Dynamics simulation analysis of the lower extremity exoskeleton robot

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Abstract

Analyzed the human body walking gait and degree of freedom of lower limbs, using Lagrange method to dynamics analyze the exoskeleton of lower extremity, after modeling the human and lower limb exoskeleton robot use CAD software Solidworks , and it was imported dynamic simulation software ADAMS. A drive is added to the lower limb exoskeleton motor to drive the human body to walk, and the flexible connection for leg and leg bands makes the simulation result closer to the real situation, it is verified the feasibility of using ADAMS for virtual simulation design.

Keywords

Lower limb, exoskeleton, dynamics, ADAMS, simulation.

1. Introduction

With the rapid development of the economy, the number of transportation tools has grown rapidly, and in particular, the number of traffic accidents caused by automobiles has increased significantly. As a result, the number of people suffering spinal cord injuries or physical injuries has been on an upward trend. At the same time, due to the advancement of science and technology and the improvement of people's living standards, China, like many countries in the world, is entering an ageing population. There are a large number of cardiovascular and cerebrovascular diseases or neurological diseases in the elderly population [1], and most of these patients are associated with hemiplegia. The lower extremity exoskeleton robot studied in this paper has important applications in assisting the handicapped, elderly and lower limb muscle weakness patients to walk and recover. Not only are they expected to improve their ability to take care of themselves, enhance their enjoyment of life, realize their dreams of standing, walking, or even running, but they can also help them perform forced rehabilitation exercises. Correct and scientific rehabilitation training plays a very important role in the recovery and improvement of limb motor function [2].

2. Analysis of human gait

The sagittal plane refers to a longitudinal section taken along the anterior and posterior directions of the human body, which is divided into two parts. The normal human body walks in the sagittal plane and has periodicity and repeatability. A gait cycle is one side of the heel to the same side of the heel and the ground again, the entire gait cycle can be divided into support and swing phase, here to the right foot as a reference, as shown in Fig. 1, from the right foot heel just Contact ground to the toe just left the ground called the support phase, this phase accounts for about 60% of the gait cycle; from the right foot toe just off the ground to the heel just contact the ground called the swing phase, this phase accounts for about 40% of the gait cycle . In addition, the entire gait cycle can be divided into a single foot support period and a double foot support period [3].

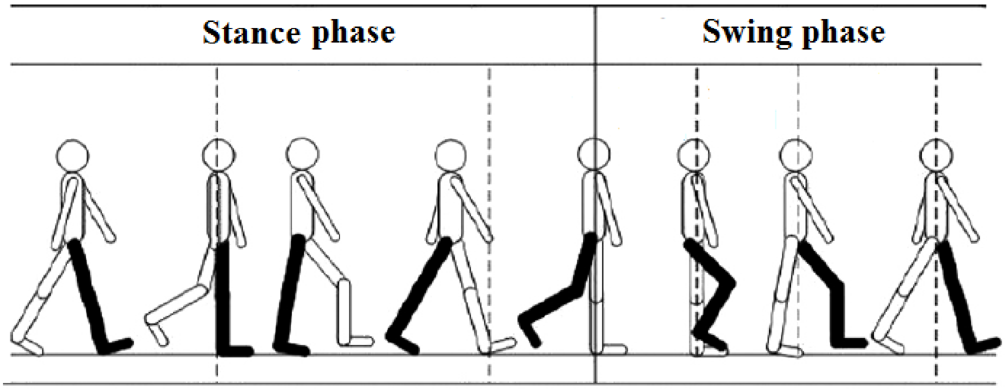

Fig. 1 Gait cycle

The design of robots for exoskeleton exoskeletons begins with the configuration of the degrees of freedom of their structures, and it is necessary to fully understand the kinematics of the human body. There are 7 degrees of freedom for the unilateral lower limbs and 3 degrees of freedom for the hip and sacroiliac joints. They are flexion/extension, abduction/adduction and internal rotation/external rotation. The knee has only 1 flexion movement. . The range of motion of the hip joint and the knee joint is large, while the ankle joint generally plays an auxiliary role and has a smaller range of motion [4].

