Exoskeleton Robot DesignBased on Multi-body Dynamics Simulation

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Abstract

In order to implement the ability of carrying heavy loads and reduce the energy consumption of the human moving, the wearable exoskeleton robot driven by hydraulic is studied in this paper. Firstly, the mathematical model of exoskeleton robot is established and the required torque of each joint is obtained through the simulation of the simplified model of the robot in ADAMS. Then, on the basis of the above analysis, the mechanism design of exoskeleton robot is completed. Finally, by using virtual prototyping technology, the simulation results show that the performance of exoskeleton robot meets the design requirements.

Keywords

Exoskeleton robot; design; multi-body dynamics simulation; hydraulic actuation.

1. Introduction

As it could significantly implement the ability of carrying heavy loads, reduce the energy consumption of the movements and adapt to all kinds of terrain, the wearable exoskeleton robot has been a new branch of robotics technology and been widely studied in recent years [1,2]. The related research of exoskeleton robot in the domestic is still on the stage of testing inside lab, while Lockheed – Martin Company of United States has developed the wearable exoskeleton robot named Human Universal Load Carrier (HULC), which has already been tested on the battlefield [3, 4].

In order to obtain the ability of carrying heavy loads and high trafficability, the exoskeleton robot with hydraulic actuated is taken as the studied object and it is verified by using virtual prototype technology that the mechanism design of the robot meets the requirements.

2. Mathematical Model of Exoskeleton Robot

As it directly determines the performance of the exoskeleton robot, the mechanism design of lower limb is divided into three sections, which are thigh, shank and foot respectively. In addition, the hip, knee and ankle joints of the lower limb have three active degrees of freedom, one active degree of freedom and three passive degrees of freedom respectively.

The design of the knee joint of the lower limb is taken as example in this paper and the mathematical model of the exoskeleton robot is established as shown in Fig. 1, where A, B and C points are respectively located at the end of the hydraulic cylinder, in the knee joint, and at the end of the piston rod, set AB=c, BC=a, CA=b and h is the distance from B to AC, which is the torque of the knee joint generated by the hydraulic cylinder. Moreover,θ that is formed between AB and BC is named the angle of the knee joint and its rotational range is allowed from 45 ° to 170 °.

According to Fig. 1, the geometry relationships among the parameters of the knee joint are given, as follows:

$$b^2 = a^2 + c^2 - 2ac\cos\theta \tag{1}$$

$$hb = ac\sin\theta \tag{2}$$

$$T_e = p\frac{\pi d^2}{4}h \tag{3}$$

Where p is the oil pressure, and d is the diameter of the cylinder piston. Te is the torque of the knee joint.

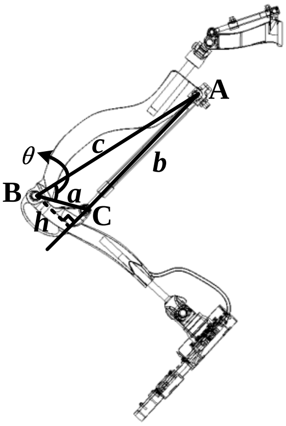

Fig. 1 Mathematical model of the exoskeleton robot.

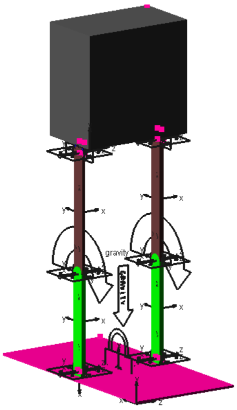

Fig. 2 Simplified simulation model of the exoskeleton robot.

The required torque of the movement of each joint is the basis for the mechanism design. The simplified simulation model of the exoskeleton robot is established in Adams and during the movement of the knee joint, its maximum torque is obtained through the simulation of the squat to stand in situ of the exoskeleton robot. In addition, a rotational motion is applied to the knee joint and the shank is connected to the ground through a passive rotation, as shown in Fig. 2. The parameters of simulation model are set as follows: the total weight of the back frame and carrying loads is 70kg, the weight of the thigh and shank is respectively 2 kg and 1.1kg, and the whole time of the simulation is 2s. Through simulation, the curve of required torque of the knee joint is shown in Fig. 3.

As shown in Fig. 3, the more the rotational angle of knee joint increases, the greater the required torque is. In the whole simulation, the maximum required torque of the knee joint is 197.4 N·m.

