On the structure optimization and kinematics analysis of the lower extremity exoskeleton robot

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Abstract

Designed a kind of lower extremity exoskeleton robot to assist the disabled, the elderly and patients with lower extremity muscle weakness, basing on the analysis of human walking gait and the degrees of freedom of the lower extremities to carry out the optimization design of mechanical structure. Using CAD software Solidworks to model the lower extremity exoskeleton, make every axis of rotation as possible through the center of the joint, added some buffer device to make the wearer feel more flexible and comfortable. Using the D-H method to kinematics analysis the unilateral lower extremity of lower extremity exoskeletonand. provided a reference for the next step to design a new type of assisted walking lower extremity exoskeleton robot prototype.

Keywords

Lower extremity exoskeleton, mechanical structure, Solidworks, D-H method.

1. Introduction

Lower extremity exoskeleton robot technology is an emerging technology developing rapidly in recent years, has played an important role in the field of military, medicine, has made great achievements after decades development[1-2], has become one of research hot spots in the world.There are basically three kinds of lower extremity exoskeleton robots. The first is the lower extremity exoskeleton robot with enhances human function, which is mainly used in military and earthquake relief work, such as BLEEX [3-4], XOS;The second is the rehabilitation training lower extremity exoskeleton robot, which is mainly used to assist doctors and rehabilitation training for patients, such as Lokomat[5].The third is the assist walking lower extremity exoskeleton robot, which is mainly used to assist walking disabled people, elderly and lower extremity muscle weakness, and improve their self-management ability, such as HAL [6-7], ReWalk.This paper mainly studies the third, it's different from the first and two kinds, the mechanical structure of the third kinds has good flexibility and certain bearing stability.In order to reduce the impact on the human body, some cushioning devices should be added to the exoskeleton.

2. Movement Mechanism

The lower extremity exoskeleton is worn by people and walking synchronization with human, so should be research the humans of the gait first, people’s walk has the characteristic of periodic and legs symmetrical, andmovement basic is completed in the sagittal plane.The gait cycle can be divided into support and swing phase, now take right foot for reference,see Fig. 1. It is defined support phase from the right foot heel just touches the ground to tiptoe just left the ground, which

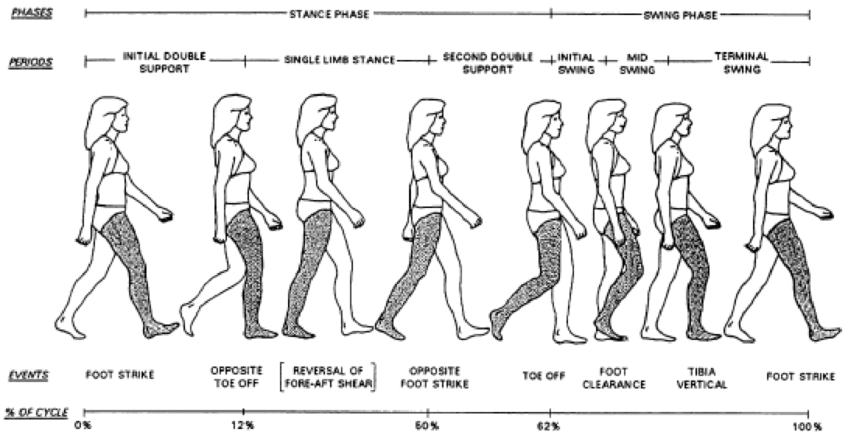

Fig.1.Human walking cycle

accounts for about 60% of the gait cycle.Defined swing phase is from the toe of the right foot to the heel just touching the ground, which accounts for about 40% of the gait cycle.In addition, the whole gait can be divided into the single-foot support period and the double-foot support period [8].

The design of the robot of lower extremity exoskeleton begins with the layout of its structure freedom, so it is necessary to understand the characteristics of kinematics of human body.Human unilateral lower extremity with a total of seven degrees of freedom, the hip joint, ankle joint with three degrees of freedom, abduction/adduction, flexion/extension and rotation motion , knee joint has only one flexion movement.The range of hip joint and knee joint is wide, the range of ankle joint is small and is generally auxiliary [9].

