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Design and application of climbing arm assist system

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Abstract. As a new research field, the human assistance has been developed according to the needs of the application field, and has been reflected in the field of industrial and automotive engineering and rehabilitation medicine, military equipment and so on. In this paper, we take how to realize the human arm power as the research task, and through human - machine system kinematics and dynamics analysis, establish the kinematics and dynamics of mechanical system model of arm and exoskeleton. In addition, we use simulation technology to verify the correctness of the dynamic model of the arm and the exoskeleton mechanical system, which provides theoretical support for the research on tracking strategy control. We make detailed analysis of the control strategy theory, establish the expression of the assistance characteristic curve for the typical control strategy, and design the software and hardware to realize the control strategy. The data collected by prototype experiment is rationally analyzed, and the experimental results verify the correctness and feasibility of the control strategy. In addition, through the experimenter's arm assist system, we successfully complete the flexion movement of arms carrying the dumbbell. The effect is obvious and it achieves the desired objectives of the design.

Key words. Arm assist system, exoskeleton, control strategy.

1. Introduction

The human assist system is of great significance to improve the body's physical quality and break the human motion and physiological limits. As the external executive part of human in few number, its executive ability will directly affect the development of human beings and the survival ability to adapt to the harsh environment. It is the direct reason why the United States Department of Defense attaches great importance to introduce the upper limb and the lower extremity exoskeleton into the army, to assembly in each soldier's body [1]. In the future, the arm assist system can be used in the field of disaster relief and other fields, so as to improve the ability of human beings to overcome natural disasters, which has certain significance and value in saving human life and property.

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After the comparison and analysis of existing human assist mechanical system, we try using different mechanical systems, demonstrate the feasibility of the arm four-rod assist mechanical system, and conduct the mechanical system kinematics and dynamics modeling. In addition, we use Matlab software for the analysis of kinematics simulation of mechanical system, and modify the parts size of the arm four-rod assist mechanical system; moreover, we use Pro/E to complete the 3D design of the arm assist mechanical system, and introduce the 3D model into the dynamic simulation software Adams environment for the simulation. Through comparing Matlab dynamic simulation results with Adams simulation results, we manufacture the power machinery of arm assist system.

2. Mechanical system

2.1. Motion function planning of arm assist system

The previous human-assisted robot was used in medical and military applications. As it needs to consider the effect of many unknown external environmental parameters and its action function implementation in the military field, the technology is challenging and frontiering. The Honda Corporation of Japan in 2007 saw a gap in the application field, and developed a civil leg exoskeleton assist robot. The robot is placed in the motor on the leg side, which is the Honda Corporation of Japan motor R & D products: flat type brushless DC motor, quite small in the volume. The motor completes the transmission through the connecting rod connected fixedly together by the leg side [2].

In this paper, according to the different application fields of arm assist system, several action function requirements are put forward. Firstly, meet civilian needs and achieve the arm carrying heavy objects, pushing and pulling objects and further assist actions; secondly, meet the needs of the medical field and realize the auxiliary nurse nursing for the bedridden patient, patient arm rehabilitation training and further assist actions; thirdly, assist actions can be achieved in military including arm throwing objects, climbing obstacle and so on.

2.2. Mechanical system design and kinematics and dynamics analysis

After deep analyzing the characteristics and performance of the existing mechanical system, the four-bar mechanism [3] that can be analyzed by theoretical analysis, and exploratory application of new mechanism is conducted in the field.

The application of four-bar mechanism in the human arm assist system is derived from the following aspects:

First of all, in the arm assist action function defined in the paper, the tensile force of the elbow joint plays a key role, restricting the realization and effect of arm function, and even causing sports injury; in addition, the shoulder joints and elbow joints, in the upper extremity throwing motion simulation, show that the elbow joint tensile force safety limit is 3000 N, and the shoulder joint tensile force safety limit is

4500 N [4].

Secondly, movement characteristics of four-bar mechanism meet the realization requirements of arm assist action function (forearm reciprocating swings) [5]. If taking the main arm and the forearm as two hinged connecting rods, the connecting rod can achieve the swing action of the forearm, as shown in Fig. 1.

