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ORIGINAL RESEARCH ARTICLE

Design of a wearable upper limb rehabilitation robot and its motion simulation and dynamics analysis

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ABSTRACT

Objective: A new wearable upper limb rehabilitation robot is designed to address the disadvantages of the current desktop upper limb rehabilitation robot, which is bulky and inconvenient to move, and the rationality of the design is verified through the analysis of its motion characteristics and the calculation of joint moments. **Methods:** Firstly, according to the principle of modular design, the overall structure was designed. Secondly, the SOILDWORKS is used for three-dimensional modeling, and the SOILDWORKS Motion is used to simulate the elbow flexion/extension movement, shoulder flexion/extension movement and shoulder-elbow joint linkage movement of the robot. Finally, the dynamic equation of the system is established based on Lagrange method, and the change curve of the joint torque of the manipulator is calculated by MATLAB software. **Results:** The simulation results confirmed that the motion simulation curves of shoulder joint, elbow joint and wrist joint were smooth. The dynamic analysis confirmed that the joint torque variation curve was smooth and the maximum joint torque was less than the rated torque of the motor after deceleration. **Conclusion:** The design of wearable upper limb rehabilitation robot is reasonable, which lays a theoretical foundation for the subsequent research on upper limb rehabilitation robot.

Keywords: upper limb rehabilitation robot; kinematics; simulation; dynamics analysis; MATLAB

1. Introduction

Stroke is one of the major diseases threatening human health and safety. With the increasing aging, incidence rate of cerebrovascular accident or stroke secondary diseases is increasing. According to the Report on the Chinese Stroke Prevention (2015), about 15% of China's population over 40 years old are at high risk of stroke. After 55 years of age, the relative incidence rate of stroke increased 1 time[1] every 10 years. There are many sequelae after stroke. About 85% of stroke patients are accompanied by upper limb dysfunction in the early stage of onset[2], 55%–75% are still accompanied by upper limb dysfunction 3–6 months after onset[3,4], about 2/3 of

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stroke patients still regard the loss of upper limb function as the main problem 4 years after onset[5], and about 25% are still accompanied by severe paralysis of upper limb 5 years after stroke[6]. Therefore, it is particularly necessary to study the upper limb functional rehabilitation of stroke patients and its robot.

At present, most of the upper limb rehabilitation training equipment at home and abroad are desktop, such as the ARMin series exoskeleton upper limb rehabilitation robot[7,9] developed by the University of Zurich, Switzerland. Among them, ARMin II has 7 degrees of freedom[10], and ARMin III is the latest generation. ARMin III can assist patients with 3 degrees of freedom of shoulder joint, 1 degree of freedom of elbow joint, forward/backward rotation of the forearm, and wrist flexion/extension training, and the exchange function of left and right hands is added on the basis of Armin II[11]; CADEN-7 has been developed by the University of Washington in the United States, which uses rope for transmission to reduce the moment of inertia of the mechanism[12]. The Swiss company Hocoma has developed Armeo series upper limb rehabilitation training system, in which Armeo spring uses spring weight reduction mechanism to balance the weight of the arm, but it can only carry out active movement, which makes the application scope of the device small[13,14]. Armeo power has comprehensive functions, but due to the use of more motors, the shape is complex and huge[15]. Shanghai Jiao Tong University has developed a 6-DOF unpowered upper limb exoskeleton rehabilitation training equipment with gravity compensation function[16]. This upper limb rehabilitation training equipment have the problems of complex structure, huge volume and inconvenient movement. Therefore, this paper proposes the design of a wearable upper limb rehabilitation robot, which aims to design an upper limb rehabilitation training equipment with simple structure, lightweight and suitable for patients' home. At present, there are few mature products related to wearable upper limb rehabilitation robots in the market. Compared with the representative American emerging technology company Mypower 1000[17] and the University of Pennsylvania TitanArm[18] driven by ratchet and flexible cable. Their exoskeleton power is concentrated in the elbow joint, but the actual situation is that the shoulder and elbow joints of paralyzed patients have partial or total loss of motor function, Single joint drive cannot meet the needs of patients.