3. Mechanical Structure

The design of the mechanical structure of lower extremity exoskeleton should take into account the following points:

(1) The degree of freedom and position of the lower extremity exoskeleton should be reference to the human body, and the size of the bar should be adjusted to suit the human of different height and body types.

(2) The lower extremity exoskeleton robot degrees of freedom of joints corresponding to the human body, to ensure the movement form is the same as human, each rotation axes pass through the center of joint ;

(3) There must be a certain limit device for each joint of the lower extremity exoskeleton, which should not only have the necessary motion scope but also ensure the safety of the wearer's movement.

(4) The lower extremity exoskeleton robot is as simple as possible, with light weight and easy to carry, which can accommodate many different environments, such as flat, sloping land, grassland, stair, etc.

Due to it is bigger force that hip, knee and ankle in sagittal plane when people in the walk, squat, cextremity stairs, and in most sports, the hip, knee, and ankle joints are actively driven.The adduction/abduction motion of hip take actively driven played an important role in the walk, related to the movement of flexibility. The mechanical structure of the hip joint of the exoskeleton robot,see Fig.2, there are three degrees of freedom of hip, flexion/extension and adduction/abduction motion in the process of the walking motion amplitude is bigger to take the motor drive, and it limits the scope of activities to protection the human body.Rotation motion is the passive joint, which is driven by the user's corresponding joints.The thigh bar and the waist pole are used in the rod structure, and their length can be adjusted to suit different body types.

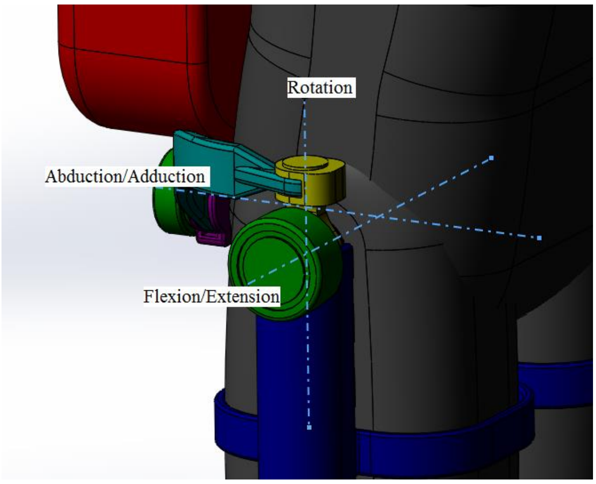

Fig.2. Hip joint mechanical structure

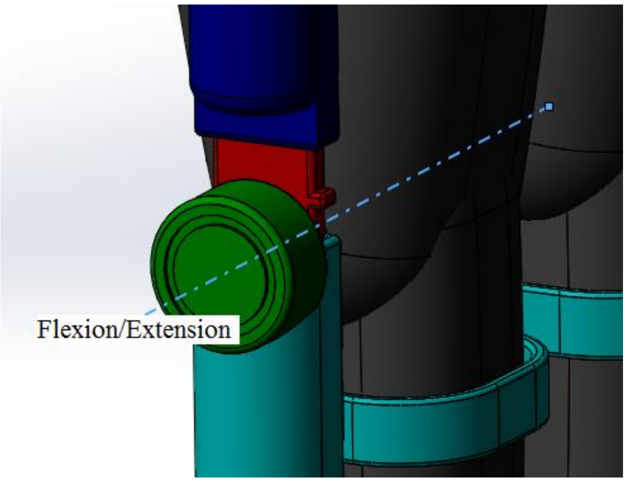

Fig.3. Knee joint mechanical structure

There is only one flexion/extension of the lower extremity exoskeleton robot knee joint see Fig. 3, thigh bars using rod structure adjusted according to human leg length, and limits the maximum range to protection the human body.