3. Kinetic analysis

The Lagrange dynamics method [5] is widely used in the research of robots. It is an energy-based dynamic method with explicit structure and clear physical meaning.

For lower limb exoskeleton rods, the kinetic energy of the *i*-th rod is denoted by k_i

$$k_i = \frac{1}{2} m_i v_{c_i}^T v_{c_i} + \frac{1}{2} {}^i w_i^T \, {}^{c_i} I_i \, {}^i w_i \tag{1}$$

The first item in the formula is the kinetic energy generated by the linear velocity of the barycenter, and the latter is the kinetic energy generated by the angular velocity of the adjacent bar.

The potential energy of the *i*-th link is denoted by u_i

$$u_i = -m_i \, {}^0 g^T \, {}^0 P_{c_i} + u_{refi} \tag{2}$$

In the first item, ${}^0 g$ is the 3X1 lower extremity exoskeleton rod gravity vector, ${}^0 P_{c_i}$ is the vector of the rod center of mass, and u_{refi} in the second term is a constant that makes u_i the minimum value.

Let $q_i (i = 1, 2, \cdots, n)$ be the generalized joint variable that gives the system a fully defined position. $\dot{q}_i$ is the corresponding generalized joint velocity. The total kinetic energy of the lower limb exoskeleton rod can be expressed as $k\left(q_i, \dot{q}_i\right)$ and the total potential energy can be expressed as $u(q_i)$.

The Lagrangian function of the system can be expressed as

$$L\left(q_i, \dot{q}_i\right) = k\left(q_i, \dot{q}_i\right) - u(q_i) \tag{3}$$

Substituting (1), (2) into (3) gives the value of *L*. The Lagrangian equation is

$$\tau = \frac{d}{dt} \frac{\partial L}{\partial \dot{q}} - \frac{\partial L}{\partial q} \tag{4}$$

Substituting (3) into (4) formula, taking into account that people have a certain force on the exoskeleton of the lower extremity, the dynamic equation of the exoskeleton of the lower extremity is finally obtained.

$$\tau_a + \tau_b = M(q)\ddot{q} + V(q,\dot{q})\dot{q} + F\dot{q} + G(q) \qquad (5)$$

Where τ_a is the torque applied by the actuator, τ_b is the man-machine torque, ie the torque applied by the operator, $M(q)$ is the inertial force, $V(q,\dot{q})$ is the Coriolis term, F is the coefficient of motion friction, and $G(q)$ is the gravity.

4. Human body wear exoskeletal dynamics simulation analysis

For the complex mechanical structure of the lower extremity exoskeleton robot, if it is simply analyzed by mathematics, it is not only time-consuming and labor-intensive, it is also rather complicated, and it is also not very accurate. With computer CAD/CAE technology, the calculation can be simplified and the efficiency of lower extremity exoskeletons can be improved.

The gait data is very important in the walking simulation of the human body model wearing the exoskeleton of the lower extremities. Fig. 2 shows the curve of each joint angle change during a gait cycle in the clinical gait analysis (CGA). The angle change data is imported into ADAMS [6] to generate the SPLINE curve. Then use the AKISPL function call to drive the lower extremities of the human body [7].

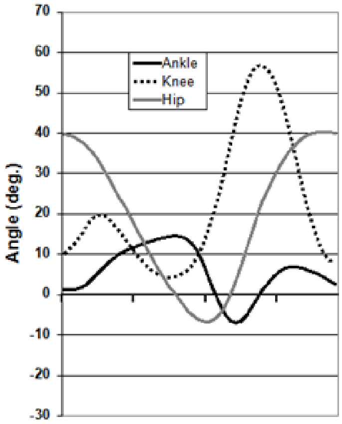

Fig. 2 CGA gait curve

This article refers to the Chinese adult human body size (GB10000-88) [8] using Solidworks to model the human body and exoskeletons, as shown in Fig. 3 for human body wear exoskeleton model. The human body is at the beginning of a gait cycle when the right foot just touches the ground. The model was imported into the ADAMS software. Refer to the human body inertial parameters (GB/T 17245-2004) to establish mass and inertia parameters for each part of the human body. The human model weighs approximately 60kg, height 175cm, and the exoskeleton model weighs approximately 17kg.

