems in the market, such as single function, difficult operation and lack of safety protection. The walking aid robot can not only meet the demands of the old people, satisfy the basic requirement of walking or the transfer between sitting and standing, but can also help the old grab objects from the further place. It has the advantages of simple operation, abundant functions, low cost in maintenance, high degree in safety index and so on, which can completely meet the needs of modern society.

1. Background

1.1 Social background and current status

According to the State Statistical Bureau, in recent years, the Chinese population is aging rapidly (Figure 1.). In the late 2018, there are 249,490 thousand people who are 60 or older, accounting for 17.9% of the total population. Comparing with other countries in the world, the average increasing rate from 1990 to 2020 is 2.5%, while China’s annual rate is 3.3%. Forecasting from the existing data, the proportion of the aging people will be raised up to 30%[1].

With the gradual increase of age, the aging of the body reduces the ability of the elderly to move, so the elderly cannot walk or stand like ordinary people. Therefore, some elderly people try to avoid walking and stay in a sitting position for a long time. But sedentary will also have an adverse effect on the elderly. From sitting to walking, lying to standing, the elderly will spend more time and energy than average people. Therefore, with the assistant of walking aids can effectively help the elderly achieve mutual conversion between various postures and reduce sitting time at the same time. With the aging of human body, the strength of your muscle decreases year by year, and there are some dissimilarity in the body due to the different parts. The specific manifestation is "His leg is his first aging site". Because of the greatly reduce in elderly’s strength in their lower limb, our walking aid is designed to support the whole body by upper limbs[2][3].

In the face of the situation, an issue we need to solve urgently is designing a robot that can help the elderly to complete the mutual conversion between various postures using only the power of the upper body.

Assistive devices (Figures 2, 3, and 4), which can support the elderly and help people with inflexible legs or even walking ability to take care of themselves, to make them can go out for walks like normal people. Mobility equipment can be divided into three types according to the structure: fixed type, interactive type and wheeled ahead type[4].
Figure 1. China’s population aged 60 or over from 2010 to 2018

Regarding the stair climbing robot, research work in western countries has certain advantages in terms of starting time and both in the depth. The relatively formed stair climbing structure can be summarized into the following five types (Figure 5.): wheel type, crawler type, leg structure climbing type, wheel & track & leg composite type, as well as lift assisted climbing devices.

Figure 5. different types of stair climbing devices

There are two types of devices that assist the elderly to get up are common in the market (Figures 6, 7, and 8.). One is a dedicated electric nursing bed, and the other is a lifting support belt which does not require electricity[5].

2. Function and principle

2.1 Design ideas

The stair-climbing multifunctional walking robot is composed of five systems. It can not only complete the function of the existing walkers to help the elderly to walk, but also can transform to the position according to the wishes of the elderly. At the same time, it can also rely on its power of electricity to go up and down the stairs, and provide support to the elderly during the climbing process (Figure 9.).
In addition, the robot is equipped with a holding arm (Figure 10.), which can help them stand and sit. The robotic arm on the robot can help older people grab items beyond what they can touch. Instead of bending down or standing up, what they only need to do is to move their fingers to complete all operations. We have also designed multiple safety mechanisms to ensure the safety of the elderly during their use.

2.2 Concrete structure

2.2.1 Mobility system
The mobility system is consisted of a frame and a chassis with motors and wheels. The design of the bracket has referred to a variety of existing walking equipment and adopts ergonomic design to strive for the elderly to use the walker in the most comfortable posture. On the support of the walker, there equip a quick-release device, which can quickly adjust the height to meet the needs of elderly people of different heights. There is a variable angle and elbow locked support in front of the handle of the walker (Figure 11.). When the elderly use the walker to help them move, they can not only hold the handle to support the body, but also put the entire forearm on the elbow support of the walker (Figure 12.), so as to reduce the force of the opponent and reduce fatigue.

