Structural Optimization and Motion Simulation of Robot of Shoulder Exoskeleton

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Abstract. Stroke is a kind of acute cerebrovascular disease, its sequelae can lead to hemiplegia, great influence on their daily life, as the current increasing the hemiplegia patients caused by stroke, for patients with limb disorders long-term scientific recovery training, the traditional rehabilitation training is a professional medical staff for hand-in-hand rehabilitation training, it is difficult to meet the rehabilitation needs of the increasing number of patients, to provide a certain degree of help for this problem, shoulder exoskeleton robot was designed to add a telescopic rod structure to its original structure, allowing it to move up and down and realize the function of normal shoulder movement requirements, Solving and verify the forward and inverse motion by the D-H parameter method, The tion simulation of the robot using MATLAB, it observed no mutation in the position, speed and acceleration during the exercise, so as to verify the rationality and effectiveness of its workflow and meet the requirements of human shoulder rehabilitation training. The robot enables shoulder hemiplegia patients to achieve more diversified exercise while conducting normal shoulder rehabilitation training. However, the structure still has the problem that it cannot achieve synergistic movement, and it is difficult to perform other shoulder movements while they shrugged the shoulders.

Keywords: Optimum structure, D-H law, motion simulation.

1. Introduction

Stroke is an acute cerebrovascular disease, the brain tissue damage caused by the sudden rupture of the blood vessels into the brain, including ischemic and hemorrhagic stroke [1]. According to recent data from the World Health Organization, stroke is the largest cause of death besides heart disease and cancer, and it also has the highest disability rate. With the improvement of medical technology at home and abroad in recent years, the survival rate of stroke patients has reached more than 60%, but 80% of the surviving patients have left the sequelae of upper or lower limb movement disorders. Therefore, rehabilitation training is necessary for limb disorders is necessary. Traditional training is that patients regularly go to the hospital and manually repeated passive rehabilitation training by professional medical staff, which is time-consuming and laborious. So it is a major challenge for rehabilitation medicine to provide long-term and effective, scientific and targeted comprehensive rehabilitation training for upper limb hemiplegia patients. The shoulder exoskeleton robot can automatically and repeat the rehabilitation training and record the data in real time, which can not only reduce the manpower consumption of the hospital and help patients to recover more efficiently, but also record the data to help patients with similar conditions to recover more quickly and scientifically in the future. Therefore, it is imperative to study the exoskeleton robots.

The domestic and foreign research of exoskeleton upper limb robot has been able to realize patients 'rehabilitation needs, in the 1990s, by the MIT Hogan and others team developed the world's first upper limb rehabilitation robot training system MIT-MANUS can help upper limb hemiplegia auxiliary rehabilitation training, padova university research team designed a three free NeReBot upper limb rehabilitation robot system [2, 3], with rope drive instead of traditional rod drive to realize the flexible rehabilitation movement. The University of California and the Chicago Rehabilitation Institute jointly developed a three-degree of freedom traction rehabilitation robot ARM Guide The robot fixed the affected limb at the splint, flexion the affected limb by motor driving linear rail [4, 5], and the magnetic powder brake for shoulder internal and outer rotation. Tongtong Zhao et al. proposed a new 7 degree of freedom of upper limb exoskeleton robot [6], with a new hand fixation device instead of the traditional grip, can make the wrist get better training. However, at present, the shoulder exoskeleton robot still has defects in the movement range up and down and the shoulder shrug function, so the expansion rod mechanism is added to the shoulder exoskeleton robot to achieve the above functions, and to have the related functions of the shoulder exoskeleton robot. In this way, the recovery needs of normal shoulder hemiplegia patients are more diversified recovery exercise.

In the robot design, will use SolidWorks for shoulder exoskeleton robot structure optimization modeling, at the same time using the D-H method of robot positive and inverse kinematics solution and verify its rationality, finally use MATLAB motion simulation, by observing the speed, acceleration and position in the process of movement in order to verify the rationality of its structure.

