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Lower limb rehabilitation training device

HE Jing，HUANG Lingjie，ZHOU Xingyu, HE Chunshan
Institute of Mechanical and Vehicle Engineering,Changchun University
Corresponding Author: HE Chunshan

ABSTRACT: *This article introduces the mechanical structure design of a sit-down and lie-down lower limb rehabilitation robot that can provide rehabilitation training for patients with lower limb movement disorders. Due to the long treatment process and the lack of obvious effect in treating lower limb movement disorders, it is particularly important to design a rehabilitation robot that can help patients with reasonable, intelligent and effective rehabilitation treatment. The rehabilitation training of the sit-down and lie-down lower limb rehabilitation robot simulates the human walking action, allowing patients to sit or lie on the seat and complete the walking action of the lower limbs with the mechanical movement of the rehabilitation robot. The designed rehabilitation robot can freely adjust the length of the thigh and calf, and has a three-degree-of-freedom joint structure that can simulate human gait movement. The seat mechanism is designed with a backrest that can be adjusted to complete the training in different sitting postures. The mechanical structure design of this device mainly includes the design of the mechanical leg and the seat mechanism, based on ergonomics. The design of the mechanical leg is the core part, including the structural design of the three joints of the lower limb.*
Keywords: *Lower limb rehabilitation robot; Ergonomics; Mechanical structure design*

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I. INTRODUCTION

In the 1960s, robotic technology was first applied to assist patients with mobility impairments. During the initial research and development stage in the 1980s,significant progress was made in the field of rehabilitation robots in the 1990s. Tomeet diverse needs and training methods, various scientific research institutions indifferent countries carried out a series of developments and designs, achievingconsiderable success. From different research perspectives, lower limb rehabilitation robots have generally evolved into four different structural types: single-degree-offreedom, suspended, wearable, and lie-down.

The current prototypes of rehabilitation robots mainly focus on the upper limbs, covering all the joints of the upper limbs and the hand joints. The lower limb rehabilitation prototypes are mainly single-degree-of-freedom lower limb rehabilitation robots, which have a relatively simple structure and are very easy to operate, allowing many people to use them and being cost-effective. However, they only have simple movements and cannot meet the rehabilitation needs of patients50[1]. Suspended rehabilitation robots have shown effective results in gait recovery, but patients are suspended by ropes, which is uncomfortable and the process of wearing the device is very cumbersome; wearable ones are only suitable for later-stage assisted walking for hemiplegic patients who can walk independently; while bicycle-type rehabilitation training has simple movements and poor rehabilitation effects, making it difficult to meet the needs of patients with complex conditions.

Therefore, this design aims to develop a small-sized, lightweight, comfortable and aesthetically pleasing sitting and lying lower limb rehabilitation robot for patients with brain injuries, strokes, etc., to assist them in conducting rehabilitation training more efficiently and significantly improve the rehabilitation effect.The design of this project first involved the design of size parameters for each part and performance parameters.

II. Parameters Design of Rehabilitation Robots for Lower Limbs

Dimensional parameters of lower limb rehabilitation robot

Due to the varying body sizes of patients, the design of the lower limb rehabilitation robot in terms of thigh, calf, hip width, and foot length needs to be suitable for patients of all body types. Based on the average body dimensions of the general adult population in China, the average values for the majority of patients were obtained. Fig. 1 shows the measurement standards for various body parts.