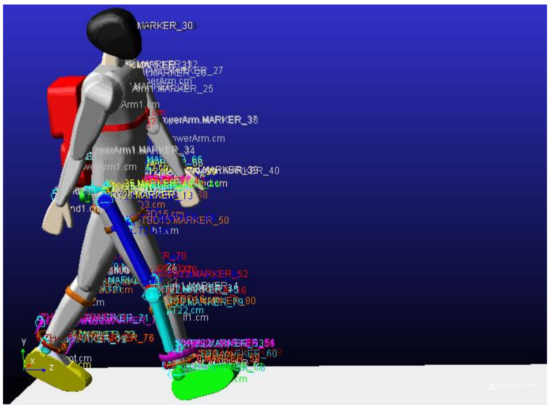

Fig. 3 Human Body Exoskeleton Model

This simulation was performed only in the sagittal plane. Only the flexion/extension movement of the joint was preserved, the contact force was established between the strap and the exoskeleton, and the exoskeleton and the ground. The rotation of the motor shafts of the lower extremities and the exoskeleton was set. The other parts that do not move relative to each other have a fixed connection. Add the AKISPL function to the motor axis as the driver function. The AKISPL function format is AKISPL(time, 0, SPLINE, 0), where SPLINE is the CGA gait curve mentioned above. Simulated motion for two gait cycles with a set step length of 200 steps. Because the wearer wears slower than the normal person, the simulation time is set to 8 seconds. The default initial movement angle is zero degrees. The results show that the human body model can stably advance during the two complete gait cycles, and the smoothness of each joint angle curve is basically consistent with the CGA gait curve, as shown in Fig. 2 and 4, indicating that the simulation results are better.

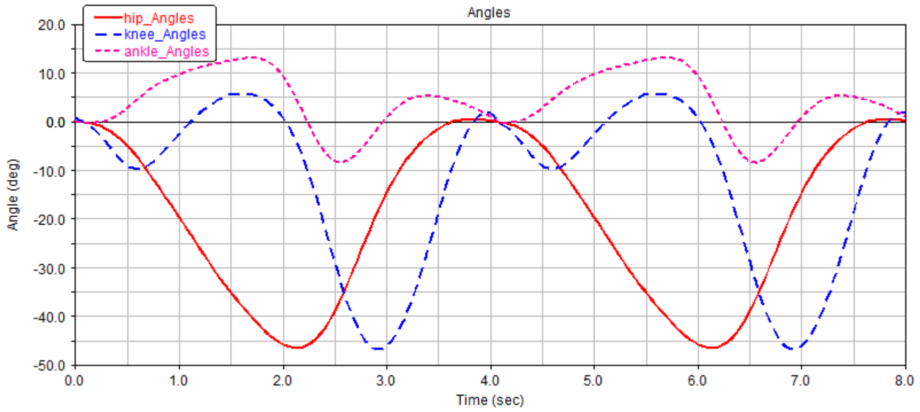

Fig. 4 Curve of angle change of each joint

In the Postprocessor module Postprocessor, you can also get the curve of more parameters on each joint. Fig. 5 shows the curve of the angular velocity of each joint. From the figure, it can be seen that the curve of the angular velocity of each joint is relatively smooth, indicating that the exoskeleton travels more smoothly.

