Dynamic Analysis and Research of Lower Extremity Exoskeleton Robot

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Abstract

Exoskeleton robot is called "wearable robot" and it is a kind of wearable auxiliary device with anthropomorphic mechanical power structure and artificial intelligence control. In this paper, the dynamics of lower extremity exoskeleton robot is researched and analyzed. The dynamics of lower extremity exoskeleton is the theoretical basis of the design of drive system and control system. It is also beneficial to understand the lower extremity exoskeleton in a variety of common exercises, The movement mechanism of each joint. The exoskeleton's kinetic model has significant nonlinearities similar to the traditional legged robots except that the exoskeleton dynamics model relies heavily on the phasing of the human gait. Therefore, on the basis of human gait research, this paper analyzes the positive and inverse kinematics of lower extremity exoskeleton robot, and then uses the Adams and Matlab co-simulation to verify its correctness and lays the foundation for the control of lower extremity exoskeleton.

Keywords

Lower extremity exoskeleton, Dynamics, Adams, Matlab.

1. Introduction

The classification of exoskeleton robots is various, and the exoskeleton robots can be divided into upper exoskeleton robots, lower exoskeleton robots, whole body exoskeleton robots and various joint exoskeleton or joint rehabilitation or rehabilitation exoskeleton robots. The exoskeleton has the functional division, the exoskeleton robot can be divided into two categories: the first is the medical rehabilitation assisted exoskeleton robot, such as supporting the disabled or elderly walking exoskeleton robot to assist stroke patients As well as patients with traumatic brain injury rehabilitation exercise to complete the body's ability to exercise. The second is to enhance the function of human-powered exoskeleton robot.

Exoskeleton robot technology has many promising applications: In the military field, exoskeleton robots enable soldiers to carry more weapons and equipment, and their own power units and sports systems can enhance the march of soldiers, which can effectively improve the single In the civil field, exoskeleton robots can be widely used in mountain climbing, tourism, fire prevention and disaster relief, which require heavy loads and equipment and vehicles can not be used. In the medical field, exoskeleton robots can be used to assist disabled people People, the elderly and lower limb muscle weakness walking, can also help them forcible rehabilitation exercise, have good prospects for development.

Due to the advantages of exoskeleton robots, many countries in the world have actively carried out research on exoskeleton robots. 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 the structure of exoskeleton and the research of drive control system. Formed at the Berkeley University, the United States Raytheon and Lockheed Martin exoskeleton products for military use available, the main driver for the hydraulic drive. Domestic research on lower extremity exoskeleton robots focuses on medical rehabilitation. For example, Shanghai Medical University, East China University of Science and Technology, Harbin Engineering University and Zhejiang

University have conducted researches on rehabilitation medical exoskeleton robots. For military purposes, the lower extremity exoskeleton robots The research progress is slow. In the analysis and modeling of lower limb dynamics, the subjects of Berkeley University mainly study the lower extremities of unilateral human body in a gait cycle, and obtained the moments and powers of the hip, knee and ankle joints.

2. 2. Human gait analysis

Human body in the three-dimensional space is divided into sagittal, frontal and horizontal plane perpendicular to the three reference planes, corresponding to the human body foreshadowing axis, sagittal axis and vertical axis of the three mutually perpendicular reference axis. All the basic movements of the human body move around these three reference axes. The human body in the completion of gait movement, the forehead around the axis of the performance of the most prominent.

The three planes shown in FIG. 1 are respectively defined as a section which divides the human body into left and right parts in the anteroposterior direction, which is called a sagittal plane, and a section which divides the human body into left and right parts, Known coronal); the body along the direction parallel to the ground divided into upper and lower section, known as the horizontal plane (also known as cross-section). The directions and positions of the three reference axes are shown by the arrows in Figure 1, wherein the axis perpendicular to the frontal plane is called the sagittal axis (anterior-posterior direction), the vertical axis (up and down) perpendicular to the horizontal plane, Surface known as the forehead axis (left and right direction).