2. Optimization of Mechanical Mechanism of Shoulder Exoskeleton

The designed shoulder exoskeleton robot uses a single arm structure and consists of three rotating joints. As shown in Figure 1, it mainly realizes the three modes of movement of the whole shoulder through three motors, the shoulder, and shoulder rotation and shoulder adduction, the design of the shoulder exoskeleton robot has three rotating joints, each rotating joint has independent motor drive, and the shoulder joint using parallelogram-diamond-parallelogram structure connection three rotating joint, the shoulder joint rod space structure space compared to the traditional parallelogram structure reduce 45. 97% [7-10]. From Figure 2 and Figure 3, the three motor axes are connected at the center of rotation, so the design has no shoulder fixation problem. The three motors respectively realize shoulder abduction / abduction, internal / external rotation and flexion / extension functions. On this basis, adding a telescopic rod structure below the motor 3 can not only expand the upper and lower motion range of the whole exoskeleton robot, but also help the patient to achieve the auxiliary function of shoulder shrug, so that the function of the whole shoulder exoskeleton robot is more comprehensive. It can also adapt to the needs of more people. The shoulder joint information mainly achieved by the motor was shown in Table 1, and the table shows the required movement mode of the motor, the driving mode, and the size of the rotation angle.

2.1. Kinematic Analysis and Validation

When studying the motion characteristics of the robot, the kinematic model is generally simplified according to the D-H parameter method and solved by the forward motion and inverse motion. The initial pose of the robot corresponding to the linkage coordinate system is shown in Figure 2, and this figure establishes the coordinate system of the improved D-H method, which facilitates the angle calculation of positive kinematics. The D-H parameter table is established according to the Table 2 coordinate system. In the table, the joint angle θi, the link offset Di, the link length ai-1, and the link torsion angle αi-1 are analyzed [11].

Table 1. Joint information.

mode of exercise	Drive way	angle of rotation /°
Shoulder adduction / outreach	motor drive	-180 to 30
Shoulder inner spin / outer spin	motor drive	-150 to 60
Shoulder flexion / extension	motor drive	-90 to 130

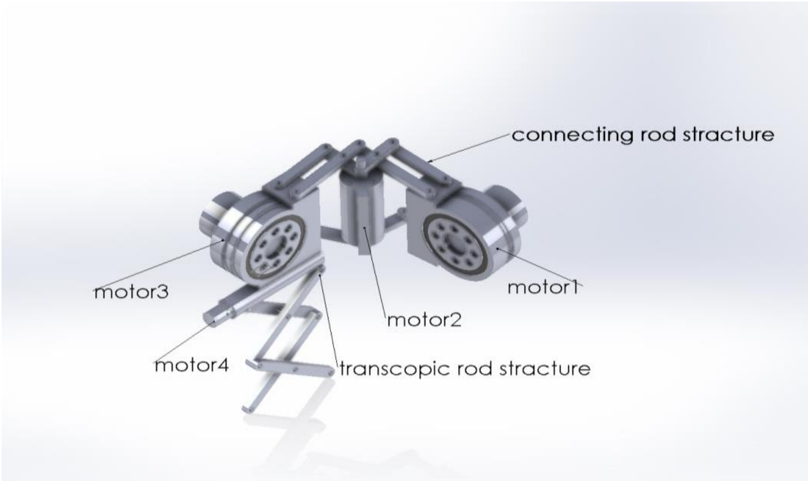

Fig 1. Structural design (Photo credited: Original).

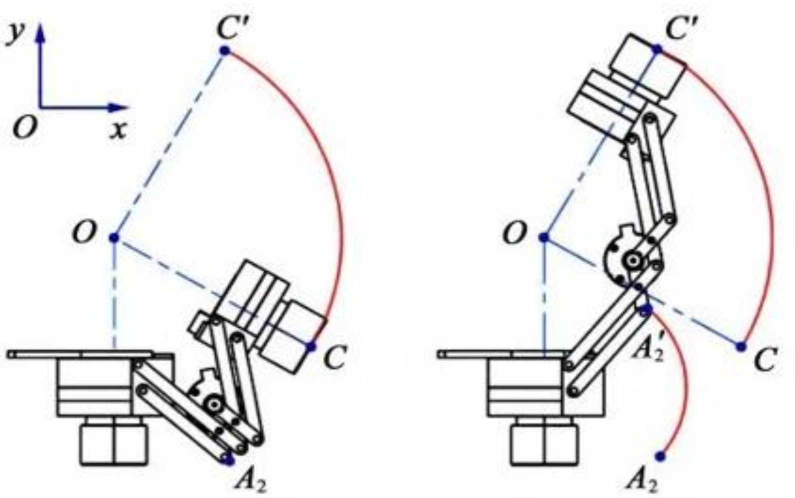

Fig 2. The exoskeleton robot rotation center [10].