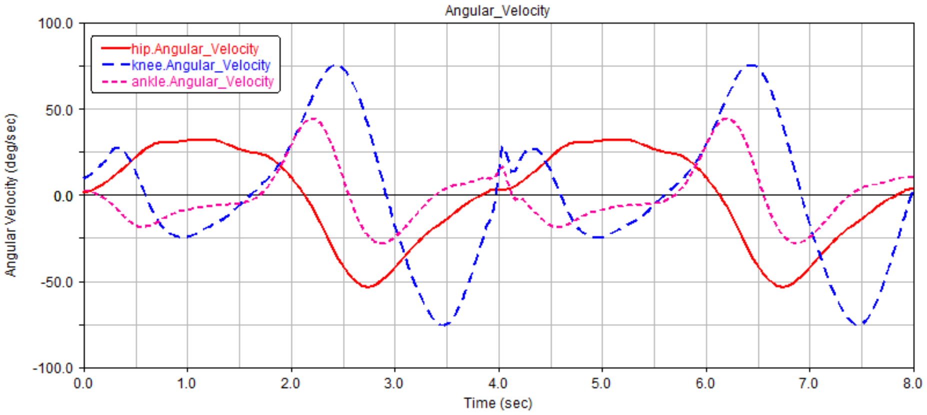

Fig. 5 Curves of angular velocity of each joint

Fig. 6 shows the curve of each joint motor driving torque. Fig. 7 shows the curve of the power consumption of each joint motor. It can be seen that the curve shows a certain regularity. When the foot is just on the ground, each joint will suddenly receive a large torque. And power, and sometimes there is a sharp point, this is because the lower limb exoskeleton model is a rigid body, instantaneous collision will make the torque and power suddenly become larger.

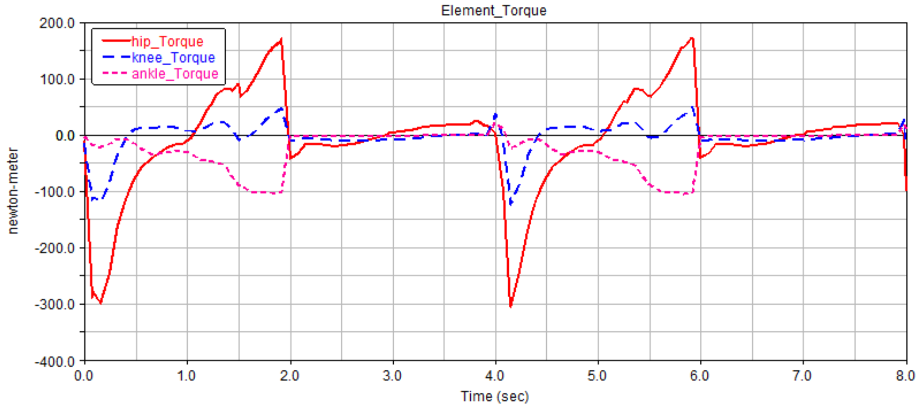

Fig. 6 Curve of torque variation of each joint motor

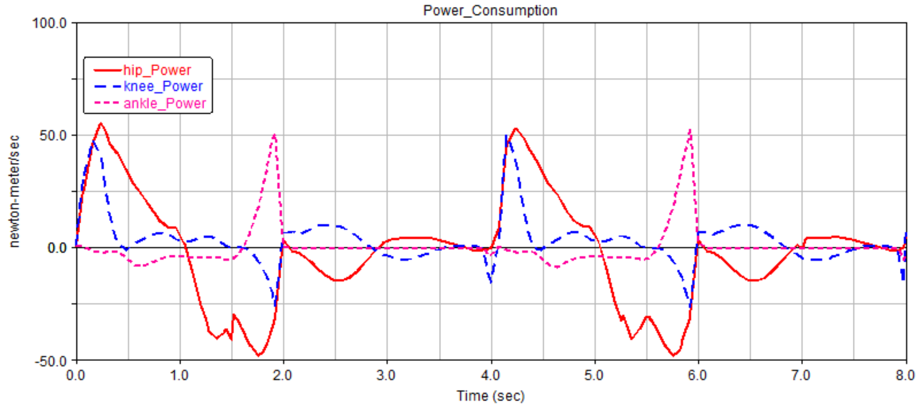

Fig. 7 Curve of power consumption of each joint motor

In practical applications, in order to reduce the impact, the exoskeleton robot's sole can be replaced with a cushioning material such as a plastic, and the walking stick can also be used as a support when walking.

5. Conclusion

In this paper, the mechanical structure of the assisted walking exoskeleton robot is optimized. The results show that reasonable mechanical structure design can take into account good flexibility and good bearing stability. Some damping devices such as spring dampers are added to the mechanical structure to reduce the impact on the human joints. Based on a certain planning of the gait of the exoskeleton of the lower extremity, a virtual prototype was established through ADAMS and simulations of the two gait cycles were performed, which showed that the gait curves were basically consistent with the CGA gait curve, indicating changes in fitting with the AKISPL function. Curve function, the gait is relatively stable in the simulation.

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