# Research on lower extremity assisted exoskeleton for people who need rehabilitation training and stairs assistance

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**ABSTRACT.** *The Assistant Exoskeleton for Lower Limbs are able to help the following three kind of people walk better: People with congenital defects in the lower limbs, those who have suffered major trauma to their the lower limbs, and those who use the lower limbs for work in a high frequency. For the exoskeleton of this project, aluminum alloy is adopted as the main material, high-power steering gear as the driving part, Arduino Uno as the main board, hard plastic as the lumbar support board, and Velcro as a aid for wearing. In order to make the movement of the exoskeleton more flexible without being too rigid, in this project, an extra set of exoskeleton was manufactured to collect motion data, and a program was written to record the movement of people walking. In the end, this exoskeleton device will mainly provide support for the waist, and share the pressure on the legs, so as to can help anyone with walking fatigue and care for people's waist and leg health.*

## 1. Introduction

Powered exoskeleton (also known as powered armor or powered suit) is a wearable mobile device that is driven by electric motors, pneumatic devices, levers, hydraulic systems or a combination of the above, to enhance the strength of limbs and endurance of their movements. The device is designed to provide back support, sense user movement and send signals to drive motors. Most exoskeletons are able to support shoulders, waists, and thighs, and help people move or lift and hold heavy objects, while reducing the pressure on the back. While the lower extremity Assistant exoskeleton can help people with atrophied waist and leg functions, it can also provide assistance to people who often use their waist and leg to perform a lot of work to prevent future functional injuries. Compared with other invented instruments, in addition to operating more in line with normal feeling of force, the exoskeleton can effectively support the human body from the root, but also solves the physiological defect inferiority that is very common among some people.
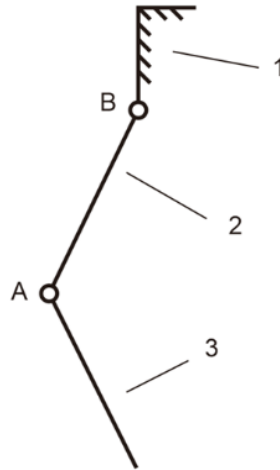
## 2. Theoretical Research



*Figure. 1 Unilateral mechanical schematic.*

From F (degrees of freedom) = 3n (number of free members)-2FL (number of low pairs)-FH (number of high pairs), we can know that the degree of freedom of the device on one side is $3 \times 2\text{-}2 \times 2\text{-}0 = 2$ . In addition, the device is unilaterally driven by two high-power steering gear power sources. From the analysis result of the unilateral degree of freedom and the power source, it can be known that the unilateral degree of freedom = the number of power sources, meaning that the device has a certain motion situation.

In the mechanical schematic diagram (Figure 1), a total of 2 rods are identified, and Nos. 2 and 3 are each a free rod.

The low pair refers to the kinematic pair composed of two members through surface contact. In the present exoskeleton, they are both plane-rotating pairs, a total of two.

The high pair refers to the kinematic pair connected by points or lines in the two kinematic members, which does not appear in this device.
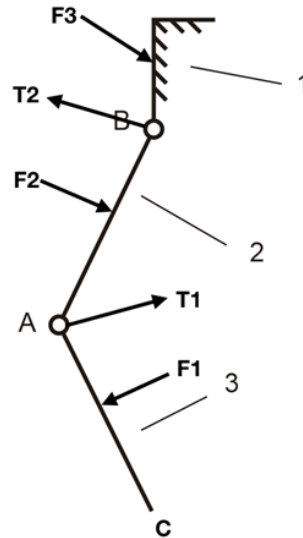
*Figure. 2 Unilateral force analysis.*

As shown in the figure (Figure 2) is the unilateral force analysis diagram of the exoskeleton. In the picture, F1, F2 and F3 are the combined force of the pressure exerted by the user on the exoskeleton and the weight of the exoskeleton, but due to the posture, they can be regarded as three different forces. Then we get:

$$F1_y + F2_y + F3_y = G \tag{1}$$

The forces generated by the servo torque are expressed as T1 and T2. Due to the limitation of the height of the raised leg, the size of the resistance arm that the steering gear needs to resist in each case is about 23.5cm at the maximum.

Assuming that F1, F2, and F3 evenly disperse the total pressure, we get the following formula:

$$\frac{2}{3} \times \sqrt{2} \times \left( G_h + G_e \right) \times L_r = a_2 \, T2 \times L_s \tag{2}$$

Assuming $G_h$ is about 70kg, $G_e$ is about 10kg, and the power arm is about 4.8cm, the calculation results show that the size of the steering gear must reach 370kg / cm. This proves that the 380kg / cm steering gear that has been purchased can just maintain the operation of the exoskeleton.

In terms of hardware (Figure 2.3), Assistant Exoskeleton for Lower Limbs is controlled by a single-chip microcomputer and driven by a high-power steering gear, and the material is mainly a bent aluminum alloy plate. A knob is set at the waist position to switch between different walking modes, such as flat ground and step up.

*Figure. 3 CAD screenshot of the exoskeleton.*

In terms of program, we wrote one that records the changes in joint angles of people during walking for a set of replica exoskeleton made of wood, and used it to record angle changes data in various walking states, and the main exoskeleton is adopted to read the data at these angles to simulate the movement of a person while walking.

In terms of wear, in order to let the exoskeleton fit the body of different people well, we chose Velcro as the binding material and foam plastic as the pad, and through this, the exoskeleton can be fixed to the user.