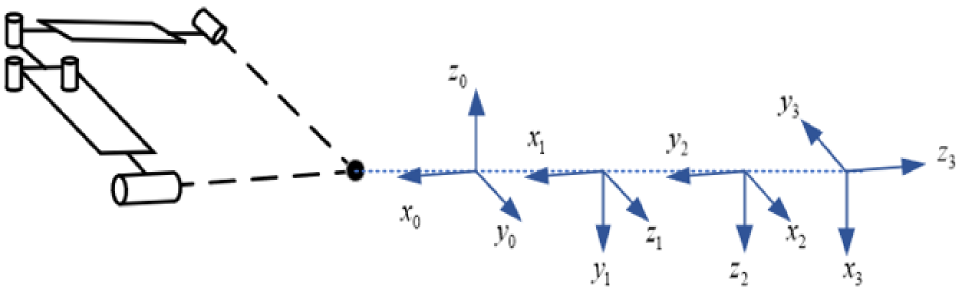

Fig 3. Linkage coordinate system (Photo credited: Original).

Table 2. D-H parameters.

Link	θ_i /(°)	Di/(mm)	ai-1/(mm)	αi-1/(°)
1	$\theta1$	0	0	-π/2
2	$\theta2$	0	0	-π/2
3	$\theta3$	0	0	π/2

2.1.1. Forward Kinematics

Forward kinematics is the method of finding the terminal pose of the robot according to each joint angle, obtaining the equation of motion according to the D-H parameters of the three motors, and the transformation formula of two adjacent rods is:

$$ {}^{i-1}T_i = \begin{bmatrix} c\theta i & -s\theta i & 0 & ai-1 \\ s\theta ci\alpha i-1 & c\theta ic\alpha i-1 & -s\alpha i-1 & -dis\alpha i-1 \\ s\theta si\alpha i-1 & c\theta is\alpha i-1 & c\alpha i-1 & dic\alpha i-1 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1} $$

Where c stands for cos, and s stands for sin

The robot kinematic equation is to

$$ 0T3=0T11T22T3= \begin{matrix} nx & ox & ax & px \\ ny & oy & ay & py \\ nz & oz & az & pz \\ 0 & 0 & 0 & 1 \end{matrix} \tag{2} $$

Where the position coordinates are:

$P_x=L_{s2}c\theta_1\theta_2-dc\theta1$

$P_y=L_{s2}c\theta_1s\theta_2-ds\theta_1$

$P_z=L_{s2}s\theta_2-L_{s1}$

Positive kinematic validation is as follows:

In the initial position of the robot, take the joint angle q1= [0,-π/ 2,π/ 2], Ls 1 take 0, Ls 2 take 37.5mm, and bring the upper formula into MATLAB.

$$ 0T3= \begin{matrix} 0 & 0 & -1 & 37.5 \\ 0 & -1 & 0 & 37.5 \\ -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{matrix} \tag{3} $$

The results are consistent with the results of the MATLAB modeling robot (see Figure 4) and the linkage coordinate system, so the correct kinematics calculation is correct.

