Mechanical design and motion simulation of human lower limb exoskeleton

Dezhi Shen [a], Ximao Wang [b]

School of Shandong University of Science and Technology, Shandong 266590, China.

[a]sdz19940427@163.com, [b]18315913676@163.com

Abstract

In view of the recent studies on the exoskeletons of lower limbs in the world and the increasing number of people suffering from arthritis in the world, a set of equipment was designed to assist lower limbs to walk.This design adopts motor drive mode, also known as rehabilitation medical robot, to design the basic structure of the lower limb bone structure.It includes the design of hip, knee and ankle joints by using bionics principle, and the design of whole lower limbs to simulate lower limb joints, motion freedom and human gait.Adams software was used to build a virtual prototype to simulate the motion of knee, hip and ankle joints, and the corresponding motion trajectory was analyzed.The simulation results show that this model is feasible to assist patients to walk and exercise.

Keywords

Lower limb exoskeleton,Mechanical structure,Adams simulation.

1. Introduction

According to the investigation and research, up to now, China has a serious aging population, and many people in the aging population have hemiplegia diseases. It is really based on the actual situation of the country and the viewpoint of the system theory of human-computer interaction that a walking auxiliary device is designed.To help patients increase muscle power, it is difficult to walk on the strength of their lower limbs alone.This lower limb exoskeleton robot skillfully combines the patient with the mechanical device. The lower limb of the human body USES the motion intention to send instructions to the lower limb exoskeleton robot, making the movement of the mechanical structure drive the lower limb to move together, so as to achieve a walking purpose and reduce fatigue.

Mechanical exoskeletons are mainly used in military, medical, aerospace, products for the elderly, large manual workers and other fields.The research of the United States and Japan is in the leading position in the world.The classic products of mechanical exoskeletons in the world include BLEEX[1], HULC[2], XOS[3], Rewalk[4] and ELEGS[5], etc. These exoskeletons are constantly improved in the research update.Domestic research on assisted lower limb exoskeleton robot affine has been improving. The function that can be realized follows the body to do shake, strengthen the body muscle strength.In foreign countries, great progress has been made in the research of lower extremity exoskeleton robot. The main research directions are the detection of human motion intention, the improvement of exoskeleton structure and the research of drive control system.Raytheon of the university of Berkeley, Raytheon of the United States and lockheed Martin of the United States all have molded products for military use in the exoskeleton, mainly driven by hydraulic pressure.Domestic and foreign bone research focuses on medical technology to assist patients to walk and recover.For example, Shanghai university, east China university of science and technology, Harbin engineering university and zhejiang university have all carried out relevant studies on the exoskeleton robot of rehabilitation medicine, but the progress in human-computer interaction has been slow and there has been no significant progress.The traditional lower extremity exoskeleton robot is fixed by means of rope binding. If a long time of wearing training, the contact between exoskeleton equipment and human body will be damaged to varying degrees by friction forklift.Therefore, in terms of man-machine interaction, it is more complex ergonomics for the robot exoskeleton and human lower limb, and it is to minimize unnecessary friction damage when the patient wears the robot of lower limb exoskeleton when walking.This design specially designs a set of exoskeleton equipment for the above problems, paying more attention to human comfort and the intelligent interaction between human and machine.

2. Analysis of Human Walking Characteristics

2.1 Freedom of Lower Limb Joints

The reason why the human body can walk depends on the movement of the ankle, knee and hip joints of the lower limbs. Therefore, to study the motion of the lower limbs, it is necessary to study the motion characteristics of freedom of the joints of the lower limbs.As shown in figure 1, it is clear that the hip and ankle joints have three degrees of freedom, namely rotation, flexion and extension, and abduction and adduction, and the knee joints have one degree of freedom. The range of human joint movement in literature provides a good reference for the design of exoskeleton joints.

Bending/stretching: rotating around the coronal axis in a sagittal plane, bending forward and stretching backward (opposite to the knee joint).

Abduction/adduction: the movement of the coronal plane around the sagittal axis, away from the middle of the human body is abduction, close to adduction.