The walker bracket is equipped with a grip (Figure 13.). The grip integrates a multi-function control system and adopts ergonomic design. It can also rotate the entire forearm on the elbow bracket of the walker to rotate the shaft. It is connected with a spring to a pressure sensor and can rotate within a range of -2 ° ~ 3 °. The elderly do not need to move the walker by themselves. If the speed of the walker needs to be changed, (when unlocked) only a different amount of force needs to be applied to the handle of the walker. The main controller recognizes the force detected by the pressure sensor, and then instructs the motor to accelerate or decelerate, thereby realizing the design concept of controlling the robot movement according to the user's intention.

2.2.2 Building climbing system
Since most of the old buildings in which the elderly live does not have elevators installed, the elderly need to use the handrails of the corridor to assist them in climbing the stairs. And if the walker can provide support to the elderly during the climbing process, it will greatly facilitate the elderly's travel and reduce the potential safety hazards. Therefore, we have designed a climbable chassis.

After consulting relevant information, we found that the structure, a mature and feasible method to achieve building climbing, which is three wheels as a group, distributed in a triangle and constitutes a large group of wheels. Therefore, the robot's climbing system is composed of two sets of triangular climbing wheels. The front small wheel is an omnidirectional wheel (Figure 14.), and the rear small wheel is an ordinary wheel (Figure 15.). The triangle wheel set is controlled by a motor mounted on the chassis, and the three small wheels on the triangle are driven by gears to rotate through the motor mounted on the triangle.

After the elderly switch the walker to the "climbing mode" through the handle, when encountering the steps, the sensor detects that the front wheel encounters resistance and automatically makes the triangle wheel set rotate, and the small wheel also rotates forward, turning 120 °, the robot climbed up a step. Similarly, when going downstairs, after the sensor detects that the front wheels are suspended, the triangle wheel set is rotated forward, so that the action of going downstairs is completed.
As the robot climbs the floor, the angle between the chassis and the ground will continue to change. This will cause the angle of the stent to change accordingly. The elderly also need to adjust the holding posture according to the angle of the stent when in use, which is very inconvenient and has potential safety hazards. Therefore, we designed a bracket angle adjustment mechanism driven by a motor driven worm gear reducer at the bottom of the bracket (Figure 16.). It can keep the bracket level with the ground at all times (Figure 17.), making the elderly safer and more convenient when using it.

### 2.2.3 Sitting system

People with reduced mobility often need to rest, and they also have many difficulties when standing and sitting. Traditional walkers can only solve the problems of standing and walking, and cannot provide support for the elderly in the process of sitting up. Therefore, we designed a sit-up system, which consists of two left and right arms, each of which contains three joints that change direction and two support rods of variable length. Arms can help the elderly to stand and sit.

When helping the elderly to stand, the arm of the walker is first opened (as shown in Figure 18.), and then retracted. The robot automatically recognizes the seat and adjusts the support cushion to the same height as the seat. Then the arm angle decreases and gently supports the hips of the elderly (Figure 19.). Then extend the shoulder support bracket and rise along the gap between the elderly's arms and body until they support the elderly's shoulders (Figure 20.). When standing up, the arms of the walker support the hips and shoulders of the elderly at the same time, helping the elderly to slowly stand up. At the same time, the elderly can also help to stand by holding a variable angle bracket (see Figure 21). The above actions are performed in the opposite direction to help the elderly to sit down.

The arm is designed to be retractable, and it can automatically adjust the length to suit the elderly of different sizes. When not in use, the arm can be stowed to the side of the stand post so as not to interfere with other movements of the walker.

### 2.2.4 Pick-up system

Older people's waists are not flexible enough, and they have less power, which is very inconvenient if they need to grab items. So, we designed a system to help the elderly to pick things up (Figure 22. and 23.). It consists of a robot arm and a robot claw. The carefully designed robot arm is composed of three sections, and two motors are connected at each two sections to control the rotation in the up, down and left and right directions respectively. The mechanical claw is composed of four small claws, which
increases the grip of the object. After calculation, the manipulator can reach the range of motion from the ground to the height of the human hand.