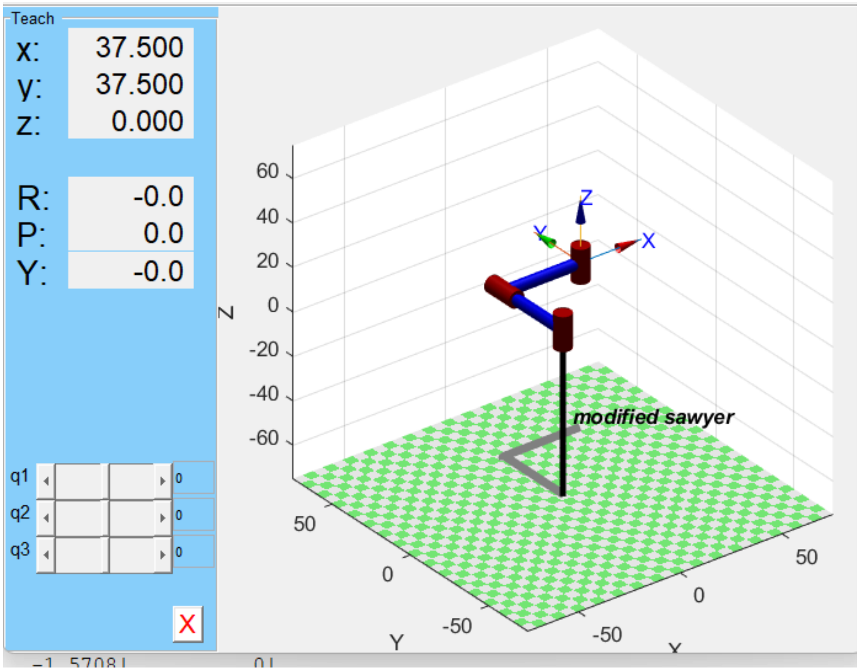

Fig 4. MATLAB terminal pose (Photo credited: Original).

2.1.2. Inverse kinematics

The inverse kinematics is the method of finding each joint angle of the robot according to the terminal pose. According to formula 2, the algebraic method is used to solve the equations:

$P_x=Ls_2c\theta_2c\theta_1-dc\theta_1$

$P_y=-Ls_1+Ls_2s\theta_2$

$P_z=-c\theta_2c\theta_3$

Taking ls_1 as 0 and ls_2 as 37.5mm, 2 sets of solutions are obtained in MATLAB programming calculation, finally determining the positive and negative q= [0,-1.5078, 1.5078] according to the value of θ_2, then taking Π as 3.1416, then q is equal to the positive kinematics q_1, proving that the inverse kinematics calculation is correct.

3. Motion Simulation

In rehabilitation training, the robot is usually required to continuously and smoothly make repeated movements on the specified trajectory, which can be reflected by the changes of various kinematic parameters of the robot. MATLAB is used to build the sawyer robot model and conduct trajectory planning. The starting point joint angle q1= [0,-π/ 2, π/ 2], and the endpoint joint angle q2= [-π/ 4,-2π/ 3, π/6], and the results are shown in Figure 5. It can be seen from the figure that the robot position is smooth, the speed and acceleration are the same at 0s and 2s, and the speed reaches the maximum or minimum at 1s.