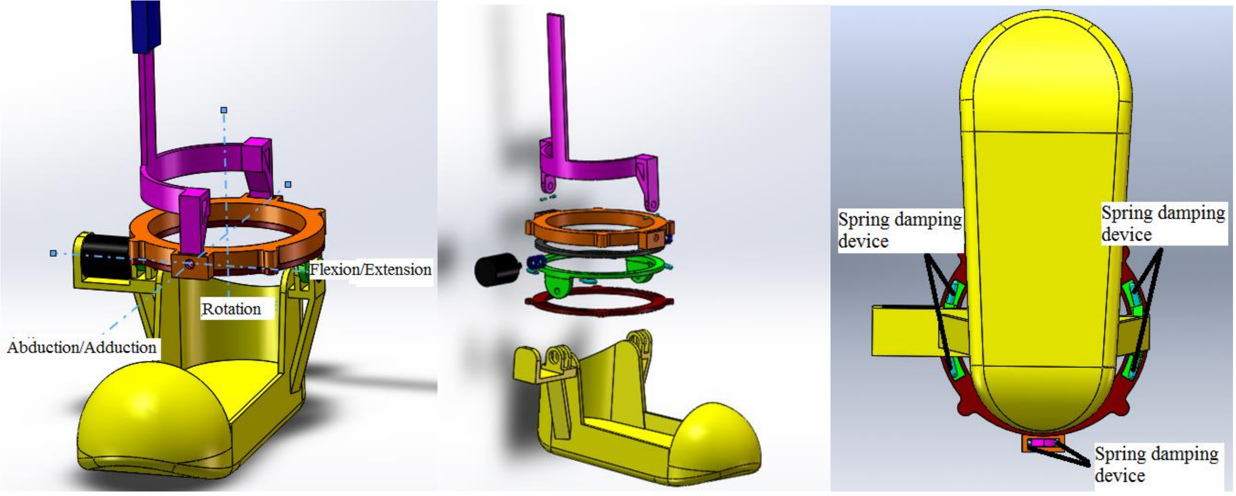

Fig.4. Ankle mechanical structure

The mechanical structure of lower extremity exoskeleton robot ankle joint [10],see Fig. 4,The foot is attached to the lower extremity exoskeleton, and motor fixed on the motor frame, it’s rotation can be realized toe flexion/dorsiflexion movement. Inner rotating bearings can be rotated, and rotary motion and outreach/adduction movement have installed spring damping device, when you walk along it changes accordingly with the human body.

4. Kinematics Analysis

For the kinematics analysis of lower extremity exoskeleton robot, it is necessary to make a proper simplification of the model. This paper studies the unilateral lower extremity as an example.

The D-H method [11] is a method for studying the kinematics. The coordinate system is established see Fig. 5. α_i is the angle from $\hat{Z}_i$ to $\hat{Z}_{i+1}$ measured about $\hat{X}_i$; a_i is the distance from $\hat{Z}_i$ to $\hat{Z}_{i+1}$ measured along $\hat{X}_i$; d_i is the distance from $\hat{X}_{i-1}$ to $\hat{X}_i$ measured along $\hat{Z}_i$;and θ_i is the angle from $\hat{X}_{i-1}$ to $\hat{X}_i$ measured about $\hat{Z}_i$, see Table Ⅰ.

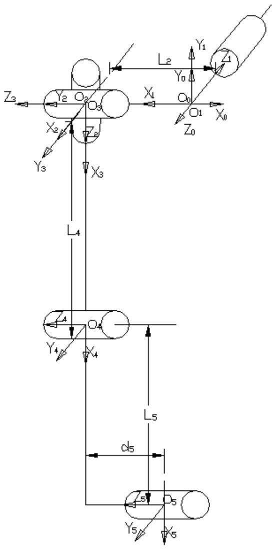

Fig.5.A single lateral lower extremity kinematic coordinate system

TABLE Ⅰ Link parameters

i	α_{i-1}	a_{i-1}	d_i	θ_i	关节变量
1	180°	0	0	180°	θ_1
2	90°	L_2	0	-90°	θ_2
3	-90°	0	0	-90°	θ_3
4	0	L_4	0	0	θ_4
5	0	L_5	$-d_5$	0	θ_5