In view of the above problems, this paper adopts the modular design principle, through the reasonable choice of the degree of freedom of the manipulator and the selection of light materials, designs a new 4-DOF wearable upper limb exoskeleton rehabilitation robot with simple structure and light weight. In addition, this paper also establishes the theoretical basis for the motion simulation of human elbow/extension machine, and verifies the rationality of the motion of elbow/extension machine.

2. Overall mechanical structure

The mechanical structure of the wearable upper limb exoskeleton rehabilitation robot designed in this paper is based on the portable wearing design of the whole mechanism. On the premise of meeting the patients' normal wearing of the mechanism and considering the needs of patients' rehabilitation training, the mechanism is simplified as much as possible. Three degrees of freedom of shoulder joint and one degree of freedom of elbow joint are selected as the degrees of freedom of the manipulator from the seven degrees of freedom of human upper limb. Only one driving motor is installed at the shoulder joint and elbow joint, and light materials are selected to reduce the weight borne by the patient when wearing the mechanism and reduce the possible secondary injury to the patient's shoulder caused by the device. This design can not only ensure that patients can carry out passive training of shoulder and elbow joints when the muscle strength of upper limbs is relatively weak, but also add active training according to their own situation when patients recover to a certain extent. In the design, the modular design principle is adopted for the overall structure design, which can be divided into three modules, including shoulder module, shoulder module and elbow module. The whole mechanical mechanism is shown in **Figure 1** (3D modeling in SOLIDWORKS).

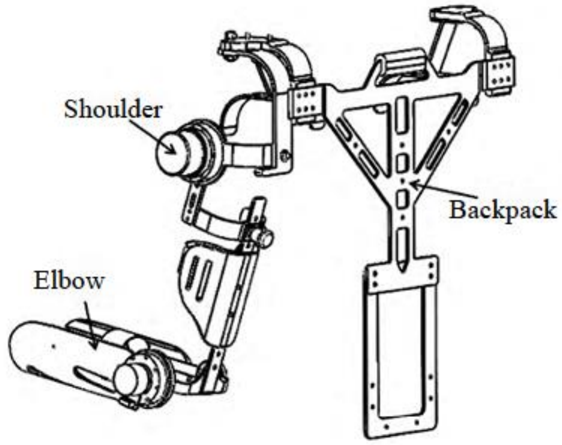

Figure 1. Overall structure of the wearable upper-limb rehabilitation robot.

The backpack module is mainly composed of back support frame and waist rod, which mainly plays the following roles:

(1) As an installation platform for installing motor drive, control board, battery and other hardware equipment; (2) As the mounting base connecting the shoulder module, it provides support for the shoulder module; (3) The mounting frame as a wearing mechanism is connected with a wearing mechanism for users to wear.

The shoulder module is composed of a shoulder back bracket, a shoulder blade frame and a shoulder motor base. The connection between the shoulder back bracket and the back support frame and between the shoulder back bracket and the shoulder blade frame provides two non-motor driven degrees of freedom: horizontal adduction/abduction and coronal adduction/abduction. A brushless DC motor and a harmonic reducer are installed on the shoulder motor base to form the shoulder power source to drive the shoulder joint to complete the forward flexion backward extension in the sagittal plane. Through this mechanism, the bionic restoration of three-dimensional spatial degrees of freedom of human shoulder joint (ball axis joint) is completed.

The elbow module is mainly composed of forearm support, elbow motor fixing ring, etc. a power source composed of DC brushless motor and harmonic reducer is installed to drive the elbow joint to flexion/extension movement. In addition, in order to reduce the power consumption of the motor driving mechanism and enhance the service life and endurance of the battery, a coil spring balance mechanism is designed at the elbow of the exoskeleton robot, and a tension spring balance mechanism is used at the shoulder mechanism. Through these balance mechanisms, the self-weight of the mechanical structure is balanced and the movement of the mechanism is smoother.