The robotic arm is controlled by a rocker and buttons on the handle of the bracket. The user can use the rocker to control the angle of the robotic arm, and use the buttons to control the opening and closing of the mechanical claw. In this way, the elderly can grab the items they want without bending down or using force. We also reserve the setting of changing the parameters of the robot arm in the control system of the display screen. The user can control the robot arm in different ways according to his preference.

2.2.5 Security system
The most important thing to provide mobility equipment for the elderly is to ensure the safety of users. If something unexpected happens during use, the consequences will be unimaginable. Therefore, we have designed multiple safety guarantee mechanisms to ensure the safety of the elderly.

When the elderly use the grip, they may want to move the position of the robot, or they may just want to use a walker to maintain their balance. If at this time, the force signal acting on the grip is mistakenly identified as "moving", it will cause a great safety accident. To prevent such accidents, we have designed a multi-redundancy anti-mis-operation mechanism. The elderly need to press the "Unlock" button on the grip while applying force (Figure 24.), and their legs are in the centre of the walker chassis (detected by the infrared sensor, as shown in Figure 25.) before the robot recognizes the signal To "Move" and change the position.

When the robotic arm is extended, its centre of gravity will change according to the angle between the chassis and the ground. If the elderly then exert lateral force on the walker at this time, the walker may overturn, causing a safety accident. So we designed two counterweight sliders on the robot's chassis (Figure 26.). The weight slider can be automatically driven by the motor and screw when the centre of gravity of the robot changes, to move forward and backward to adjust the center of gravity. After calculation, the robot can withstand a maximum force of 103.3N / 81.5N (front / rear) when going upstairs; it can withstand a force of 59.7N / 203.3N when going downstairs. In normal use, it is very difficult for a dumping accident to occur. In the process of helping the elderly to sit up, the robot's centre of gravity will also shift extremely backward. It is not enough to just use the weight slider at this time. Consider that the robot is at a standstill when sitting up. We designed two foldable support legs (Figure 27.), which are installed at the rear of the robot. When it is needed, the robot will place the support leg on the ground to ensure that the robot does not fall back.
In addition, in order to prevent accidents when the elderly are walking outdoors, we will add a camera in front of the walker to visually identify the elderly and warn them when an accident may occur. In the event of an emergency, the elderly can also quickly ask their families for help through the screen on the armrest.

3. Design Parameters
Since the use environment of the climbable multifunctional walking robot is concentrated in the old quarters, the corridors here are mostly narrow. In order to design a robot that is more suitable for the environment, we conducted a field survey of the corridors of the old community. It is found that the minimum width of the stairs is 1000mm, the height of each step is about 160mm, and the length is about 300mm. By calculation, we determined the size of the robot.

The design parameters of the robot are shown in the following table:

| PARAMETER       | NUMERICAL VALUE | PARAMETER       | NUMERICAL VALUE |
|-----------------|-----------------|-----------------|-----------------|
| Length          | 710mm           | Minimum turing angle | 998mm          |
| Width           | 700mm           | Climbing height  | 177mm           |
| Height          | 975-1175mm      | Quality         | 25kg            |
| Wheelbase       | 380mm           | Lateral maximum force(up) | 81.5N/103.3N |
| Wheel diameter  | 140mm           | Lateral maximum force(down) | 59.7N/203.3N |
| Wheel width     | 40mm            | Battery capacity | 1000Wh          |
| Classis height  | 85mm            | Rated voltage   | 24V             |

4. Design summary
This climbing-type multifunctional walking robot has advanced functions, convenient use, simple maintenance, and high safety, which is suitable for families to buy and use. Due to the raw material restrictions of the robot, its production cost will not be too low. However, due to his great help to the elderly, he can liberate the young labor force, and the price is still acceptable to ordinary families. So, we expect it to have a good market outlook.

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