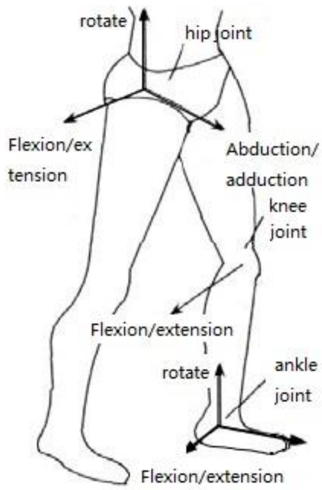

Fig 1. Lower extremity of the human joint basic form of movement

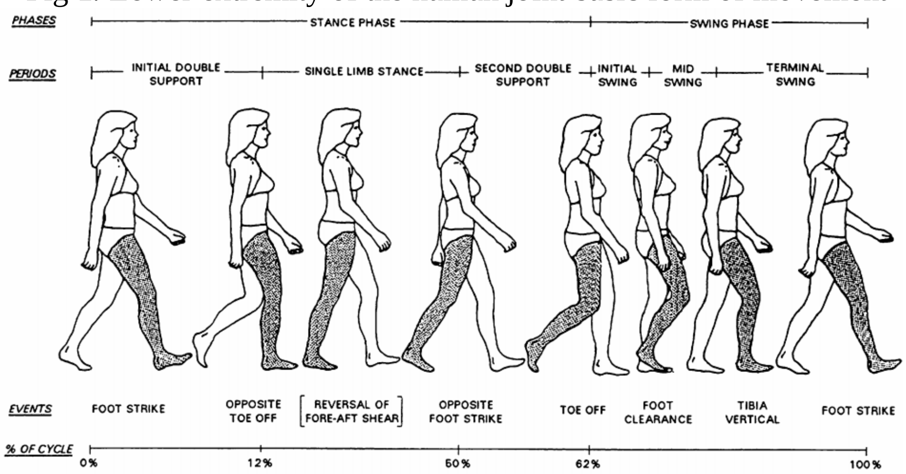

Fig. 2. Human walking cycle

A normal gait cycle can be divided into two phases, as shown in Figure 2, which are the supporting phase and the wiggling phase, respectively, from the heel to the ground to the tiptoe off the ground, 60% of the state cycle; swing phase refers to the tiptoe off the ground to the heel to touch the ground, which accounts for about 40% of the gait cycle.

3. Dynamic modeling and analysis

The robot dynamics analysis includes two opposite problems, positive and negative. Among them, the kinematic inverse problem is the known robot's state of motion, that is, knowing the displacement, velocity and acceleration of each joint of the robot to solve the joint moment. It is related to the robot control, can also provide a basis for the selection of the drive is a research question of real value.

3.1 Dynamic Modeling

$$\tau_1 + \tau_2 = M(q)\ddot{q} + C(q,\dot{q})\dot{q} + G(q) \quad (1)$$

$\tau_1$is the driving torque of lower extremity exoskeleton robot; τ_2 is the moment applied by the wearer; $M(q)$ is the generalized mass matrix; $C(q,\dot{q})$is the centripetal force and Coriolis force matrix; $G(q)$ is the gravity matrix. Exoskeleton robot in order to be able to play a good role in boosting, should make the wearer applied torque τ_2 approach 0.

Single-leg support mode: Seven-link simplified model shown in Figure 3, which includes the upper extremity trunk, left and right thighs, left and right lower leg and left and right foot.Figure 3 m_i for the quality of the various sections, the location of each segment Centroid position; l_i is the length of each segment; a_i is the distance from the centroid of each segment to the joint; q_i is the included angle between each segment and the vertical axis, and counterclockwise is positive. Obviously, the included angle between the support leg and the vertical axis is 90 °.