Therefore, the design of the wearable mechanism and the wearable upper limb of the patient is a key issue in the design of the wearable mechanism. The weight of the mechanism is evenly distributed in all parts of the body, and the back weight is arranged from top to bottom to maintain the stability of the center of gravity of the mechanism.

In order to adapt to the body size difference of different users and achieve better wearing effect, the overall mechanism is designed to adjust shoulder width, upper arm and forearm length, which can adapt to the average body size (18–60 years old) of 10%–99% of the human body in Human Dimensions of Chinese Adults (GB/T 10000–1988). IT meets the use needs of most people, and has good applicability.

3. Kinematics simulation of robot

In order to verify the effect of motor driven motion at each joint of the wearable upper limb exoskeleton rehabilitation robot, the established 3D mechanism model is analyzed in the motion simulation module motion of SOLIDWORKS. The motion analysis solver of motion adopts the solver of the mechanical system dynamics self analysis software ADAMS[19,20].

3.1. Kinematics simulation of elbow joint

In consideration of the requirements of rehabilitation training, the movement of the affected limb should be gentle and slow, and the movement process should be gentle (there should be no sudden change of movement, etc.) to prevent secondary injury. In the Motion simulation module of SOLIDWORKS, take the elbow joint as the coordinate origin, add a motor at the elbow joint, set the motor motion mode as oscillation, the oscillation frequency as 0.25 Hz, and set the maximum motion angle as 120° (i.e. the average speed of the elbow joint is 10 R/min and the motion cycle is 4 s). In motion, conduct a flexion / extension of the forearm in the sagittal plane driven by the motor for motion simulation. The flexion process is shown in **Figure 2** (the extension is the inverse process in the figure).

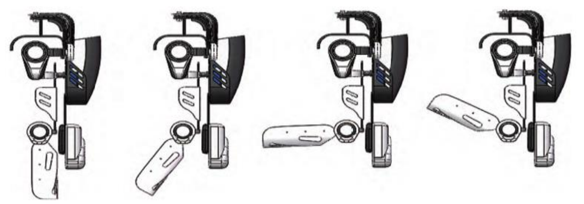

Figure 2. Motion simulation of flexion and extension in elbow joint.

In the process of forearm movement, the forearm can be simplified as a connecting rod rotating around the elbow joint, while the wrist joint (forearm support end) can be regarded as another end point of the simplified connecting rod, and its displacement data can reflect the overall situation of forearm movement (whether the displacement is smooth or not). After the motion simulation, the required angular displacement curve of elbow joint and linear displacement curve of wrist joint can be generated by using the "results and diagrams" in SOLIDWORKS Motion. The system will automatically generate the corresponding curve, and the user can modify and set the relevant attributes of the curve. It can also generate the corresponding Excel spreadsheet recording the relevant motion data in the whole motion process, and use these data to draw the curve through Excel. In this way, the specific value of each data point can be seen intuitively, and it is more convenient for users to edit and process the curve. Therefore, this paper uses this method to generate the angular displacement curve of elbow joint and the linear displacement curve of wrist joint in this motion cycle (**Figure 3**).

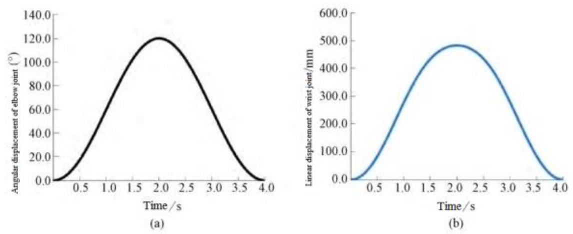

Figure 3. Angular displacement of elbow joint **(a)** and linear displacement of wrist joint **(b)**.

As shown in **Figure 3**, the change curve of angular displacement and linear displacement of the exoskeleton mechanism driven by the motor is smooth, indicating that the whole movement transition is smooth and close to the normal movement of human movement, which proves that the design of the exoskeleton elbow mechanism is reasonable and in line with the law of human movement, which can effectively assist the user in training and prevent secondary injury.

