Low Cost Two-footed One-handed Stair Walker

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Abstract: Aiming at the limitations of existing climbing equipment, this paper designed a "two-footed and one-handed" automatic climbing system to go upstairs. Through the climbing shoes and gloves, it is more convenient for carry than electric wheelchairs, and cheaper than seat stair-climbers. In addition, it only needs to install foot rails and hand rails in the corridor, and no power devices are required in the building fixtures. Thus, it overcomes the high installation cost and post-maintenance of traditional stair-climbers. Therefore, it is very beneficial for a widespread promotion and the market prospects are very broad.

1. Introduction

Nowadays, most of the buildings below seven floors in China are not equipped with elevators. The difficulties of going up and down have become problems for high-rise households, especially the elderly. At the same time, the high cost of changing a house, the high price and complex approval process for installing traditional van elevator, have all become obstacles to living room with elevators.

In the world market, there are mainly two kinds of electric wheelchairs to solve the problems of climbing stairs. One is a ratchet-shaped stair-climbing wheelchair, which is mainly achieved by splitting one wheel into a three-wheel structure; and the other is a crawler-type wheelchair, relying on crawler belt lapping between the upper and lower steps at the same time. However, the former must be assisted by outsiders. It has so poor adaptability to different spacing stairs that travel course is bumpy. Also, the latter is bulky for carry, complicated in structure and expensive. As a result, these existing stair-climbing wheelchairs are mainly served for the disabled and special need occasions.

In order to solve these problems, for the stair-climbing system installed in buildings, China has successfully developed two kinds of stair-climbing machine, which is clinging to the stair railings. One is to install a sliding seat on the handrail fence, and the other is to install a translatable pedal instead. These two types of stair-climbers are also called seat stair-climbers or pedal stair-climbers. They are mainly composed of three parts: track, driving device, seat or pedal. Such seat elevators have been applied very few in Shanghai, Tianjin and other cities. Although compared to retrofitting van elevators, such a stair climber is small in size and easy to install, but its driving device is fixed in the building, resulting in an installation cost of 50,000 per floor and hundreds of thousands per units. Even in large cities with high housing prices, because of high installation fees, equally shared electricity and post-maintenance issues, the promotion progress of the seat stair-climber is still very slow. Furthermore, since there is only one seat or pedal on the same floor, this type of stair-climber cannot achieve many people climbing simultaneously in the same floor, and the travel speed cannot be controlled by users. So there are also some function limitations besides price limitations.

2. System Structure

Aiming at the limitations of existing equipment, we designed a "two-footed and one-handed" automatic climbing system to go upstairs. Through the climbing shoes and gloves, it is more convenient for carry than electric wheelchairs, and cheaper than seat stair-climbers. In addition, it

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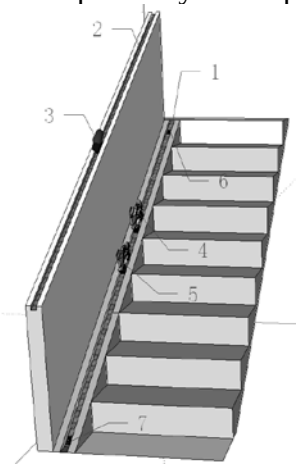
only needs to install foot rails and hand rails in the corridor, and no power devices are required in the building fixtures. Thus, it overcomes the high installation cost and post-maintenance of traditional stair-climbers. Therefore it is very beneficial for a widespread promotion and the market prospects are very broad.

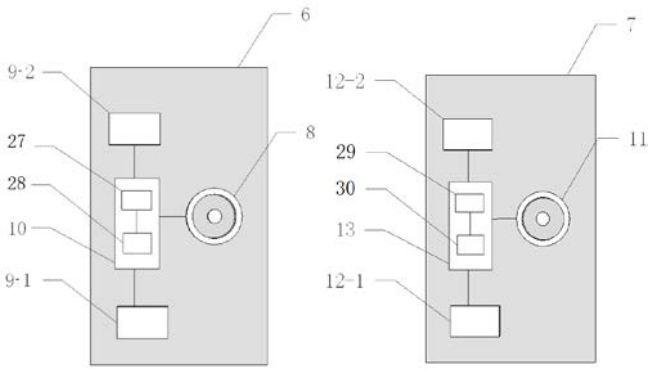
As system structure shown in Figure 1, the system includes: foot track, hand track, two electric shoes and one electric glove. The electric shoes include left foot and right foot. The only one glove should be wore on your left or right hand respectively with up or down the stairs.