Based on the size of the lower limbs of the adult, the parameters of the mechanism are initially determined as follows: c=450mm, p=21Mpa, d=20mm. As the parameter b changes within a certain range, the curve of Te could be obtained by simulating in Matlab according to the (1), (2) and (3), as shown in Fig. 4.

According to Fig. 4, the maximum output of the torque of the knee joint is determined by the parameter a. Above all, the parameter a value is set as 0.1m and the corresponding curve of Te-θ is shown in Fig. 5. It can be seen that the output of the torque generated by the hydraulic cylinder in the knee joint is much more than the required torque of the movement of the knee joint, which totally meets the requirement of the mechanism design.

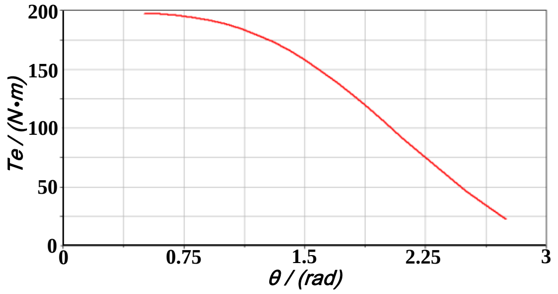

Fig. 3 Required torque of the movement of the knee joint.

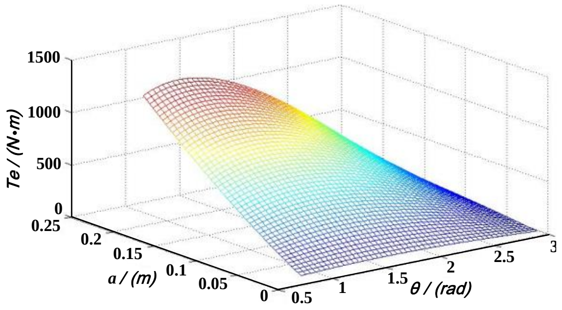

Fig. 4 Output torque of the movement of the knee joint.

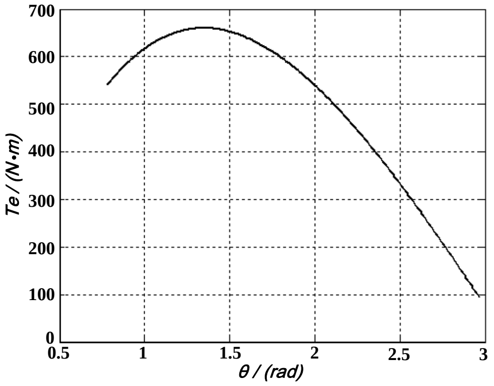

Fig. 5 Output torque of the movement of the knee joint as a=0.1m.

3. Mechanism Design of Exoskeleton Robot

3.1 Mechanism Design

The three-dimensional model of the exoskeleton robot is designed in this paper, as shown in Fig. 6.

3.2 Selection of the Parameter of the Hydraulic System

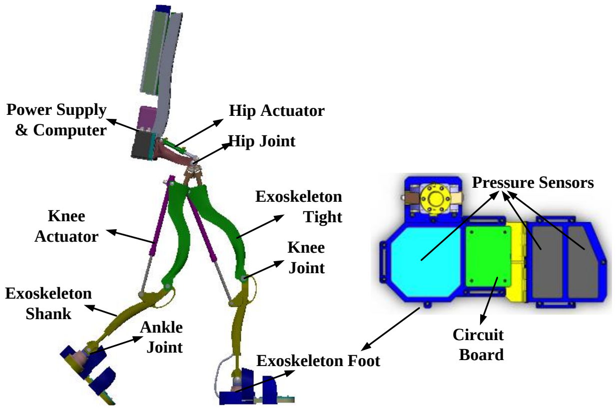

Fig. 6 The three-dimensional model of the exoskeleton robot.

As the hydraulic actuation has the advantages of high power-mass ratio, large output force and rapid response, it becomes feasible to make the hydraulic-actuated robot carry heavy loads, which can be applied in areas such as transportation and disaster relief. The selection of the parameters of the hydraulic system on the one hand should ensure the sufficient output of the force and torque, on the other hand the size of the whole hydraulic system should be as small as possible. As the output torque of the hydraulic cylinder is determined by the oil pressure and the diameter of the servo cylinder, the key parameters of the hydraulic system are selected in order to make sure that the exoskeleton robot that carries 50kg weight has the ability of high trafficability, as shown in Table 1.