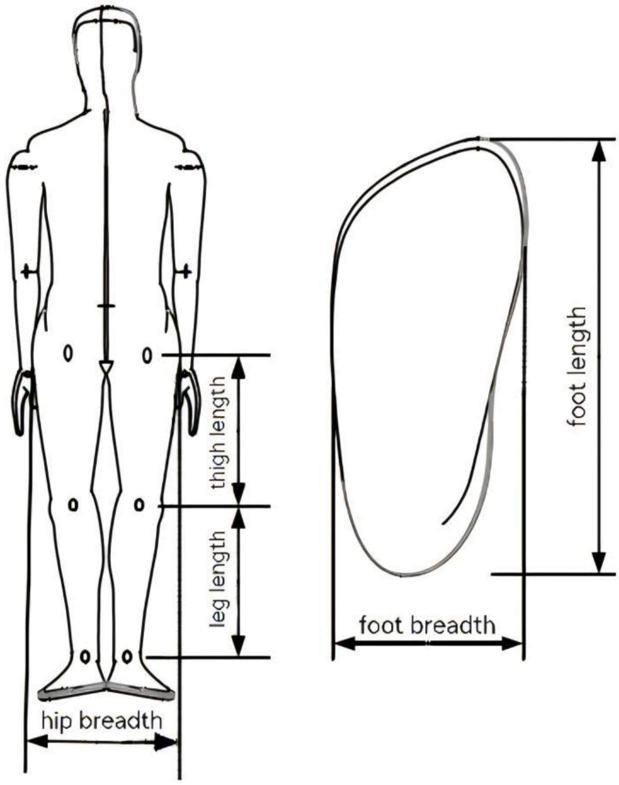
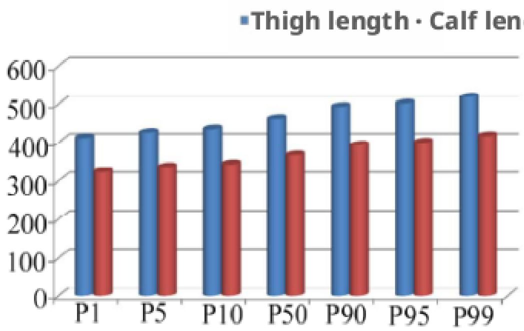


Fig. 1 Benchmarks for measuring the dimensions of various parts of the human body

Dimensional parameters of lower limb rehabilitation robot

To accommodate the variations in human body size, the thigh and calf sections of the rehabilitation robot can be designed with adjustable lengths, facilitating the use by patients of different heights. The range of adjustment for the thigh and calf can be determined based on the proportions shown in Fig. 2 and 3.

The adjustable range for thigh length is 390mm to 460mm, and for calf length, it is 360mm to 430mm.



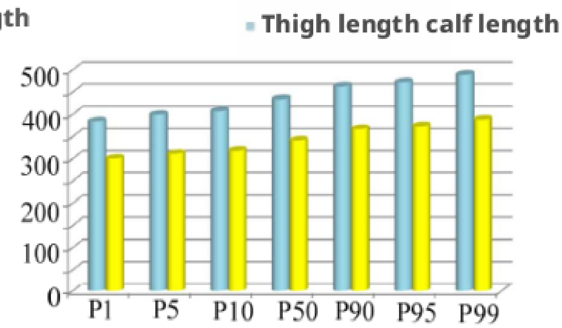


Fig. 2 Distribution of thigh-to-calf ratio in males **Fig. 3 Distribution of thigh-to-calf ratio in females**

Based on the data analysis in the previous text, the approximate weight of the rehabilitation robot's legs and the range of lengths for each part were roughly designed. The thigh component of the designed rehabilitation robot weighs approximately 4kg, and the calf component weighs approximately 4kg, and the ankle joint component weighs about 2kg. The patient's weight is taken as 75kg based on the average adult weight distribution. According to the above values, both the thigh and the calf sections are equipped with self-made manual length adjustment mechanisms, with an adjustment range of 70mm. The length adjustment device is shown in the figure.