1,foot track;2,hand track;3,electric glove;4,right electric shoe;
5,left electric shoe;6,top floor module;7,bottom floor module

Fig.1 The general sketch of the “two-footed and one-handed” climbing system

The foot track and the hand track are fixed on the slope ground and handrail on the side of the stair railing. The top and bottom of each foot rail are respectively provided with a top floor module and a bottom floor module (As shown in Fig. 2), which all include a camera, a travel switch pair and a start & stop control transmitter module.



6,top floor module;7,bottom floor module;8,top floor camera;9-1,9-2,top floor travel switch pair;10,top floor start & stop control & transmitter module;11,bottom floor camera;12-1,12-2,bottom floor travel switch pair;13,bottom floor start & stop control & transmitter module;27,floor-top single chip;28,floor-top wireless transmit module;29,floor-bottom single chip;30,floor-bottom wireless transmit module

Fig. 2 Top floor module and bottom floor module

Each electric shoe include a power, an electric shoe rack, a bottom plate, front and rear wheels. Below the electric shoe rack is the shoe bottom plate. In the front and back of the shoe’s bottom plate, there are respectively the front and rear shoe wheels, embedded in which are the front and rear wheel motors. The electric shoe sole is provided with a user identification code, a receive& control module and a speed control & transmit module; the speed control & transmit module includes an acceleration gravity sensing device, a deceleration gravity sensing device and a speed control & transmit circuit.

Similar to the above, electric glove include a power, glove body, bottom plate, front and rear

wheels. Below the glove body of the electric glove, there is the bottom plate of the electric glove. In the front and back of the glove bottom plate, there are respectively the front and rear glove wheels , embedded in which are the front and rear wheel motors. A hand receive & control module is arranged on the glove bottom plate.

When the system works, the cameras at the bottom and top floor are responsible for taking pictures of the user's identification codes when the left and right feet slipping. Thereby the start control&transmit modules in the top and bottom floor can identify the left or right foot and the user's information. Then a start or stop signal with the user name is issued according to the touch sequence of the two travel switches in the top or bottom floor. During running, the accelerating gravity sensing device and the decelerating gravity sensing device in the bearing shoe can respectively receive a certain pressing force of the forefoot and the rear heel, thereby respectively generating an acceleration signal or a deceleration signal. Then the speed control&transmit circuit will send these signals together with the user information. The two-foot's receive&control module and the hand's receive&control module are responsible for receiving the start-stop signal from the start control&transmit module in the bottom and top of the floor, and also receiving the acceleration/deceleration signal sent by the speed control&transmit module. So that they can start/stop and accelerate/decelerate the motors in front-wheel and rear-wheel of the left foot, right foot and the electric glove.

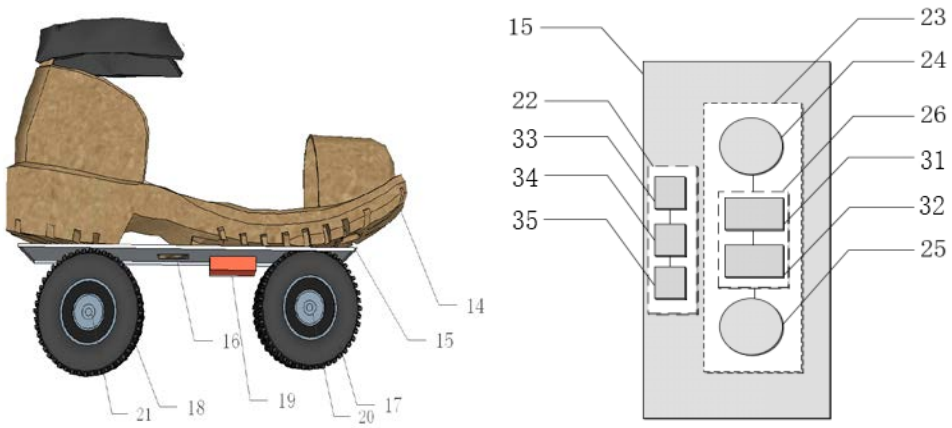
3. The Optimization and Realization for the Design

3.1 The Optimization

On the basis of the system architecture, in order to improve the driving force, safety and user experience of the climbing system, the project team carried out a series of optimizations for the design.