Using the linkage transformation formula, the coordinate system of the neighboring bars can be connected to each other, and the linkage transformation matrix is used to represent ${}^{i-1}_{i}T$:

$$ {}^{i-1}_{i}T = R_X(\alpha_{i-1})D_X(a_{i-1})R_Z(\theta_i)D_Z(d_i) \tag{1}$$

Expand on:

$$ {}^{i-1}_{i}T = \begin{bmatrix} c\theta_i & -s\theta_i & 0 & a_{i-1} \\ s\theta_i c\alpha_{i-1} & c\theta_i c\alpha_{i-1} & -s\alpha_{i-1} & -s\alpha_{i-1}d_i \\ s\theta_i s\alpha_{i-1} & c\theta_i s\alpha_{i-1} & c\alpha_{i-1} & c\alpha_{i-1}d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

(where s is shorthand for sin, c for cos, Hereafter all adopt this convention)

Substituting table 1 parameters into the values of ${}^{0}_{1}T$, ${}^{1}_{2}T$, ${}^{2}_{3}T$, ${}^{3}_{4}T$, ${}^{4}_{5}T$, the transformation matrix of the relative base coordinate system of the foot is obtained.:

$$ {}^{0}_{5}T = {}^{0}_{1}T{}^{1}_{2}T{}^{2}_{3}T{}^{3}_{4}T{}^{4}_{5}T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

The results of the expressions are as follows:

$$n_x = c_{34}\left[c_1c_2c_5 - s_1s_5\right] - s_{34}\left[s_1c_5 + s_5c_1c_2\right] \tag{4}$$

$$n_y = -c_{45}\left[s_3c_1 + s_1c_2c_3\right] + s_{45}\left[s_1s_3c_2 - c_1c_3\right] \tag{5}$$

$$n_z = s_2\left[s_3s_{45} - c_3c_{45}\right] \tag{6}$$

$$o_x = s_{45}\left[s_1s_3 - c_1c_2c_3\right] - c_{45}\left[s_1c_3 + s_3c_1c_2\right] \tag{7}$$

$$o_y = c_{35}\left[s_1s_4c_2 - c_1c_4\right] + s_{35}\left[s_1c_2c_4 + s_4c_1\right] \tag{8}$$

$$o_z = s_2\left[c_3s_{45} + s_3c_{45}\right] \tag{9}$$

$$a_x = -c_1s_2 \tag{10}$$

$$a_y = s_1s_2 \tag{11}$$

$$a_z = -c_2 \tag{12}$$

$$p_x = L_2c_1 - L_5\left[s_1s_{34} - c_1c_2c_{34}\right] - L_4\left[s_1s_3 + c_1c_2c_3\right] + d_5c_1s_2 \tag{13}$$

$$p_y = -L_2s_1 - L_5\left[c_1s_{34} - s_1c_2c_{34}\right] - L_4\left[c_1s_3 + s_1c_2c_3\right] - d_5s_1s_2 \tag{14}$$

$$p_z = d_5c_2 - L_5s_2c_{34} - L_4c_3s_2 \tag{15}$$

When you enter multiple joint variables, you can get a series of coordinate points（p_{xi} ,p_{yi} ,p_{zi}）(i=1...n) of the foot relative to the frame zero, you can get the trajectory.

5. Conclusion

In this paper, the mechanical structure of lower extremity exoskeleton robot was optimized., the results show that reasonable mechanical structure design can be both good flexibility and good stability.The addition of some spring damping mechanisms to the mechanical structure can reduce the impact on human joints.Using the results of the kinematics of the institution, the end position of the mechanism can be obtained from the angles of the joints, which is the basis of the mechanism velocity analysis, acceleration analysis and mechanism synthesis.The movement of robot control is actually controlling the motion of each joint drive motor, so that the motion of each joint is coordinated and the feet can be moved according to certain path in space.

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