## 3. Hardware Design

### 3.1 Design of Sheet Metal Parts

In the "Limb" section of the exoskeleton, we chose sheet metal as the main material. Sheet metal is a thin metal plate (usually under 6mm), which is made through a comprehensive cold working process, including cutting, punching / cutting / compositing, folding, welding, riveting, splicing, forming (such as automobile body). The salient feature is that the thickness is the same for the same part. The products processed through the sheet metal process are called sheet metal parts. The designed sheet metal is in the shape of "[" (Figure 3). Without adding a lot of extra weight, this structure significantly improves the material's lateral pressure resistance, as a result, the entire structure is more stable, and the maximum load it can bear is greater.

*Figure. 4 Cross section of the "calf" in the exoskeleton.*

### 3.2 Design of Waist Support

In order to better help users reduce the pressure on their waists, or to help users with waist injuries to apply waist strength normally, a lumbar support is installed in the front and back of the user's body (Figure 5). With this device, no matter what body posture, the user can get the support of the waist, making some activities that use the waist easier.



*Figure. 5 Appearance of the front and back lumbar supports.*

### 3.3 Joint Design

At each joint, the connection from the servo shaft to the sheet metal is achieved by a flange. For example (Figure 6), at the "knee" joint, the steering gear is fixed on the "thigh", the flange is fixed on the round shaft of the steering gear by a top wire, and then the "calf" is fasten to flange.



*Figure. 6 Connection method of "knee" joint.*

### 3.4 Wearing design

In order to make the exoskeleton fit well to different people's bodies, we chose Velcro as the binding material and foam plastic as the pad (Figure 7). In this way, the exoskeleton can be fixed to the user. Since the Velcro can be fixed at different lengths and the foam is compressible, people of different ages and different body sizes can comfortably wear the exoskeleton.



*Figure. 7 Velcro ring and foam plastic pad.*

### 3.5 Design of control device

In order to facilitate the user's control and let them intuitively operate, the exoskeleton mode is switched by using a knob. The circuit, the single-chip machine and the knob are all integrated into a box (Figure 8) in the "waist" of the exoskeleton, and the knob is extended out of the box to facilitate user control. Currently, there are two types of exoskeleton walking options: walking mode and stair climbing mode.



*Figure. 8 Circuit box and knob.*

## 4. Entry and Reading of Gait Data

### 4.1 Data Entry

In order to enter gait data (Figure 9), this project also needs a set of exoskeleton for recording data. To reduce costs, thin wood is selected as the material for the "data recording exoskeleton" and an adjustable resistor / potentiometer is chosen as the joint. By writing a program and using a single-chip computer to record, when the experimenter is wearing a "data recording exoskeleton" to walk, the adjustable resistance / potentiometer will record the gait data in real time and process the corresponding raw data. All processed gait data will be saved in 4 data sets for processing by the main exoskeleton.

*Figure. 9 Upright posture data being entered.*

### 4.2 Data Reading

The main exoskeleton will read the gait data set recorded and processed by the "Data Log Exoskeleton" and respond accordingly with corresponding actions. However, due to systematic errors, the initial data did not fully meet the requirements of the action. So we wear the main exoskeleton ourselves and experience the feeling of walking. During the process, we recorded the movement errors and finely adjusted the parameters and the offset of the original data in the program.
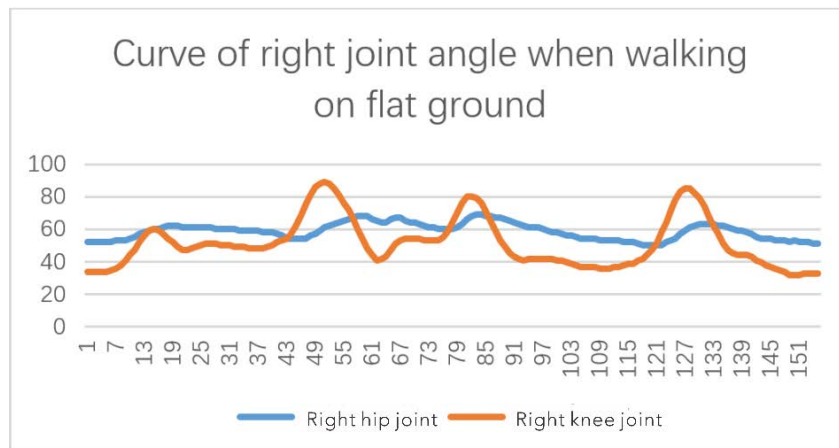


*Figure. 10 Curve of right joint angle when walking on flat ground.*

After several tests and adjustments, the gait data set can almost completely control the main exoskeleton to make corresponding actions, which meets the design requirements.

## 5. Summary and Outlook



*Figure. 11 Final product.*

Through the above design and adjustment, the limb-Assistant exoskeleton (Figure 11) basically meets the design requirements. Within the acceptable weight range (7.5kg / 10kg), it can support the weight of an average adult (<= 90kg), assist walking, and reduce the pressure on the waist and legs. For the final product, the mode selection function can also run normally. In different modes, it can accurately imitate the gait of ordinary people. After several tests, the project is summarized as follows:

1. The Assistant Exoskeleton for Lower Limbs can play a good role in the function of dispersing and reducing the pressure on the waist and legs.

2. Through a knob, the Assistant Exoskeleton for Lower Limbs can freely switch and adjust between several different walking modes

3. The Assistant Exoskeleton for Lower Limbs is equipped with a gait recorder, and more different walking patterns can be entered subsequently.

4. The Assistant Exoskeleton for Lower Limbs with simple results, can be applied to assembly line production.

In the process of production and testing, the following aspects can be improved:

1. Exoskeleton weight can be further reduced to improve portability and make it more market-competitive;

2. The exoskeleton wearing process can be further simplified to optimize the use experience;

3. In the future, the program can be designed to be further automated to determine walking gait on its own in some specific scenarios.

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