In order to make the action of the hydraulic system accurate, the servo valve with good performance, fast response and small size is selected as the control valve of the hydraulic system. The hydraulic pump is driven by electric motor and the entire system power source is provided by two high-performance lithium batteries installed on the back of exoskeleton robot. The oil tank of the hydraulic system is also placed in the upper part of the back frame.

3.3 Mechanism Design of Other Parts

The back frame of the exoskeleton robot is mainly used to place high energy density batteries, motors, hydraulic pumps, servo valves, the controller, the oil tank and other parts. The corresponding three-dimensional model of the back frame is shown in Fig. 7, where the number 1 to 7 are the hydraulic pumps, the hydraulic system servo valves and accessories, lithium batteries, the control module and oil tank, the motors, cooling system of the belt and back frame respectively.

Table.1 value of the selected parameters of the hydraulic system

Parameters of the Hydraulic System	**Value**
Oil pressure (Mpa)	21
Diameter of the cylinder (mm)	20
Diameter of the piston rod (mm)	16
Area of the rodless cavity (cm^2)	3.14
Stroke of the piston rod (mm)	170
Maximum force of the piston rod (N)	6597

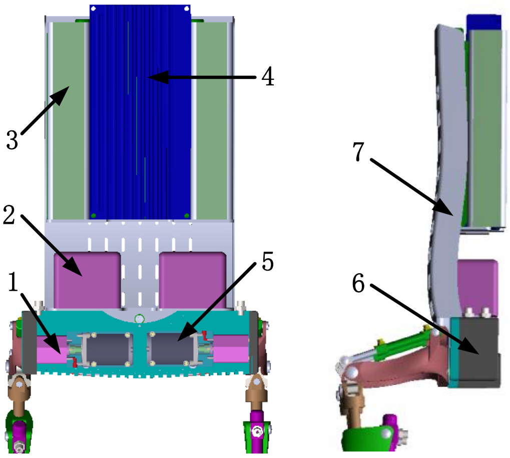

Fig. 7 The three-dimensional model of the back frame.

4. Virtual Prototype of Exoskeleton Robot

The three-dimensional model of exoskeleton robot is established in SolidWorks. Then the model is imported to the Adams in which the constraints and the driving functions are added to make the virtual prototype have the humanoid gait [5], as shown in Fig. 8. The parameters of the model in simulation are set as designed: the weight of the exoskeleton robot is 30kg and carrying 50kg loads. The driving function curve of the knee joint and hip joint are shown in Fig. 9 and 10 respectively.

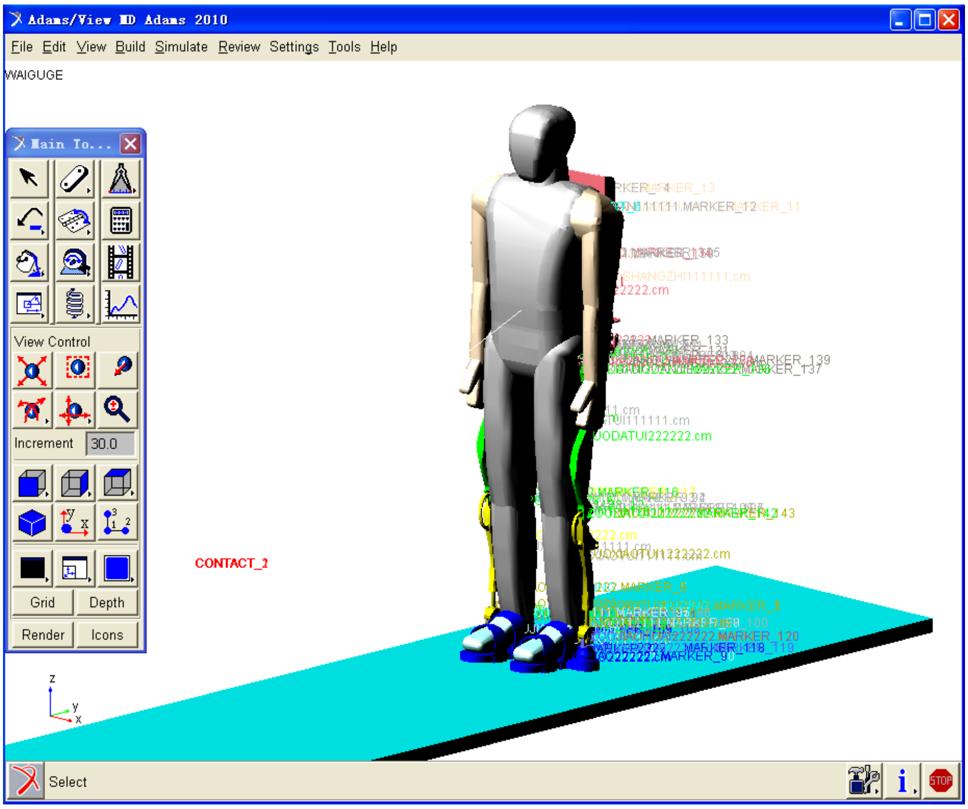

Fig. 8 Virtual prototype of the exoskeleton robot.