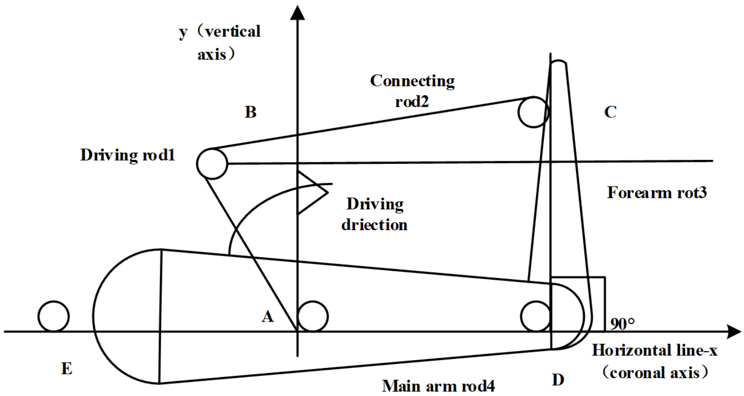

Fig. 1. A four-bar framework sketch map

Thirdly, the linkage mechanism has one of the biggest advantages. It is that the agency itself can guarantee the safety of forearm swing, through good design and size of the crank rod. Driven by a motor, the arms only repeatedly move in the range of a certain angle, and it will not cause arm dislocation or fracture accident caused by the arm movement overload because of the system and motor.

3. Dynamic modeling and simulation analysis of mechanical system

In this chapter, the relationship between the rod 3 (forearm) angular acceleration and other relevant variables and active torque M_1 of the rod 1 is established by using the Lagrange equation [6]. With the help of Adamas dynamic simulation software, the correctness of the mathematical model is verified by the simulation model of the mechanical system.

3.1. Derivation of mechanical system dynamic equation

Lagrange kinetic equation is

$$M_1 = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\partial T}{\partial \theta_1}\right) - \frac{\partial T}{\partial \theta_1} + \frac{\partial U}{\partial \theta_1}\,. \tag{1}$$

According to the mechanism model constructed in the paper, the quality of the connecting rod can be ignored by selecting the lightweight material and optimizing the structural dimension, but only focusing on the quality of human forearm. And the formula for calculating the quality of forearm is:

$$m_{\text{total}} = m_{\text{hand}} + m_{\text{forearm}} = 0.247 + 0.595 = 0.842\,\text{kg}\,. \tag{2}$$

The l-hand centroid refers to the distance from the centroid the center point to elbow, and elbow centroid indicates the distance from the forearm centroid to the center point to the elbow. The data of the centroid position of each part of the arm should be transformed to the center point of the elbow joint. Symbol T is the system kinetic energy, and U denotes the system potential energy. The system kinetic energy is

$$T = \frac{1}{2}(m_2 l_{3\text{c}}^2 + J)\dot{\theta}_3^2\,. \tag{3}$$

Also, the expression of function relation is established as

$$\theta_3 = \lambda_1 \theta_1\,. \tag{4}$$

After the above kinematic mathematical analysis, it was found that θ_3 and θ_1 have an ideally linear relationship. Now, equation (1) can be rewritten into the form

$$M_1 = \frac{\text{d}}{\text{d}t}\left(\frac{\partial T}{\partial \dot{\theta}_3} \cdot \frac{\partial \dot{\theta}_3}{\partial \dot{\theta}_1}\right) - \frac{\partial T}{\partial \theta_3} \cdot \frac{\partial \theta_3}{\partial \theta_1} + \frac{\partial U}{\partial \theta_3} \cdot \frac{\partial \theta_3}{\partial \theta_1} \tag{5}$$

When $\theta_3 = \alpha \cdot \theta_1^2 + b \cdot \theta_1 + c$, which is a second-order interpolation function relation, then

$$M_1 = (m_3 l_{3\text{c}}^2 + J)\ddot{\theta}_3(2a\lambda_2(\theta_3) + b) + (m_3 l_{3\text{c}}^2 + J)\dot{\theta}_3(2a\lambda_2(\dot{\theta}_3) + b) + \\ + m_3 g \cos\theta(2a\lambda_2(\theta_3) + b)\,. \tag{6}$$

Here, (4) may be reversely transformed as $\theta_1 = \lambda_2\theta_3$ and $\dot{\theta}_1 = \lambda_2\dot{\theta}_3$. It is necessary to choose three typical coordinates Al≡(62.5, 54.9712), A2≡(117.5, 110.4102), and A3≡(172.5, 155.2312) in allusion to the relation curve in Fig. 2(a), and the unit is the length. After the calculation, we can get $a = -0.0018$, $b = 1.3239$, and $c = -20.9162$.