The foot track and the hand track are designed as U-shaped grooves with the depth of 2-4 cm, that is, about 3 cm recessed from the surrounding water level, which can embed nearly half of the electric shoe wheel and the electric glove wheel into the ground or the handrail. The bottom surface of the groove is made of high-friction concrete material. The bottom of the groove is provided with a toothed belt to mesh with the motor roller, which prevents the sliding and derailing of the wheel when it is stationary, and ensuring the safety and reliability of the traveling process. The smooth over-track is used to connect adjacent stairs at the corners. That is, the foot track includes the corners of the stairs, thereby improving the smoothness of the travel. Since the 180 degree turn between the two layers is in danger of being out of orbit, it is necessary to control the motor stop during the layer changing to ensure the safety. However, because there is a track at the corner of the layer, if continue to climb the building, people do not have to go out of the track, and can use the inertia of the manpower to go to the next floor. So that the system design is convenient and reliable.

We use electric shoe racks instead of traditional electric shoes, as is shown in Fig.3. So that the users only need to attach electric shoe racks outside their shoes when using them, which is more convenient to wear and carry. Each electric shoe and electric glove has a front wheel motor and a rear wheel motor, and the two motors work together to further improve the driving force and achieve a smooth manned climbing. This paper uses a hub motor with integrated hub and motor, which can be embedded inside the tire, which greatly reduces the system volume. The user identification code is set in the middle of the lower surface of the electric shoe sole to avoid the front and rear wheels, which is convenient for the camera catching in the foot track. The power supply for the electric shoe and the electric glove are all rechargeable 36V lithium battery, which is small in size and high in energy storage. So that the load is lighter and the standby time is longer.



(a) Left electric shoe structure (b) Circuit module inside the left electric shoe bottom plate
14, left electric shoe rack; 15, left electric shoe bottom; 16, left foot user identification code; 17, left electric shoe front wheel; 18, left electric shoe rear wheel; 19, left electric shoe power supply 20, left electric shoe front wheel motor 21, left electric shoe rear wheel motor 22, left foot receive&control module; 23, speed control&transmit module; 24, acceleration gravity sensing device; 25, deceleration gravity sensing device; 26, speed control circuit
31,speed control single chip;32,speed control wireless transmit module;33,left-foot wireless receive module;34,left-foot single chip;35,left-foot motor controller.

Fig.3 Left electric shoe

For the building with the handrail in the left hand position when climbing upstairs, in this climbing system the right electric shoe is on the front, the left one behind and the electric glove is wore on the left hand when going upstairs, on the contrary, when going downstairs, the left electric shoe is on the front, right one after and the electric glove is wore in the right hand. Thus the balance of the human body is maintained and the comfort of climbing stairs is increased. Since the gravity center when moving up and down is always in the left electric shoes, the speed control module is designed only on the left electric shoe's sole. On the one hand, the center of gravity is on the left foot, so that the left foot makes the force more convenient and more real-time. On the other hand, only one foot is set as the command source, so that the control commands are more clear and no confusion. Because the forefoot is stressed when the human body leans forward. At this time, the human body is ahead of the wheel, and the wheel needs to accelerate to catch the human body to maintain the balance. Therefore, the accelerating gravity sensing device is designed on forefoot's force point. Similarly, the deceleration gravity sensing device is disposed on the heel's force point in the electric shoe sole. For the building in which the handrail is in the right hand position when climbing upstairs, the design scheme of the climbing system is similar and will not be described in detail again.

In order to further improve the climbing performance, the motor is set to the high-speed mode when going upstairs. Thereby the output current and power of the motor is increased, and the driving force of the system is increased effectively, so as to achieve climbing successfully. To ensure the safety performance when going downstairs, the motor is set to a low-speed mode to reduce the risk of falling down the stairs and achieve a smooth downstairs.