3.2. Kinematics simulation of shoulder joint

According to the established 3D model, the kinematics simulation analysis of the independent training process of the shoulder joint is carried out in the motion simulation module of SOLIDWORKS. The motion mode of the shoulder joint is set as oscillation, the oscillation frequency is 0.25 Hz, and the maximum motion angle is set as 90° (i.e. the average speed of the shoulder joint is 7.5 R/min and the motion cycle is 4 s). The motion simulation of the flexion/extension of the whole arm in the sagittal plane driven by the motor is carried out in motion. Its movement process is shown in **Figure 4**.

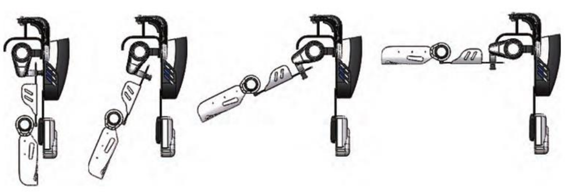

Figure 4. Motion simulation of flexion and extension in shoulder joint.

Considering that in the whole arm movement process, the elbow joint and wrist joint are the two most important joints of the upper limb except the shoulder joint (the simplified motion model of the human upper limb also simplifies the upper arm and forearm into two connecting rods and the two joints into hinges). The displacement of the two joints in a movement can approximately reflect the specific situation of an upper arm movement. Therefore, after the motion simulation analysis, use the "results and diagrams" in motion to generate an Excel spreadsheet that records the angular displacement data of shoulder joint and the linear displacement data of elbow joint and wrist joint in the whole motion process, and draw the angular displacement curve of shoulder joint and the linear displacement curve of elbow joint and wrist joint in this motion cycle through Excel (**Figure 5**).

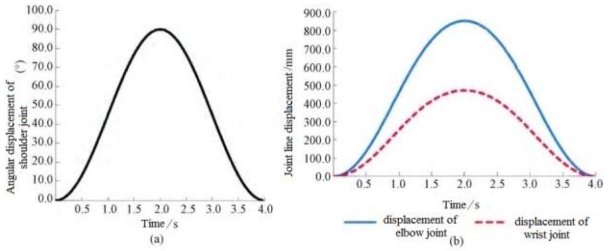

Figure 5. Angular displacement of shoulder joint (**a**) and linear displacement of elbow joint and wrist joint (**b**).

As shown in Figure 5, the angular displacement curve of the shoulder joint and the linear displacement curves of the elbow and wrist joints change smoothly during the whole arm flexion/extension movement of the exoskeleton shoulder mechanism driven by the motor. This indicates that the smooth movement speed and smooth movement curve during the whole arm movement are in line with the normal human movement pattern, which has good bionic properties and meets the relevant requirements for rehabilitation training.

3.3. Kinematics simulation of joint training of shoulder and elbow

The planned training modes of wearable upper limb exoskeleton rehabilitation robot include independent training of elbow joint, independent training of shoulder joint and joint training of shoulder and elbow joint. Considering this situation, after the motion simulation analysis of elbow independent training and shoulder joint independent training, the simulation analysis of shoulder and elbow joint linkage training mode is added to verify the motion effect of this training mode.

In the previously established model, the shoulder joint motion was set to oscillate with an oscillation frequency of 0.25 Hz, and the maximum angle of shoulder joint motion was 90° (i.e., the average rotational speed of the shoulder joint was 7.5 r/min, and the motion period was 4 s). The elbow joint motion was set to oscillate with an oscillation frequency of 0.25 Hz, and the maximum angle of elbow joint motion was 120° (i.e., the average rotational speed of the elbow joint was 10 r/min, and the motion period was 4 s). Run the shoulder elbow joint in the software environment, and conduct the shoulder elbow joint linkage training of flexion / extension in the sagittal plane. The movement process is shown in **Figure 6**.

Figure 6. Motion simulation of flexion and extension in shoulder-elbow.

The process of simulation results is analyzed and processed, and the position data of elbow and wrist in the whole simulation process are extracted. Through these position data, the displacement curves of wrist and elbow in a joint training of shoulder and elbow are generated (**Figure 7**).