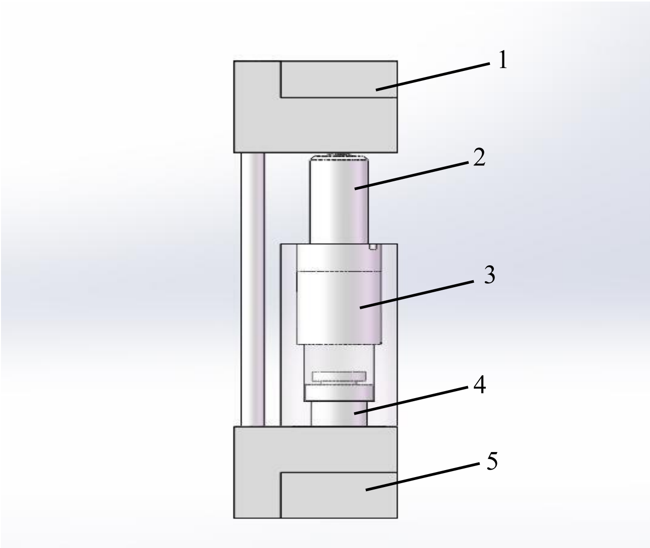


Fig. 4 Length Adjustment Device

Hip width and pedal size of rehabilitation robots

Fig. 5 shows the proportion of hip width among the population. The design of the rehabilitation robot should be suitable for the majority of users. Based on the width of the seats available on the market, the width of the seat is set at 450mm. As shown in Fig. 6, the average values of adult foot length and width are taken, so the length and width of the mechanical leg footplate are set at 290mm and 130mm, respectively.

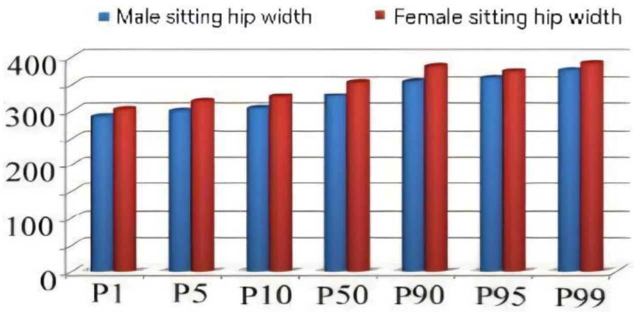


Fig. 5 Proportions of hip dimensions for male and female sitting postures

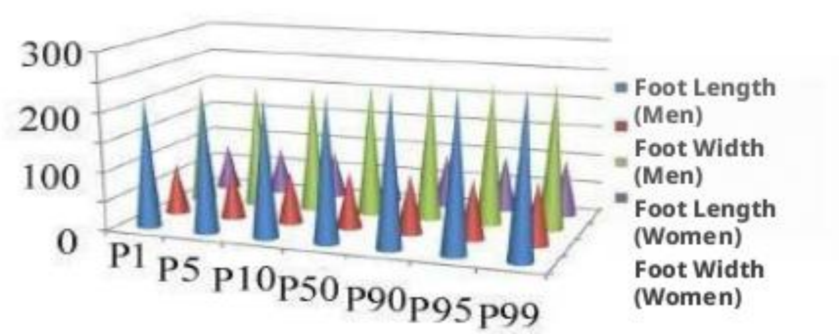


Fig. 6 Proportion of foot length to foot width for male and female subjects

Performance parameters of rehabilitation robots

1. The range of motion of the joint is limited by the servo motor: for the hip joint, it is -10° to 110°, with 0° being the position where the thigh is parallel to the ground and the upward direction being positive; for

the knee joint, it is -10° to 130°, with 0° being the position where the thigh and the calf are in a straight line and the bending direction being positive; for the ankle joint, it is -45° to 25°, with 0° being the position where the footplate is perpendicular to the calf.

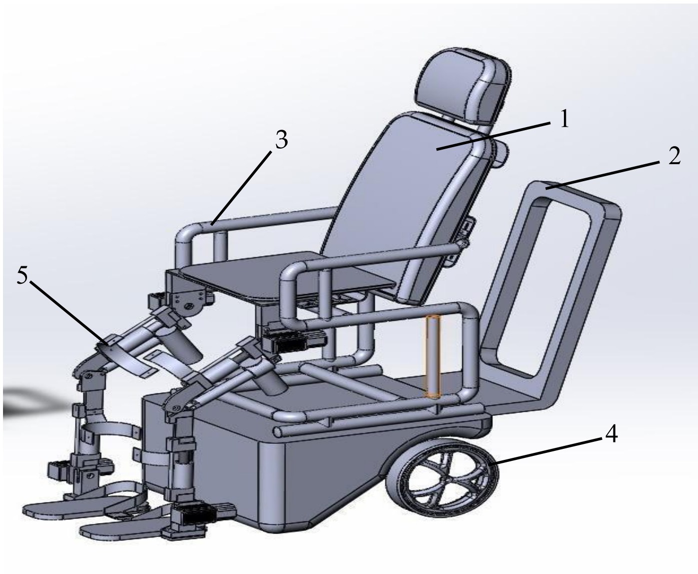
2. The maximum angular velocities of the joints: hip joint 15.18 rpm, knee joint 18.98 rpm, ankle joint 29 rpm.
3. Rated torque of joints: Hip joint 220.5 Nm, knee joint 176.4 Nm, ankle joint 70.6 Nm.
4. Seat pitch adjustment range: 90° to 136°; the position at 0° is the neutral position, and upward movement is in the positive direction.