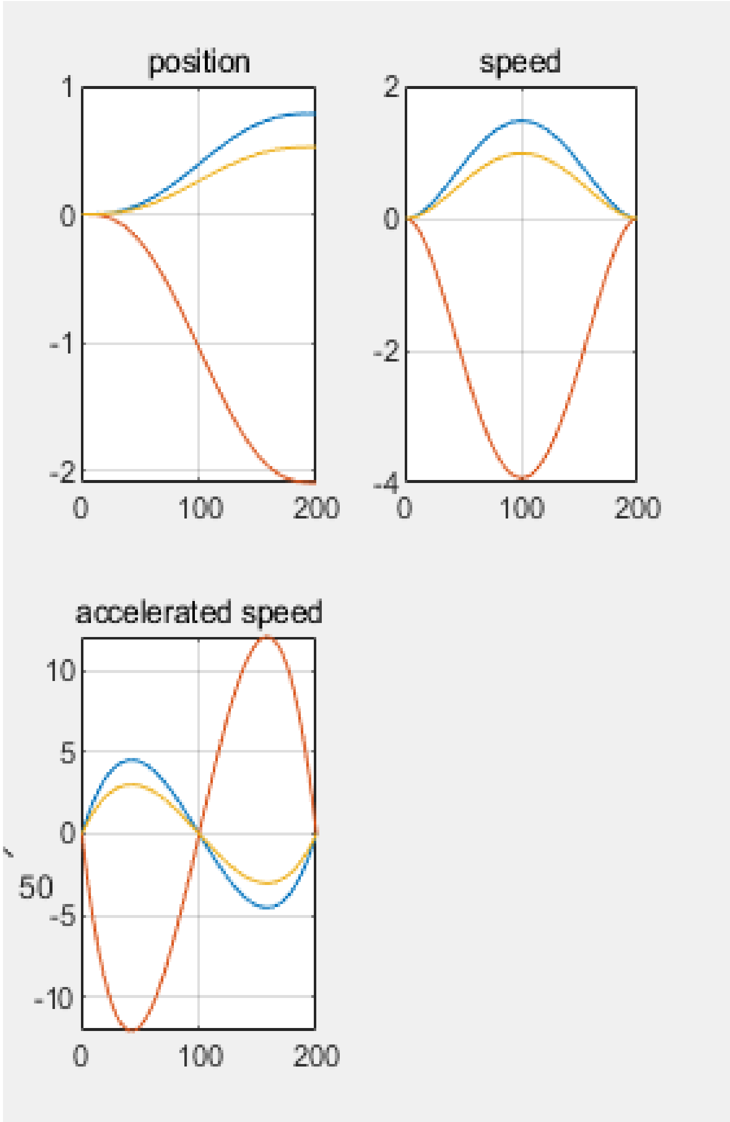

Fig 5. Motion simulation (Photo credited: Original).

It can be seen that the acceleration and speed of the robot during the operation do not change, and the operation process is smooth. Users will not be dangerous in the process of use, and the movement Angle is also in line with the needs of the human body. The speed and acceleration are suitable for the use of the human body, which is more conducive to the rehabilitation training, which proves the rationality of the structural movement.

4. Discussion

In this study, a shoulder exoskeleton robot was designed to make it more efficient in rehabilitation treatment for patients with shoulder hemiplegia.The work is summarized as follows:

(1) By using SolidWorks modeling, D-H for theoretical calculation and simulation with MATLAB to optimize the shoulder exoskeleton robot, to comprehensively prove the rationality of the robot in motion.

(2) In this design, by adding the expansion rod mechanism and threaded screw structure, the upper and lower motion range of the shoulder can be shrugged function, so as to achieve more diversified rehabilitation training for patients and enhance the effect of rehabilitation training.

(3) In the use of MATLAB simulation, only the position, speed and acceleration are analyzed, and the motion load and dynamic operability were not analyzed, and the spatial analysis is not conducted, and the rationality of its spatial use is not obtained.

(4) Due to the time problem, only SolidWorks modeling was carried out in this study, and the physical model was not established according to the modeling for the actual use in Linchuan, so there is a lack of some actual data and feedback.

The above summary analyzes some strengths and shortcomings of this study, and also puts forward some suggestions and prospects for the following research direction according to the above shortcomings:

(5) The robot model can be loaded in MATLAB and analyzed for gravity load and dynamic operability, so as to verify the rationality of the structure from the operational aspect, so as to test the rationality of the mechanism more comprehensively.

(6) We can use MATLAB to analyze the spatial motion of the mechanism, and analyze whether the space proportion in the movement process is in line with the actual space situation. If the space proportion is too large in a certain process, the space proportion can be reduced by improving the structure.

(7) This experiment to wear comfort thinking, connecting rod exoskeleton robot wear comfort is poor, can be in human body wear and motor rotation sponge mat, and study the relationship between the user wear comfortable and actual use demand, can also try to add more flexible structure in structure to achieve wear and use of comfortable and reasonable.

(8) On the basis of the above, physical modeling can be conducted, and field clinical experiments can be conducted with the help of professionals to collect use data and user feedback, and improve the robot organization according to these feedback.

5. Conclusion

To provide more scientific and effective repetitive training for patients with shoulder and limb disorders, Reduce recovery costs for hospitals and patients, Designed a shoulder exoskeleton robot, From the original structure by allowing it to increase the range of movement up and down, To achieve a more diverse recovery situation, And build the robot model by SolidWorks, Positive and inverse kinematics verification by the D-H method, Simthe robot with MATLAB and analyze the rationality of the inverse motion, The final results indicate that, The robot has no mutations in its position, speed or acceleration during the movement, This verifies that there is no safety hazard in the robot in actual operation, So the effectiveness of the robot design is proven, Meet the requirements of human shoulder recovery.

However, the robot still has some problems, such as unable to achieve some other movements of the shoulder in the case of shrugging, and it is inconvenient to control the motor of the shrugged to achieve synergy with other motors, which has certain requirements for the user's operation. Due to time and site constraints, the robot can achieve relatively simple movements, not in clinical experiments in a real environment. Expect that the above problems can be solved in the later work

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