The movement curves of the wrist and elbow joints of the shoulder-elbow linkage training show that the displacement curves of the elbow and wrist joints of the exoskeleton robot in the shoulder-elbow linkage training are gentle (the concave curve of the wrist joint is because the limit angle of the elbow joint is 120°, and the position of the elbow joint converges to the shoulder joint as the origin of the simulation system after exceeding 90°. The results show that it does not produce sudden changes in position that may cause secondary injury to the patient), which proves the reasonableness and safety of the mechanism.

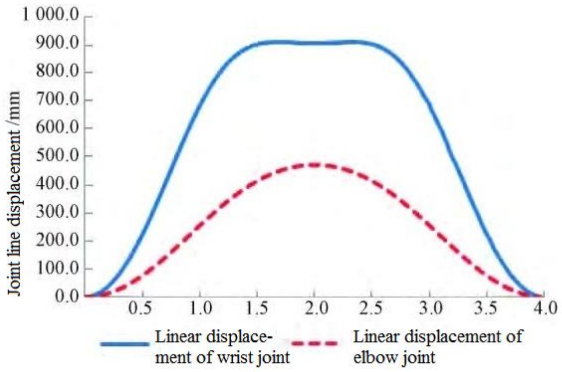

Figure 7. Linear displacement of wrist joint and elbow joint.

4. Dynamic analysis of robot

In order to verify whether the mechanical properties of the selected motor of the wearable upper limb exoskeleton robot can meet the requirements of shoulder elbow joint training, the motion of shoulder and elbow joints is analyzed and calculated.

Through the simplified analysis of the whole arm module driven by the two motors of the shoulder and elbow, it can be simplified into a two link mechanism with fixed base as shown in **Figure 8**, in which the upper arm is $l_1$and the forearm is l_2.

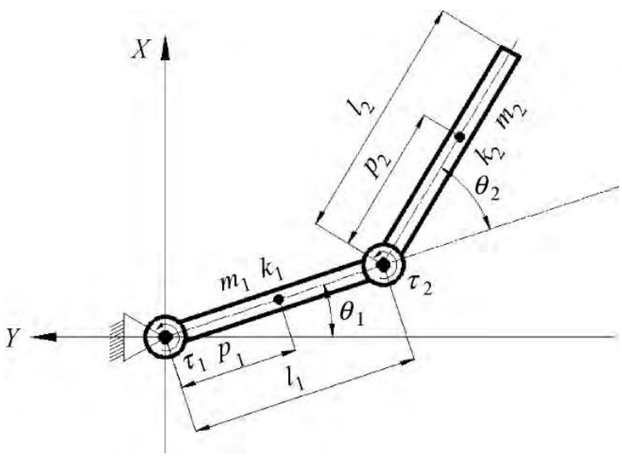

Figure 8. The robotic arm mechanism.

As shown in **Figure 8**, it is assumed that the joint variables of link 1 and link 2 are rotation angles θ_1 and θ_2, respectively. The corresponding torques of link 1 and link 2 are τ_1 and τ_2, respectively. The mass of the two links are m_1 and m_2, respectively. The lengths of the two links are l_1 and l_2, respectively. The centroids are k_1 and k_2, respectively. The distances between the centroid and the rotation center of the joint are p_1 and p_2, respectively. The rotational inertias of the two links around the centroid are I_{c1} and I_{c2}.

Select θ_1 and θ_2 as the generalized coordinates describing the position of the connecting rod, then the position coordinates k_1 of the centroid of rod 1 are:

$$x_1 = p_1 \sin\theta_1 \tag{1}$$

$$y_1 = -p_1 \cos\theta_1 \tag{2}$$

The position coordinates of the k_2 center of mass of rod 2 are:

$$x_2 = l_1 \sin\theta_1 + p_2 \sin(\theta_1+\theta_2) \tag{3}$$

$$y_2 = -l_1 \cos\theta_1 - p_2 \cos(\theta_1+\theta_2) \tag{4}$$

By deriving the time respectively, it is obtained that the velocity square of the k_1 center of mass of rod 1 is:

$$v_1^2 = \dot{x}_1^2 + \dot{y}_1^2 = \left(p_1\dot{\theta}_1\right)^2 \tag{5}$$

The velocity square of the k_2 center of mass of rod 2 is:

$$v_2^2 = \dot{x}_2^2 + \dot{y}_2^2 = l_1^2\dot{\theta}_1^2 + p_2^2\left(\dot{\theta}_1+\dot{\theta}_2\right)^2 + 2l_1p_2\left(\dot{\theta}_1^2+\dot{\theta}_1\dot{\theta}_2\right)\cos\theta_2 \tag{6}$$

The rotational angular speeds of the two connecting rods are:

$$w_1 = \dot{\theta}_1 \tag{7}$$

$$w_2 = \dot{\theta}_1 + \dot{\theta}_2 \tag{8}$$

Moreover, the plane motion kinetic energy of the rigid body can be expressed as the sum of the translational kinetic energy of the center of mass and the rotational kinetic energy around the center of mass. Therefore, the kinetic energy of the two rods can be obtained as follows:

$$E_{k1}=\frac{1}{2}m_1v_1^2+\frac{1}{2}I_{C1}W_1^2$$

$$=\frac{1}{2}\left(m_1p_1^2+\frac{1}{12}m_1l_1^2\right)\dot{\theta}_1^2 \quad (9)$$

$$E_{k2}=\frac{1}{2}m_2v_2^2+\frac{1}{2}I_{c2}w_2^2$$
$$=\frac{1}{2}m_2[l_1^2\dot{\theta}_2^1+p_2^2(\dot{\theta}_1+\dot{\theta}_2)^2+$$
$$2l_1p_2(\dot{\theta}_2^1+\dot{\theta}_1\dot{\theta}_2)\cos\theta_2]+\frac{1}{2}I_{c2}\big(\dot{\theta}_1+\dot{\theta}_2\big)^2$$

$$=\frac{1}{2}[m_2(l_1^2+p_2^2+2l_1p_2\,cos\,\theta_2)+I_{c2}]\dot{\theta}_1^2+$$
$$\frac{1}{2}(m_2p_2^2+I_{c2})\dot{\theta}_2^2+$$
$$(m_2p_2^2+m_2l_1p_2\,cos\,\theta_2+I_{c2})\dot{\theta}_1\dot{\theta}_2 \quad (10)$$

Then the total kinetic energy of the system is:

$$E_k=E_{k1}+E_{k2}$$
$$=\frac{1}{2}[m_1p_1^2+I_{c1}+m_2(l_1^2+p_2^2+2l_1p_2\,cos\,\theta_2)$$

$$+2l_1p_2\,cos\,\theta_2)+I_{c2}]\dot{\theta}_1^2+\frac{1}{2}(m_2p_2^2+I_{c2})\dot{\theta}_2^2$$

$$+(m_2p_2^2+m_2l_1p_2\,cos\,\theta_2+I_{c2})\dot{\theta}_1\dot{\theta}_2 \quad (11)$$

Taking the coordinate origin fixed at the base as the potential energy zero point, the total potential energy of the simplified two link system is:

$$E_P=-m_1gp_1\,cos\,\theta_1-m_2gl_1\,cos\,\theta_1$$
$$-m_2gp_2\,cos(\theta_1+\theta_2) \quad (12)$$

Establish the Lagrange function of the system:

$$L=E_k-E_p \quad (13)$$

According to Lagrange equation:

$$F_i=\frac{d}{dt}\frac{\partial L}{\partial\dot{q}_i}-\frac{\partial L}{\partial q_i}(i=1,2,3\cdots,n) \quad (14)$$

The moment of each joint is solved as follows.