Inside/outside rotation: the rotation around the vertical axis in the horizontal plane is called inside rotation and outside rotation.[6]

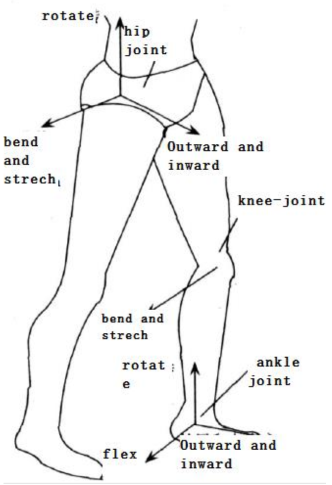

Fig. 1 freedom degree of lower limb joints

2.2 Gait Analysis

Figure 2 gait cycle diagram of human walking on vertical plane.A gait cycle is the process of following the foot from one side of the lower limb to the ground again.Walking on a human body requires sufficient ground reaction and support for the foot to move forward in a cycle. Standing and rocking are included in a human gait cycle.Standing accounted for about 62 percent of the cycle, while rocking accounted for 38 percent.A movement cycle of the human body consists of two supporting phases, one supporting phase, one rocking phase and two supporting phases.

(1) bilaterally limb support period: it is the period when both feet are on the ground while supporting the weight, which is divided into the two periods of the right lower limb pre-bearing period in the front and the right lower limb pre-swinging period in the back.

(2) unilateral limb support period: the period when the weight is supported only by the right foot, the period from the left full point to the left full point and followed the ground with the left full point, is also the period when the left lower limb swings.

(3) swing period: the period when the right foot swings, that is, the period from the right fully pointed to the ground to the right fully followed the ground, is also the period of unilateral limb support of the left lower limb [7]

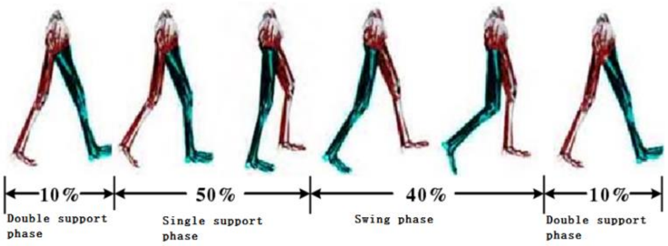

Fig. 2 gait cycle diagram

2.3 Mechanical Analysis

The force of human walking is shown in figure 3.In the process of walking, both feet support all the weight of the body, and an exoskeleton robot is designed to support part of the body weight, which can reduce the pressure on the joints and muscles of the lower limbs.In the course of walking, the foot exerts a backward force on the earth and the body gravity and the ground reaction force. The direction is basically consistent with the direction of the center of gravity.

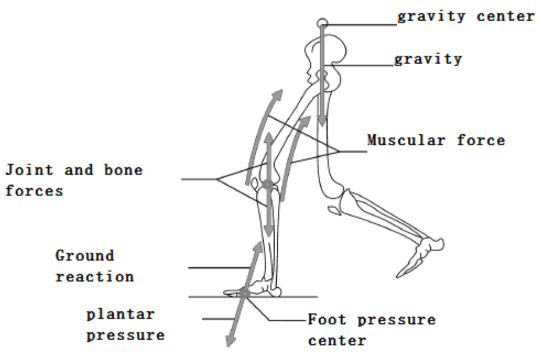

Fig. 3 walking force diagram

3. Physical Design

The overall structure design of the human lower limb exoskeleton robot is shown in figure 4.

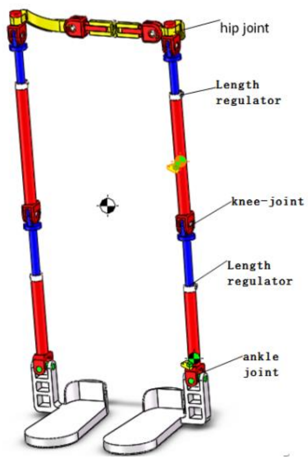

Fig. 4 structure diagram of lower limb exoskeleton robot

From top to bottom, the structure is the belt part, hip joint, thigh rod part, thigh length adjustment part, knee joint, shank rod part, shank length adjustment part, ankle joint, foot support part, among which the driving element is driven by motor.A motor is installed at the knee joint of the lower leg and leg respectively to drive the exoskeleton equipment of the lower limb to drive the human body to walk.

The exoskeleton robot is made of light aluminum alloy, which has the advantages of low cost, light structure and quick control.This mechanism has 12 degrees of freedom, including: hip joint, 3 for single leg;1 knee joint;Ankle, two.And the device has a length regulator in the legs and legs to accommodate people of different heights.

3.1 Hip Joint Design

The structure diagram of one side of the hip joint, as shown in FIG. 5, shows that in walking, squatting, stepping and most of the movement, the sagittal plane has a large bending/stretching motion force and is driven by motor.The waist member adopts the structure of thick rod sleeve and fine rod, plus the locking device, which can realize the length adjustment and adapt to people of different body types.A thigh strap is used to hold the human thigh in place and keep it moving.