III. Overall Design of the Seated and Lying Lower Limb Rehabilitation Robot

The lower limb rehabilitation robot designed in this paper mainly consists of three joint design parts: the ankle joint, the knee joint, and the hip joint. Each joint has one degree of freedom to simulate the movement of the human lower limb. To accommodate patients of different heights, the mechanical leg is equipped with a length adjuster, which can adjust the length of the upper and lower legs. By manually rotating the lead screw sleeve, the lead screw is driven to adjust the length of the upper and lower legs, thus adapting to patients of different heights. Each joint is driven by a servo motor in combination with a reducer. The rotation from the output end of the reducer drives the rotation of the hip joint and the ankle joint, enabling the mechanical leg to perform rotary movements within the specified rotation range. The seat back adjustment mechanism can achieve rehabilitation training at different back angles, allowing patients to undergo rehabilitation training in various postures.

Overall structure of the rehabilitation robot

Fig. 7 shows the overall appearance of the robot. The entire robot is divided into four parts: the seat, the armrest frame, the moving wheels, and the mechanical legs. The fact that it is assembled from individual parts makes disassembly, assembly, and transportation particularly simple. Two moving wheels are installed at the bottom of the entire machine, which can be used in conjunction with the armrest structure to achieve convenient movement of the rehabilitation robot and meet the patient's need to choose different environments for training. The backrest is made of nylon material, which can improve the patient's comfort.

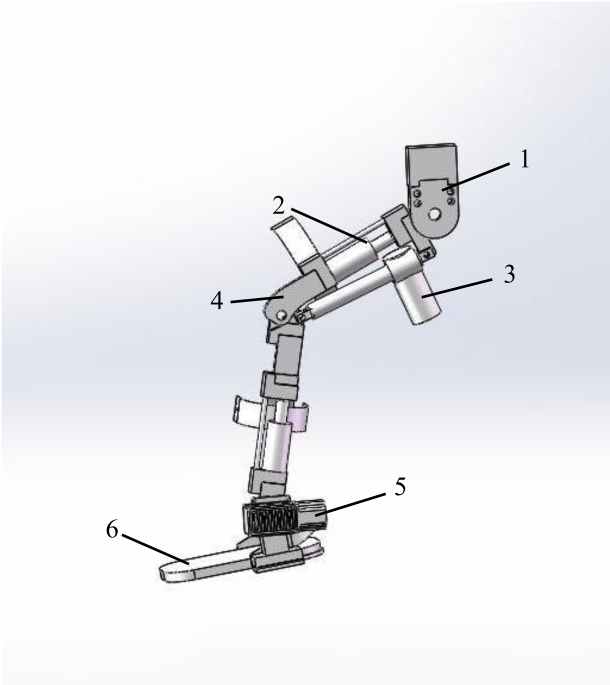


1-Seat 2-Push rod 3-Armrest frame 4-Casters 5 -Right leg

Fig. 7 Overall structure of the robot

Design of the Right Leg Mechanism for the Rehabilitation Robot

The most crucial component of the sitting and lying lower limb rehabilitation robot is the design of the mechanical leg, which is the heart of the entire rehabilitation robot. The design of other components is based on the leg design. The overall robot has a symmetrical structure, so the following focuses on the introduction of the right leg component of the single mechanical leg as shown in Fig. 8.