In order to speed up the development of the system and optimize the control performance, a series of control modules in the "two-legged and one-handed climbing system" are selected as much as possible by using the existing well-equipped microcomputer, motor controller and wireless transceiver module. For example, the start/stop control modules in the top and bottom floor are realized by the single chip and the wireless transmitting module; the speed control transmit circuit is realized by the speed control single chip and the speed control wireless transmitting module; the receive & control module of the left foot, the right foot and the hand are all realized by the wireless receiving module, the single-chip microcomputer and the motor controller. The motor controller is a dual-drive motor controller, which directly connects and controls the front wheel motor and the rear wheel motor in the left foot, the right foot and the hand.

The signals sent by the start control module in floor bottom & top and the speed control & transmit module are all carried with the user name information. Only the supporting receive & control module in left foot, right foot and the hand will respond after receiving. So that mutual interference can be avoided when multiple people climb the building at the same time.

3.2 Realization

After optimizing the design, aiming at the high driving force and specific operational requirements in the climbing process, this paper puts forward the specific implementations as follows.

The left electric shoe's front wheel motor and rear wheel motor, right electric shoe's front wheel motor and rear wheel motor, electric glove's front wheel motor and rear wheel motor are all required to be exactly the same in terms of speed, torque and other performance indicators. These can ensure that, in the travel process the left foot, the right foot and the hand can be synchronized in parallel. So that the HB-113 high-torque DC brushless hub motor of Shenzhen baisheng Steel Technology Co., Ltd. is used. The motor has a 1:4 deceleration and a large torque. The driving force is super strong and the load-bearing capacity is very good. It can smoothly realize manned climbing. The motor has an internal electromagnetic brake function, which eliminates the need for an additional brake system and makes control easier.

The left foot's motor controller, the right foot's motor controller, and the glove's motor controller are all optimized and selected by the circuit boards of the T2 type wired double drive hub motor controller of Shenzhen baisheng Steel Technology Co., Ltd., which can meet the requirements of this climbing system. For motor start & stop, acceleration &deceleration, high and low speed gear and other controls, the controller can be directly changed from the original button to the single-chip microcomputer. The modification is simple and easy, which accelerates the development process of the system.

The floor-top and floor-bottom MCU, speed control MCU, and the left-foot/right-foot/hand MCU in the system are all preferred STC12C5A60S2 MCU. The floor-top and floor-bottom wireless transmitting module and speed control & transmit wireless transmitting module in the system are all NRF24L01 type of wireless transmitting module. Also the wireless receiving module of the left foot/right foot/hand are preferably a wireless receiving module of the NRF24L01 type.

The travel switch on the foot track and the hand track is realized by the Omron D4V-8108 type of travel switch.

4. Working Principle

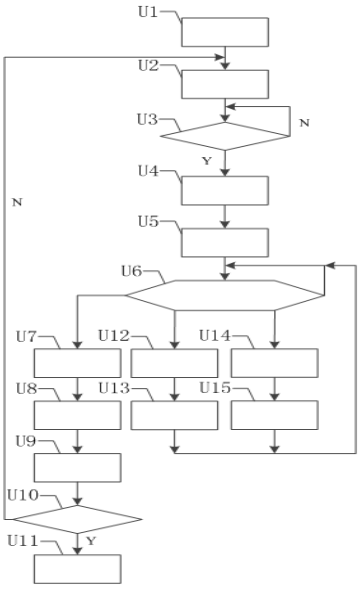


Fig.4 Working Principle Upstairs

In the designed "two feet and one hand stair walker", the upstairs operation methods are shown in Figure 4.

U1: The left and right feet are respectively put on the left electric shoes and the right electric shoes, and the left hand is put on the electric glove.

U2:At the bottom of the floor, the right foot and the left foot are stepped into the foot track one by one, and the front and rear wheels of the left electric shoe and the right electric foot are embedded in the foot track; the left hand hold the handrail and insert the front and rear wheels of the electric glove into the hand track.

U3:If the bottom travel switch of the floor is touched from bottom to top, and the bottom camera captures user's identification code in the left foot, the bottom start&stop control module collects the motor start signal and the step should enter U4; otherwise, should stay at U3.

U4:The bottom start&stop control module sends an upstairs start command with user's name information.

U5:The left foot receive&control module, right foot receive&control module and hand receive&control module simultaneously receive the upstairs start command with the user name information. Then they respectively start the left shoe's front wheel motor and rear wheel motor, the right shoe's front wheel motor and rear wheel motor, the electric glove's front wheel motor and the rear wheel motor. Each motor starts up in a high speed mode with high power and strong driving force, and the going upstairs starts up.