$$\frac{\partial L}{\partial\dot{\theta}_1}=m_1p_1^2+I_{\mathrm{cl}}+m_2(l_1^2+$$

$$p_2^2+2l_2p_2\cos\theta_2)+I_{c2}]\dot{\theta}_1+$$

$$(m_2p_2^2+m_2l_1p_2\,cos\,\theta_2+I_{c2})\dot{\theta}_2 \quad (15)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial\dot{\theta}_1}\right)=[m_1p_1^2+I_{c1}+m_2(l_1^2+p_2^2+2l_1p_2$$

$$cos\,\theta_2)+I_{c2}]\ddot{\theta}_1-(2m_2l_1p_2\,sin\,\theta_2)\dot{\theta}_1\dot{\theta}_2$$

$$+m_2l_1p_2cos\,\theta_2+I_{c2})\ddot{\theta}_2 \quad (16)$$

$$\frac{\partial L}{\partial\theta_1}=-m_1gp_1\,sin\,\theta_1-m_2gl_1\,sin\,\theta_1$$

$$-m_2gp_2\,sin(\theta_1+\theta_2) \quad (17)$$

The joint torque of joint 1 can be obtained as follows:

$$\tau_1=\frac{d}{dt}\frac{\partial L}{\partial\dot{\theta}_1}-\frac{\partial L}{\partial\theta_1}$$
$$=[m_1p_1^2+m_2(l_1^2+p_2^2+2l_1p_2\,cos\,\theta_2)+$$
$$I_{c1}+I_{c2}]\ddot{\theta}_1-(2m_2l_1p_2\,sin\,\theta_2)\dot{\theta}_1\dot{\theta}_2+$$
$$(m_2p_2^2+m_2l_1p_2\,cos\,\theta_2+I_{c2})\ddot{\theta}_2-$$
$$(m_2l_1p_2\sin\theta_2)\dot{\theta}_2^2+(m_1p_1+m_2l_1)g\sin\theta_1$$
$$+m_2gp_2\sin(\theta_1+\theta_2) \quad (18)$$

By:

$$\frac{\partial L}{\partial\dot{\theta}_2}=(m_2p_2^2+I_{c2})\dot{\theta}_2+$$

$$(m_2p_2^2+m_2l_1p_2\,cos\,\theta_2+I_{c2})\dot{\theta}_1 \quad (19)$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial\dot{\theta}_2}\right)=(m_2p_2^2+m_2l_1p_2\,cos\,\theta_2+I_{22})\ddot{\theta}_1+$$

$$(m_2p_2^2+I_{c2})\ddot{\theta}_2-(m_2l_1p_2\sin\theta_2)\dot{\theta}_1\dot{\theta}_2 \quad (20)$$

$$\frac{\partial L}{\partial\theta_2}=-m_2l_1p_2\big(\dot{\theta}_1^2+\dot{\theta}_1\dot{\theta}_2\big)\,sin\,\theta_2$$

$$-m_2gp_2\,sin(\theta_1+\theta_2) \quad (21)$$

The joint torque of joint 2 can be obtained as follows:

$$\tau_2=\frac{\mathrm{d}}{\mathrm{dt}}\frac{\partial L}{\partial\dot{\theta}_2}-\frac{\partial L}{\partial\theta_2}$$

$$=(m_2p_2^2+m_2l_1p_2\,cos\,\theta_2+I_{c2})\ddot{\theta}_1+$$
$$(m_2p_2^2+I_{c2})\ddot{\theta}_2+(m_2l_1p_2\,sin\,\theta_2)\dot{\theta}_1^2+$$
$$m_2gp_2\,sin(\theta_1+\theta_2) \quad (22)$$

In the SOLIDWORKS software environment, using the "quality attribute" function to analyze the simulation human wearable upper limb robot model, l_1=0.325 m, l_2=0.273 m, p_1=0.164 m, p_2=0.131 m, m_1=2.939 kg, m_2=2.112kg, g=9.8 m/s^2, I_{c1}=0.033 kg·m^2, I_{c2}=0.017 kg·m^2.

Bring the values into equations (18) and (22), and solve the two equations in the MATLAB software environment: Set the training time as 4 s and select the working state of two joints moving continuously for one cycle under the shoulder elbow linkage training mode as the analysis object.

After the solution, the results are processed, and the driving torque acting on the two joints in the whole process of shoulder elbow joint training can be obtained τ_1, τ_2 size change curve (**Figure 9**).