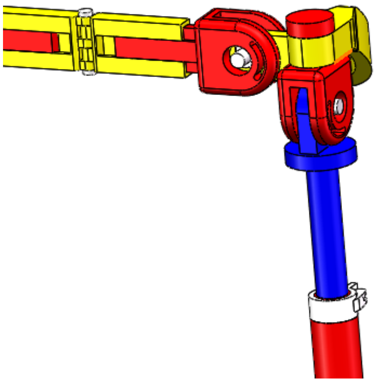

Fig. 5 hip joint structure

As shown in figure 6, the knee joint structure of the lower extremity exoskeleton robot is shown. There is only one bending/stretching motion, and the maximum force is received in the process of human motion, especially when climbing steps and squatting, so motor drive is also adopted.The shank is also made of thick rods with thin rods. The shank adopts a device that can adjust the length, and limits the maximum range of motion of the joints, thus protecting the human body.

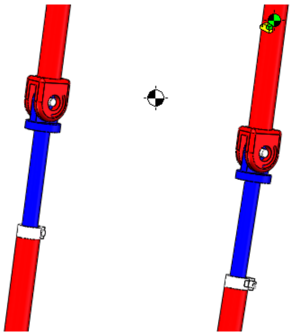

Fig. 6 knee joint structure

3.2 Ankle Joint Design

As shown in figure 7, the ankle joint of the lower limb exoskeleton is designed on the outside of the foot in the same way as most designs. The only difference is that this design adopts two degrees of freedom, which eliminates one degree of freedom and increases the movement stability of the wearer.These two degrees of freedom are bending, stretching, and abducting.A layer of rubber was added to the surface of the foot to cushion the shock.

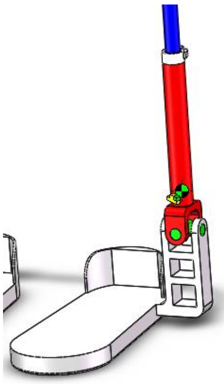

Fig. 7 ankle joint structure diagram

4. Kinematics Simulation of Human Lower Limb Exoskeleton Robot

Generally, the tool provided in Adams\view is used to build the simulation model, but only some relatively simple models can be built.However, for complex mechanism, special CAD software is needed to build the model.Then the connection between Adams and CAD software is imported into it for simulation.In this paper, design of lower limb exoskeleton is established by using SolidWorks software model, then the exoskeletons of established model is saved as a Parasolid file (*. X_t) format, imported into the Adams software, as shown in figure 8 for lower limb exoskeleton robot kinematics simulation in Adams, the exoskeleton model according to the rules of human walking on various joints constraint, set a model for the quality of aluminum alloy material and design.The mechanical structure is different from the hydraulic drive mode of BLEEX. The motor drive mode is adopted.The joints of the lower extremity exoskeleton robot are set as rotation constraints.