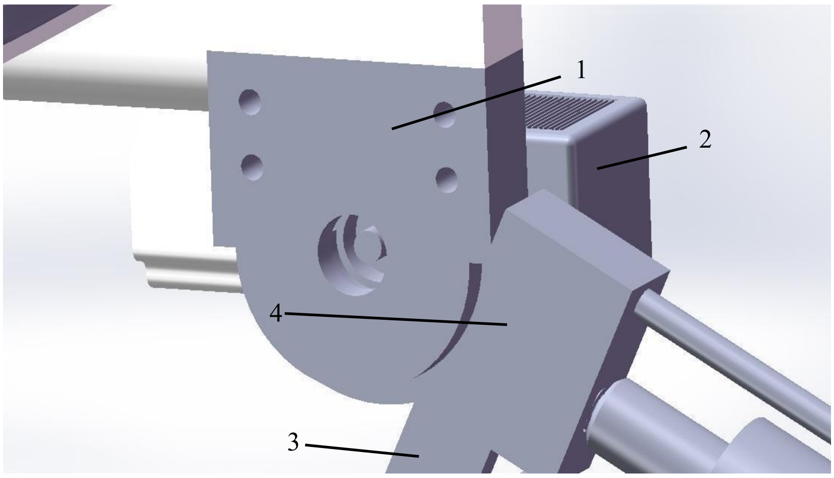


1-Hip joint components 2-Length adjustment device 3-linear actuator
4-Knee joint components 5-Actuator 6-Sole plate

Fig. 8 Right Leg Component

Hip Joint Structure Design of Rehabilitation Robot

The hip joint structure is designed to fully utilize the power. The driver is directly installed on the seat's tube frame structure. The power is transmitted to the thigh structure through the fixed block on the thigh, driving the thigh structure and the thigh adjustment structure to rotate. The mechanism diagram is shown in Fig. 9. The output end of the reducer is transmitted to the hip joint thigh connection plate by key, and a mechanical limit slot is set on the hip joint fixed part, which can prevent the joint from rotating beyond the predetermined range and causing secondary injury to the patient.

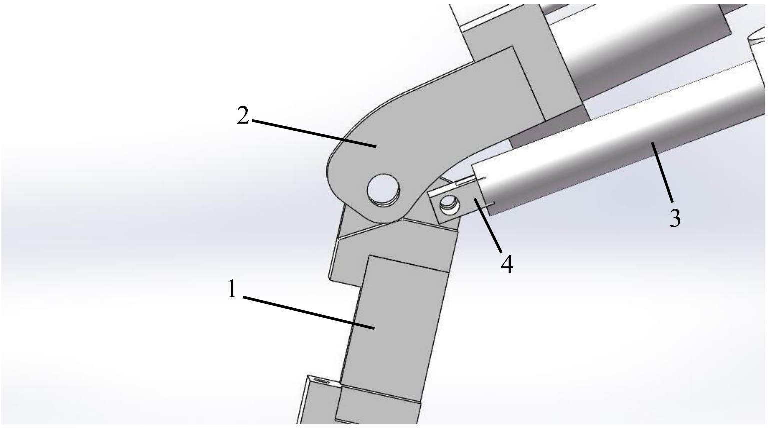


1-Hip joint fixation plate 2-retarder 3-Hip joint connecting plate of the thigh
4-Thigh length adjustment connecting plate

Fig. 9 Hip Joint Structure Diagram

Design of the knee joint structure for rehabilitation robots

The structure design of the knee joint is shown in Fig.10. An electric push rod is selected as the driving component. The extension and retraction of the electric push rod drives the lower leg connection plate to rotate back and forth around the origin of the knee joint. The arc groove of the lower leg connection plate enables the lower leg to rotate within a specified range. Since the arc groove and the extension and retraction length of the electric push rod are fixed, the rotation range of the knee joint is fixed, reducing the potential harm to the patient caused by the motor's rotation exceeding the range.



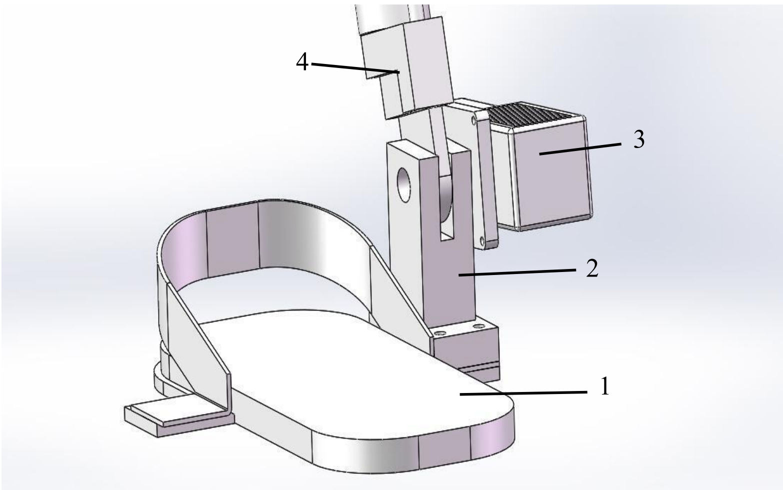
1-Calf connection plate 2-Knee joint rotation mechanism 3-Electric push rod