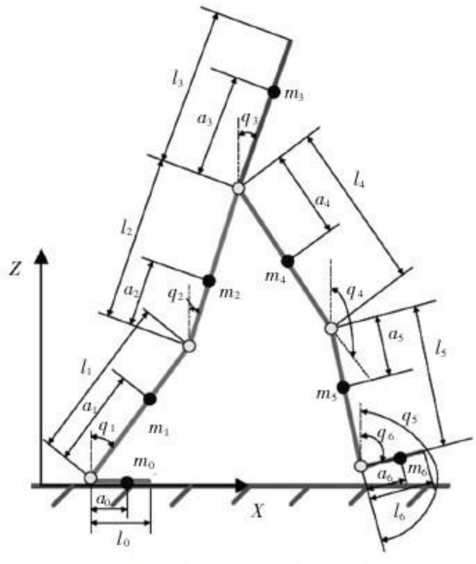

Fig. 3 The model of single feet

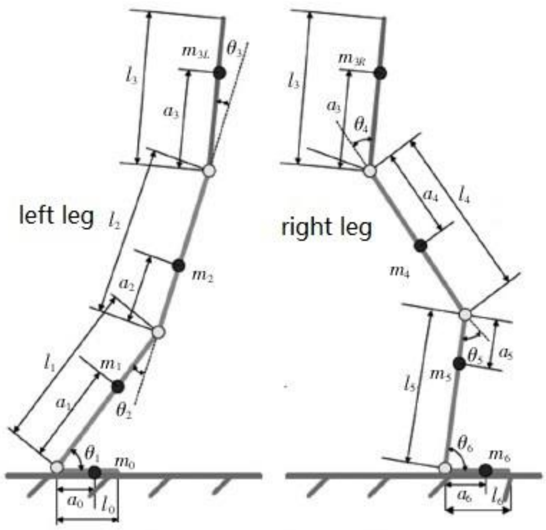

Fig. 4 The model of double feet

The total kinetic energy of the system:

$$K = \frac{1}{2}\sum_{i=0}^{6}[I_i\dot{q}_i^2 + m_i(\dot{x}_i^2 + \dot{z}_i^2)] \quad (2)$$

The total potential of the system:

$$P = \sum_{i=0}^{6} m_i g z_i \quad (3)$$

Lagrange function of six-leg model of lower limb system:

$$L = K - P \quad (4)$$

Two-legged support mode refers to the state that the two feet of the human body all touch the ground during the walking process, different from the single-legged support mode, the system in this state forms a closed-chain mechanism with the ground.For the system in this exercise mode To do kinetic analysis, the left and right legs need to be divided into two 4-bar models to study, as shown in Figure 4. The lower limb system is divided into left and right legs, the human upper extremity is also divided into two parts.Provisions on the role of the upper leg on the left leg mass m_{3L}, and the left leg center of mass to the center of mass of the upper limb x_{3L}. Upper limbs on the right leg The mass is m_{3R}, and the horizontal distance between the center of right leg and the center of mass of the upper limb x_{3R}. Through the principle of moment balance, m_{3L} and m_{3R} can be obtained. The expression is as follows:

$$m_3=m_{3L}+m_{3R} \tag{5}$$

$$x_{3L}=l_1\cos\theta_1+l_2\sin\left(\frac{\pi}{2}-\theta_1-\theta_2\right)+a_2\sin\left(\frac{\pi}{2}-\theta_1-\theta_2-\theta_3\right)-a_2 \tag{6}$$

$$x_{3R}=a_6-l_5\cos\theta_5+l_4\sin\left(\theta_5+\theta_6-\frac{\pi}{2}\right)-a_3\sin\left(\frac{\pi}{2}+\theta_4-\theta_5-\theta_6\right) \tag{7}$$

$$m_{3L}x_{3L}=m_{3R}x_{3R} \tag{8}$$

First analyze the left leg model, set the left ankle coordinate system (a, 0), then the center of mass coordinates (xi, zi) as follows:

$x_0=a+a_0$

$x_1=a+a_1\cos\theta_1$

$x_2=a+l_1\cos\theta_1+a_2\sin(\frac{\pi}{2}-\theta_1-\theta_2)$

$x_3=a+l_1\cos\theta_1+l_2\sin(\frac{\pi}{2}-\theta_1-\theta_2)+a_3\sin(\frac{\pi}{2}-\theta_1-\theta_2-\theta_3)$

$z_0=0$

$z_1=a_1\sin\theta_1$

$z_2=l_1\sin\theta_1+a_2\cos(\frac{\pi}{2}-\theta_1-\theta_2)$

$z3=l_1\sin\theta_1+l_2\cos(\frac{\pi}{2}-\theta_1-\theta_2)+a_3\cos(\frac{\pi}{2}-\theta_1-\theta_2-\theta_3)$

Lower leg left leg system of the total kinetic energy:

$$K_L=\frac{1}{2}\sum_{i=0}^{2}[I_i\dot{q}_i^2+m_i(\dot{x}_i^2+\dot{z}_i^2)]+\frac{1}{2}[I_{3L}\dot{q}_3^2+m_{3L}(\dot{x}_3^2+\dot{z}_3^2) \tag{9}$$

The total energy of the left leg system:

$$P_L=\sum_{i=0}^{2}(m_igz_i)+(m_{3L}gz_3) \tag{10}$$

Then the left leg system four-bar model of the Lagrange function L_L= K_L- P_L into Lagrange kinetic equation into the equation, we can find the moment of each mechanical joint.