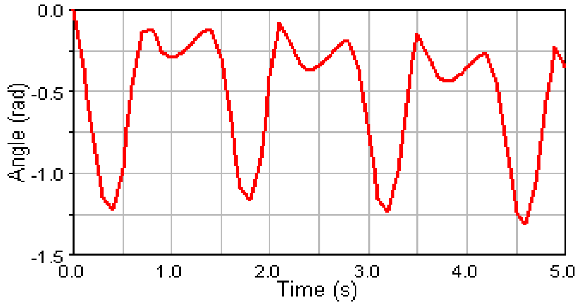

Fig. 9 Driving function curve of the knee joint.

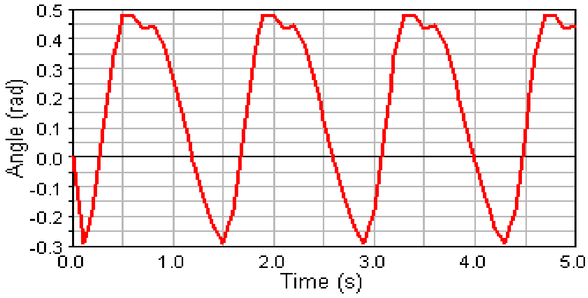

Fig. 10 Driving function curve of the hip joint.

As shown in Fig. 11, the walking speed of the robot is up to 0.55m/s. At this walking speed, the rotational torque curves of the knee and hip joints are shown in Fig. 12 and 13 respectively, in which the positive and negative peak value of the torque is respectively generated by the impact of foot with the ground and the hydraulic cylinder of the joints. The maximum absolute value of the knee joint torque is 162.5N·m as shown in Fig. 12, which is far less than the maximum output of torque generated by the hydraulic cylinder of the knee joint. Thus the mechanism design of the robot is reasonable and the selection of the parameters of the hydraulic system is suitable.

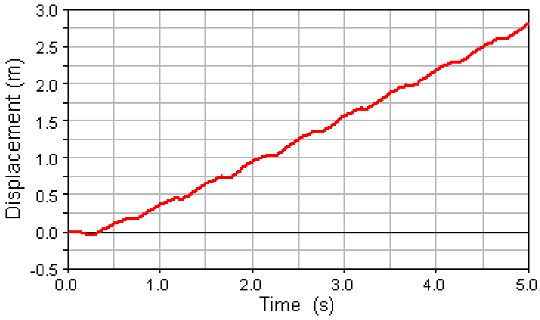

Fig. 11 Displacement curve of the center of mass of the robot.

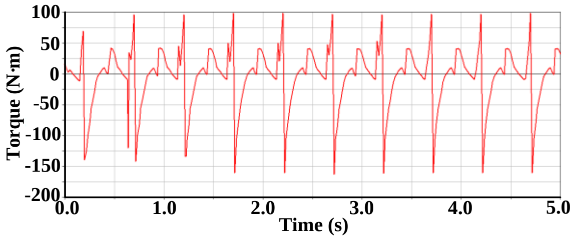

Fig. 12 Curve of the torque generated in the knee joint.

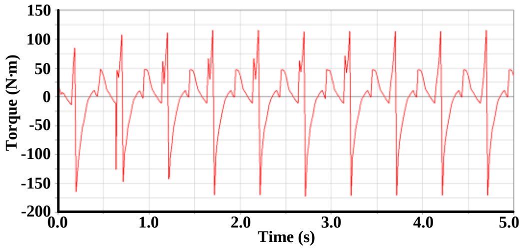

Fig. 13 Curve of the torque generated in the hip joint.

5. Conclusion

The mathematical model of the exoskeleton robot is established in this paper. Based on the simplified simulation model, the mechanism design of the robot and the selection of the parameters of the hydraulic system are completed respectively. The effectiveness of the mechanism design of the exoskeleton robot is verified through using the virtual prototype technology.

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