4-Push rod extension and retraction mechanism

Fig.10 Schematic Diagram of the Knee Joint Mechanism

Ankle Joint Structure Design of Rehabilitation Robot

The ankle joint design is shown in Fig.11. The motor is directly coupled with the reducer. The output end of the reducer is connected to the sole fixing part by a key. The driver rotates within a specified range. The servo motor and the reducer are fixed on the sole fixing part with bolts. As the motor rotates, the lower leg component remains relatively stationary, while the driver and the sole component move synchronously.



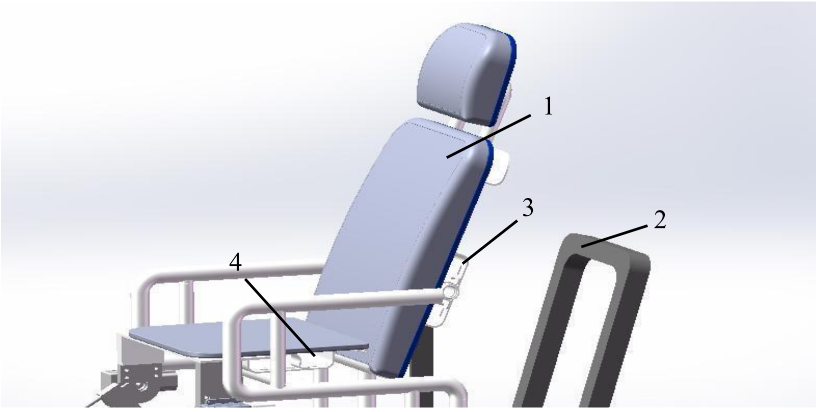
1-Sole component 2-Foot sole connecting piece 3-actuator

4-Ankle joint connecting piece of the lower leg

Fig.11 Ankle Joint Connector

Adjustable Seat Design for Rehabilitation Robots

The seat design is based on the ordinary seats available on the market and adds a backrest adjustable system. The main part of the seat is installed on a movable frame, and the adaptability of the rehabilitation robot is achieved through the movable frame, which can adapt to short-distance movement, allowing patients to use it conveniently at home. The backrest adjustable system adopts the linear motion of the guide rail slider. Through the moving lead screw slider installed inside the push rod, the linear translation motion of the slider is converted into the rotary motion of the backrest around the seat hinge plate 4 via the rotating connection shaft 3. The rotating connection shaft is fixed to the seat and the slider plate by a self-made connection block with bolts. As shown in Fig.12, the power is transmitted to the seat backrest through the lead screw slider, achieving the effect of adjusting the angle of the seat backrest. Through the calculation of the angle and installation position, the DGE-25-TB-400 lead screw slider group is selected, with a slider stroke of 400mm and a dynamic rated load of 3370N. The angle adjustment range of the seat is between 30° and 70°, and the adjustable angle of the seat backrest is 40°.



1-backrest 2-pushrod 3-Rotate the connecting shaft 4-Hinged plate
Fig.12 Diagram of seats

IV. CONCLUSION

This paper, based on a review of the current research and application of rehabilitation robots at home and abroad, and in combination with the development direction, specifically elaborates on the mechanical structure design of a sitting and lying lower limb rehabilitation robot. The main content of this design is to create a three-degree-of-freedom robot that mimics the gait motion of the lower limbs, achieving the training objective through the rotation of three lower limb joints.

The designed rehabilitation training robot can perform certain rehabilitation training tasks. However, to fully achieve automated control and enhance the robot's compliance, further research is needed in the following areas: (1) Further investigate the rationality of the actuator selection for the driving joints; (2) Research on integrating intelligent control systems to increase the robot's intelligence.

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