3.2 Dynamic Simulation

Adams was used to carry out modeling and dynamics simulation of mechanical system dynamics simulation analysis software to provide three-dimensional robot solid model, kinematics and dynamics model and animation simulation. The control system professional software Matlab is used to design the robot control system, which provides the control target trajectory, the stability control algorithm and the output driving torque. The data interface between Matlab and ADAMS is established by ADAMS / Controls interface module. The co-simulation method lays the foundation for real-time control of lower extremity exoskeleton robot.

Based on the previous human lower limb kinematics analysis, the driving torque of each joint in one gait cycle can be obtained by using Matlab and Adams co-simulation. According to the data of human clinical gait, we can get the angle change of the joints of human lower extremity in a gait cycle. According to GB10000-88 (Chinese adults body size) to get the upper and lower body geometry. According to GB / T17245-2004 (adults inertial parameters), you can get the body parts of the lower extremity of the centroid position and inertia parameters. Through the co-simulation, the results shown in Figure 4,5,6:

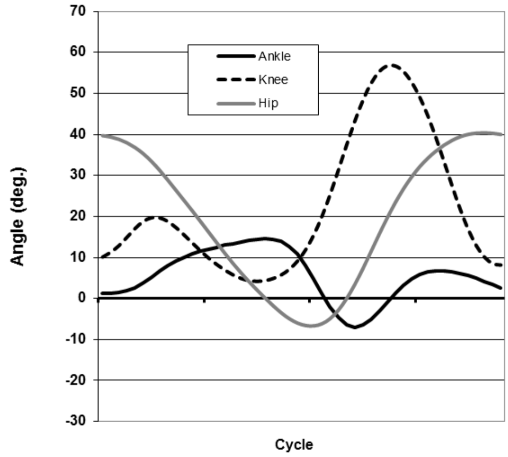

Fig. 6 The angle changes of each joint in a gait cycle

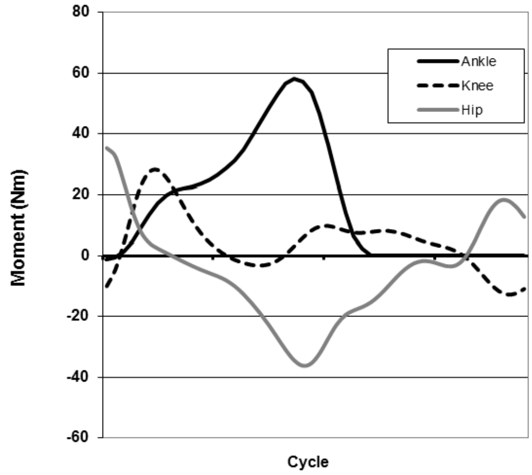

Fig. 7 The moment changes of each joint in a gait cycle

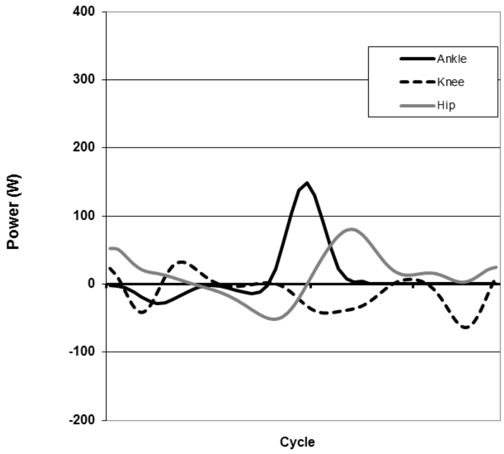

Fig. 8 The power changes of each joint in a gait cycle

4. Conclusion

This paper analyzes the characteristics of the human gait, and reduces the human body to a seven-bar model. The walking motions are divided into two modes, one-legged mode and two-legged mode, for dynamic modeling and research. The Lagrange method is used to determine each Joint moment of expression. Finally, through the joint simulation of Matlab and Adams, the angle curve, torque curve and power curve of each joint of the exoskeleton robot are obtained, which provides the theoretical basis for the control system. The co-simulation method lays the foundation for real-time control of exoskeleton robot.

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