U6: If the top travel switch of the floor is touched from bottom to top, and the top camera captures the user identification code in the left foot, the top start&stop control module collects the stop signal and the step should enter U7; otherwise, if the accelerating gravity sensing device of the forefoot collects an acceleration signal, the step should enter U12;otherwise, if the decelerating gravity sensing device of the rear heel collects a deceleration signal, the step should enter U14; otherwise, stay at U6.

U7: The floor top start&stop control module sends a parking instruction with user name information.

U8:The left foot receive&control module, the right foot receive&control module, and the hand receive&control module receive the parking instruction with the user name information. Then they respectively control the left electric shoe's front wheel motor and the rear wheel motor, the right electric shoe's front wheel motor and the rear wheel motor, the electric glove's front wheel motor and the rear wheel motor, which will stop and brake at the same time, and the going upstairs is stopped.

U9: The right foot and left foot step into the foot track on the corner of the stairs.

U10:If the target floor has been reached, enter U11; otherwise, enter U2 to prepare going to the next floor.

U11:The right foot and left foot respectively step out of the foot track, and then the left and right electric shoe, and the electric glove are took off, that is the end of the climbing.

U12:The speed control&transmit circuit sends an acceleration command with user name information.

U13:The left foot receive&control module, the right foot receive&control module, and the hand receive&control module all receive the acceleration command with the user name information, respectively accelerating the left electric shoe's front wheel motor and the rear wheel motor, the right electric shoe's front wheel motor and rear wheel motor, electric glove's front wheel motor and rear wheel motor, and then the step should return to U6.

U14: The speed control&transmit circuit sends a deceleration command with user name information.

U15: The left foot receive&control module, the right foot receive&control module, and the hand receive&control module receive the deceleration command with the user name information, respectively decelerating the left electric shoe's front wheel motor and the rear wheel motor, the right electric shoe's front wheel motor and rear wheel motor, and the electric glove's front wheel motor and rear wheel motor, then the step should return to U6.

In this system, the downstairs operation methods are similar with the upstairs, this paper won't go into details here.

5. Innovation and Application

According to the electric shoes and electric gloves, the intelligent building system of "low cost two-footed one-handed stair walker" adopts the method of left and right feet one after the other to climb the building, effectively reducing the occupation of the foot space for the stair space. The electric glove in the hand is used to climb the building, which effectively improves the driving force and balance of the climbing. The system is simple, efficient, and innovative, filling the gaps in the field of related technology at home and abroad.

At the beginning and the end of the driving, the electric shoes of the force-bearing foot touch the pair of travel switches at the starting point or the end point. So that the motor can be automatically started and stopped, avoiding the untimely and wrong operation during manual control. The motor can be continuously decelerated until it stops by lifting the ball of left foot or the body backwards, so that it can be decelerated early to avoid excessive braking or untimely braking.

This project can realize that multiple people go upstairs or downstairs on the same floor and at the same time, which overcomes the abuse that the seat climber and the pedal climber can only be climbed by single person on the same floor. The travel speed is completely controlled by the user, while the seat climber and the pedal climber is not convenient to stop and get off at any time during the ride, and the speed is too single.

Going upstairs by climbing shoes and climbing gloves, this design is more convenient to carry than the electric climbing wheelchair, and it is cheaper for cost than the seat climbing machine and the pedal climbing machine. Only the foot track and hand track are needed to be installed in the corridor. And no power device is needed in the building fixed facilities. Thus it overcomes the disputes caused by the high installation cost, post-maintenance and public electricity bill of the traditional climbing machine, which is very beneficial to popularize in the residential building. Above all, the market prospect of this climbing system is very broad.

6. Conclusion

This system is utilized to climbing up the building by electric glove and shoes. Through the system's operation process of the "two-footed one-handed stair walker", not only its travel speed can be completely controlled by the user's foot movements, but also the users can stop and get off at any time. Thus, this system overcomes the disadvantages of single speed and single person in the seat or pedal climber, the use is more convenient and reliable. The most important is, this system only needs to install two rails on the corridor to be put into use, which effectively reduces the installation and maintenance costs, and is very beneficial for widespread use in residential buildings.

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