3.2. Establish the M document of assist mechanism of dynamic mathematical model Matlab M

After taking $a = -0.0018$, $b = 1.3239$, and $c = -20.9162$ and the speed variation range of the rod 1 as well as the average speed l0 rad/s of the setting rod 1, the output torque changes with time, as shown in Fig. 2. The torque is negative, which is indicated by the fact that the applied torque is oriented in the clockwise direction. In 0.25 seconds or so, the rod 1 rotates about 145 degrees.

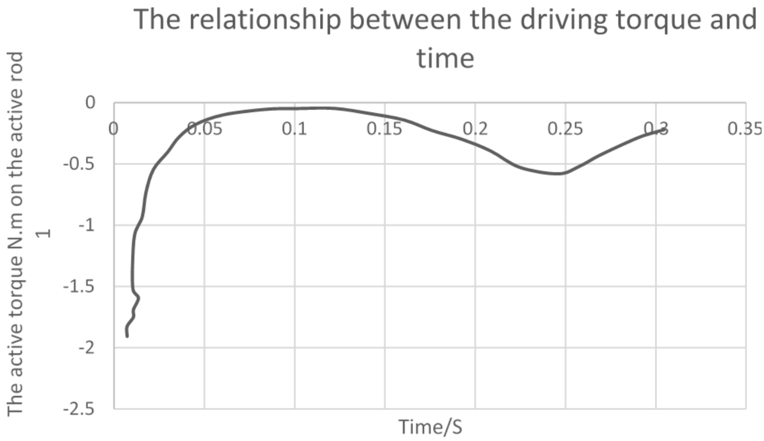

Fig. 2. Rod 1 active torque variety curve with 10 rad/s input

3.3. Simulation results of mechanical system model in Adams

In Adams/View, by setting the initial conditions of dynamics simulation operation, rod 1 adds a rotating Motion, the angular velocity is 10 rad/s, and the running time is 0.3 seconds, to ensure being consistent with initial conditions of the mathematical model of Matlab. The results are shown in Fig. 3 below. It is noted that the torque unit of the ordinate is in Nmm, and the simulation torque units in Matlab is in Nm. The torque value is positive in the simulation of the model, which shows that the rotational torque applied in the simulation environment is counterclockwise. There is no substantial impact on the next analysis of simulation results.

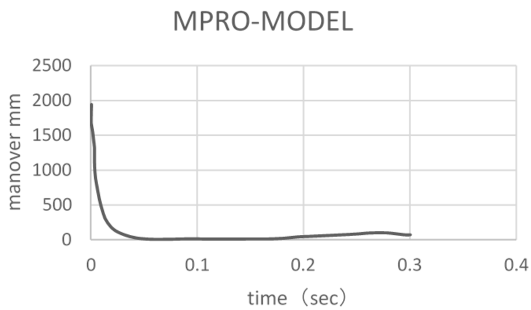

Fig. 3. Relationship between the drive torque and time of model in Adams

4. Conclusion

This paper makes full use of the dynamic simulation analysis software Adams and 3D mechanical parts design software Pro/E and takes reasonable size and shape of the mechanism. It greatly shortens the mechanical structure design and development time, and preliminarily checks the strength of parts. Then we use mechanical parts design software Autocad2005 to design part plane processing map, and eventually process the components successfully. The hinge movement is flexible after assembly and the fixed end connection is reliable, which meets the design requirements of the mechanical devices, and provides a reliable mechanical system prototype for the experiment.

It is necessary to add how to ensure the dimensions of the rod 3 and the rod 4 in the installation process. The size of the rod 3, because of choosing 79 mm, can be achieved by adjusting the distance between the fixed position of the arm and the axis of the elbow. The rod 4 can also be implemented in the same way. The elbow axis through the elbow joint differs from man to man, needing to be measured through the actual elbow movement (the methods is to fix the main arm and make the forearm rotating in the plane). In addition, according to the traces left by the forearm in plane, judge which point position is most likely the axis of the elbow joint.

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