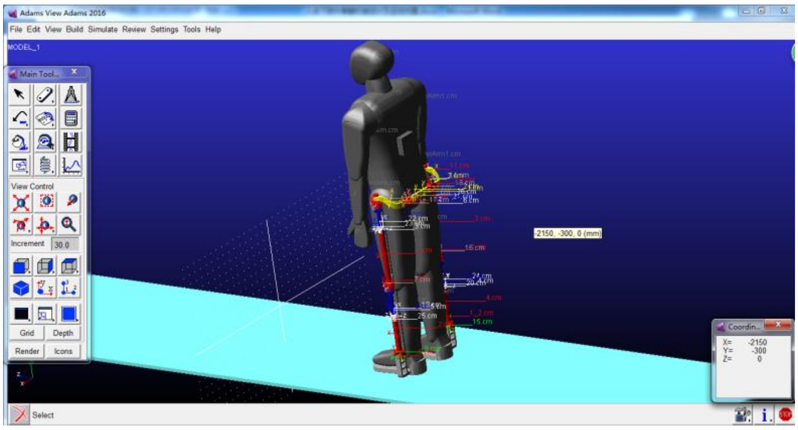

Fig. 8 simulation diagram of exoskeleton under Adams

Under the environment of simulation software Adams, the robot model of lower extremity exoskeleton was set to move at a speed of about 1.5m /s, and the simulation time was set to 5 seconds. As a result, the robot model of exoskeleton started to move in the upright state.After the end of the simulation time, the left and right hip, knee and ankle angles of the structure were respectively measured with the measuring tool, as shown in figure 9,10 below.It can be seen from the figure that the joint Angle of the two legs of the exoskeleton is basically the same.The angles of the left and right legs are arranged symmetrically and alternately.During the whole simulation exercise cycle, the knee joint has the largest Angle change range, followed by the angles of the left and right legs are arranged symmetrically and alternately.During the whole simulation exercise cycle, the knee joint has the largest Angle change range, followed by the ankle joint, and the hip joint has the smallest Angle change range, which is basically consistent with the intuitive movement rule of normal walking of human body, so as to achieve the optimal motion and to walk close to human body normally.

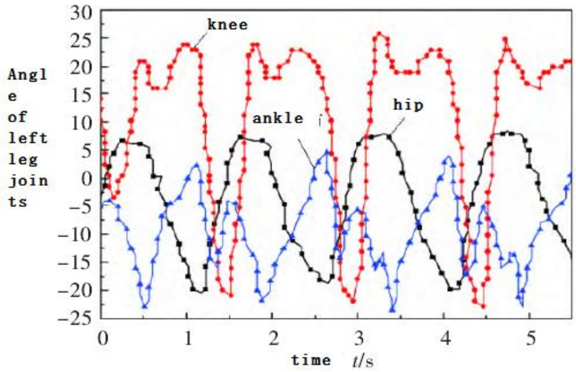

Fig. 9 joint angles of the left leg

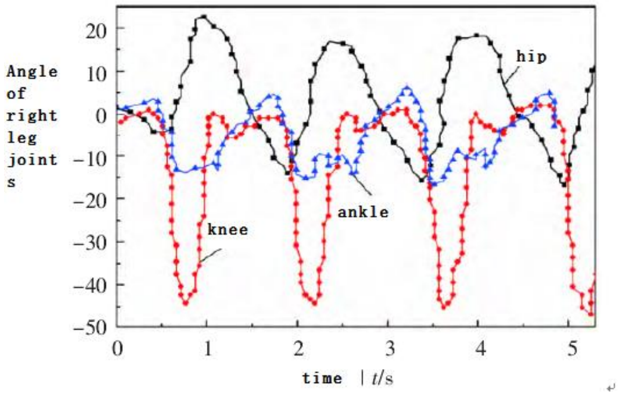

Fig. 10 Joint angles of the right leg

5. Onclusion

In this paper, a human lower limb exoskeleton robot was designed, which completed the basic structural design of the exoskeleton. It can make the wearer and the exoskeleton equipment as a whole.Using the original international studies on the stress and movement of the lower limb exoskeleton, this design only installed the drive for the ankle and knee joints, and the motor drive has the advantages of quick response, low noise and low quality.On the basis of the above, Adams was used to carry out the motion simulation of the external skeleton model, and the Angle change data of the hip joint and knee joint were obtained. The simulation results were basically consistent with the actual theories, which could provide the theoretical basis and data basis for the actual model design and other follow-up work.

References

[1] Zoss A B, Kazerooni H, Chu A. Biomechanical design of the Berkeley lower extremity exoskeleton (BLEEX). IEEE/ASME Transactions on Mechatronics, 2006, 11 (2): 128–138.

[2] Bogue R.Exoskeletonsandroboticprosthetics:a review of recent developments. Industrial Robot: An International Journal, 2009, 36(5): 421–427.

[3] Sankai Y. HAL: Hybrid assistive limb based on cybernics//Kaneko M, Nakamura Y. Robotics Research. Springer Tracts in Advanced Robotics. Berlin, 2007: 25–34.

[4] Karlin S. Raiding Iron Man's closet. IEEE Spectrum, 2011, 48(8): 25.

[5] EsquenaziA,Talaty M, Packel A, etal. The ReWalk powered exoskeleton to restore ambulatory function to individuals with thoracic-levelmotor-complete spinalcord injury. American Journal of Physical Medicine & Rehabilitation, 2012, 91(11): 911–921.

[6] damZoss,HKazerooni,AndrewChu.OntheMechanicalDe-signoftheBerkeleyLowerExtremityExoskeleton(BLEEX)[C].IntelligentRobotsandSystems(2005).IEEE/RSJInternationalconferenceon 2-6,Aug, 2005.3465- 3472.

[7] zhao yuyu. Research on lower limb rehabilitation robot [D], Harbin, heilongjiang: Harbin engineering university, 2009