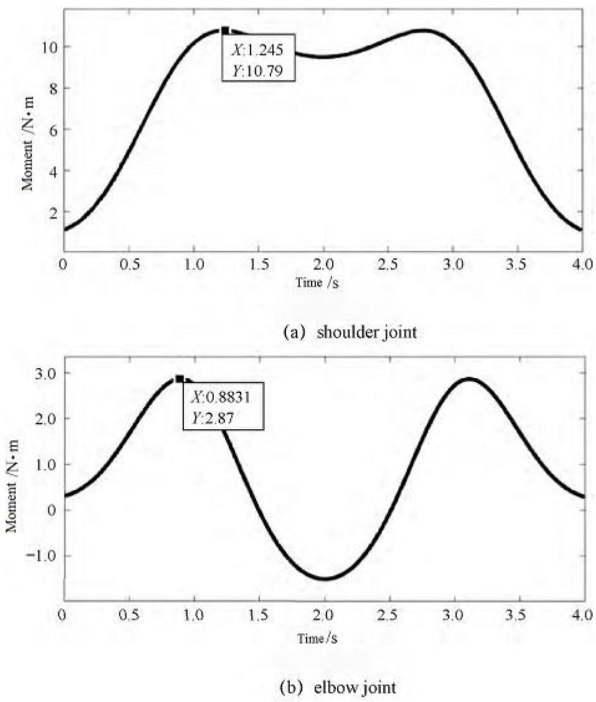

Figure 9. Torque curves of shoulder joint and elbow joint.

According to the calculation results:

(1) The maximum torque τ_1 of shoulder joint is 10.79 N·m<18 N·m (rated torque output by shoulder motor after reducer deceleration). (2) The maximum torque τ_2 of elbow joint is 2.87 N·m<7.8 N·m (rated torque of elbow motor after reducer deceleration).

Therefore, it can be seen that the motor selected on the two joints of the wearable upper limb rehabilitation robot is reasonable, and its mechanical properties can meet the ultimate mechanical requirements of the robot's shoulder and elbow joint training. In addition, it can be seen from the figure that the change curve of joint torque is also smooth, and there is no sudden change of joint torque, which can also ensure the safety of patients to a certain extent.

5. Discussion and conclusions

At present, most of the upper limb rehabilitation robots at home and abroad are complex desktop training equipment, which is expensive, and most of them need a large space for placement, which greatly restricts the possibility of upper limb rehabilitation training equipment entering the community or even the family. With the accelerating aging process and the increasing number of stroke patients with hemiplegia in China, the demand for rehabilitation robots will be greater and greater. The personalization, familization and popularization of rehabilitation medical products are the inevitable trend of future development. In this case, the wearable upper limb exoskeleton rehabilitation robot designed in this paper meets the needs of the current society. After completing the overall mechanical structure design of the wearable upper limb exoskeleton rehabilitation robot, the kinematics simulation of elbow flexion/extension movement, shoulder flexion/extension movement and shoulder elbow joint linkage is carried out in this paper. The simulation results confirm that the motion simulation curve is smooth. At the same time, the dynamic equation is established based on the Lagrange method. The joint torque change curve in the process of shoulder elbow joint linkage training meets the requirements of the optional motor, it is proved that the design of the wearable upper limb rehabilitation robot is reasonable, which lays a theoretical foundation for the follow-up research of upper limb rehabilitation robot.

The wearable upper limb rehabilitation robot designed in this paper adopts a novel knapsack mechanical structure design, which is simple and lightweight, and can be easily worn by patients. It changes the traditional physical therapy of upper limb rehabilitation and the fixed desktop training mode of upper limb robot, so that the rehabilitation training is no longer limited by the site, and has good clinical application and popularization. At the same time, because it can be carried with you, it can also assist the daily life of patients to a certain extent, so as to combine rehabilitation training with daily life assistance. This training mode is also a new trend of the development of rehabilitation training.

Conflict of interest

The authors declare no conflict of interest.

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