

Design and Analysis of a Wearable Exoskeleton Upper Limb Rehabilitation Robot

Jian Guo¹ and Pengyu Li¹

¹Tianjin Key Laboratory for Control Theory & Applications
in Complicated Systems and Biomedical Robot Laboratory
Tianjin University of Technology
Binshui Xidao Extension 391, Tianjin, 300384, China
jianguo@tjtu.edu.cn; 1574011150@qq.com.

Shuxiang Guo^{1,2*}

²Department of Intelligent Mechanical Systems Engineering
Faculty of Engineering
Kagawa University
Takamatsu, Kagawa, Japan

*corresponding author: guo.shuxiang@kagawa-u.ac.jp.

Abstract -In order to solve the disadvantages of the large size of the braced upper limb rehabilitation robot, a wearable upper limb exoskeleton robot was designed. Firstly, a 3D model of the robot was built using SOLIDWORKS based on the principle of modularity. According to the structural characteristics of the wearable upper exoskeleton robot, choose the driving mode of the robot and the installation position of the motor reasonably. Secondly, the kinematic analysis of the robot was performed using the D-H parameter method. Finally, the model was imported into ADAMS for motion simulation of shoulder joint flexion/extension, adduction/abduction and elbow joint flexion/extension. Simulation results prove that the rehabilitation robot has a well-designed shoulder and elbow joint structure, smooth motion curve, no sudden changes in speed and position, and good bionic properties. The conclusion is the wearable upper limb rehabilitation robot is well designed, can provide patients with effective rehabilitation training. A theoretical basis for future prototype production and subsequent research was laid.

Index Terms - Upper-limb Rehabilitation robot; Kinematics analysis ; Kinematics simulation ; ADAMS.

I. INTRODUCTION

Stroke is a common cardiovascular and cerebrovascular disease in modern society, which seriously threatens the health of human beings and has become the disease with the highest mortality rate, especially among the middle-aged and elderly people. According to report on prevention and treatment of stroke in 2018[10]. In the past three decades, the stroke population in China has increased dramatically and presented a younger trend, with 1.96 million patients dying of stroke every year. Modern medicine has proved that, according to the plasticity theory of neurons, patients with hemiplegia can recover their daily mobility through one-to-one treatment by physiotherapists. However, the low treatment efficiency of this method will also bring some pressure on medical resources and high cost. In order to make up for the shortage of traditional treatment methods, many institutions at home and abroad have carried out relevant exploration and research on upper limb rehabilitation robots, whose principle is to fix the affected limb on the robot and help the patient to carry out specific rehabilitation training movements. The invention of rehabilitation robot improves the efficiency of hemiplegia treatment, reduces the cost of patient treatment, and promotes the development of the medical industry. Therefore, it is necessary to research on upper limb rehabilitation.

Nowadays, rehabilitation robots are mainly divided into end-guided and exoskeleton end-guided rehabilitation robots, which are mainly used for rehabilitation training by traction of the affected limb by the actuator at the end. The American University of Delaware team designed the wearable rehabilitation robot CAREX, which uses a rope to drive the five degrees of freedom movement of the upper limb. Each rope is equipped with a sensor to detect and adjust the force applied to the upper limb of the human body, but the robot is more troublesome to wear. The range of motion is limited [1]. In 2018, the Catholic University of America invented a wearable exoskeleton robot, SPRINGWEAR, that can help patients rehabilitate their wrists, elbows, and shoulders simultaneously, achieving joint movement through a special spring mechanism[2]. In 2018, Kagawa University in Japan designed and invented an elbow-facing rehabilitation robot with variable stiffness. It has five passive degrees of freedom to ensure the user's natural joint range of motion and intra-body variability, and an integrated variable stiffness actuator (VSA) that independently adjusts joint stiffness by moving the pivot position[3]. HAI-5, a wearable exoskeleton robot designed by the University of Tsukuba in Japan, is equipped with a variety of sensors to assist patients in daily walking, but it has less freedom and can achieve limited training movements[4]. China's research on rehabilitation robots started late, but some achievements have been made. In 2011, a 10-degree-of-freedom rehabilitation robot was designed by Huazhong University of Science and Technology, the robot is driven by artificial pneumatic muscles compared to other rehabilitation robots. The main feature is that the shoulder joint has 6 degrees of freedom, which can assist patients to perform more complex daily activities [6]. In 2017, a wearable exoskeleton robot was invented by the Shanghai Institute of Technology to help patients achieve two joints in the shoulder and elbow Rehabilitation training. The robot can use EMG and voice signals to pick up the patient's movement intentions [7]. The current state of research on rehabilitation robots at home and abroad can be found that most upper limb rehabilitation robots only target the upper limb or hand of the patient, and there are few rehabilitation robots that include both hand and upper limb structures, and most of them are large and costly, which are only suitable for treatment in hospitals. In reality, most hand functions are also lost in stroke patients, and training only the upper limb portion cannot meet the patient's needs.

Based on the above findings, we design a multi-degree of freedom wearable upper limb rehabilitation robot. During the design process, we adopted the principle of modular design to carry out structural design, The hand rehabilitation robot and the upper limb rehabilitation robot were skilfully combined. In section II, the system structure and the rehabilitation processing are introduced. In section III .Based on the characteristics of human upper limb movement and the principles of modular design, a 3D model of the robot was built using SOLIDWORKS software. In section IV, a kinematic analysis of the robot was performed using the D-H parametric method. In section V, Motion simulation of the robot was completed by using ADAMS. The final part is the conclusion and future works for the whole paper.

II. THE SYSTEM OF REHABILITATION TRAINING

The robotic parts are made using 3D printing, the material is photosensitive resin, light weight and high strength, and both the forearm and upper arm are curved to make them more comfortable for patients to wear. The overall weight of the robot is only 1.8 kg. In this paper, the upper limbs rehabilitation robot can send through the upper machine control instruction to passive treatment of the patient, the patient also can wear data glove and attitude sensors, or the use of voice signal for active treatment. mirror treatment is a very effective treatment for hemiplegia. In 2013, Thieme and others in the study compared the mirror treatment curative effect with other therapies, found that the mirror therapy can effectively improve the function of upper extremity function in patients with cerebral apoplexy in daily life and ease the pain.[12]. Therefore, we used data gloves and Attitude sensor to realize the mirror treatment of the patient, and the healthy side of the patient drove the affected side for treatment. Structure of rehabilitation robot system show in Fig. 2.



Fig. 1 Wearable demonstration of exoskeleton device

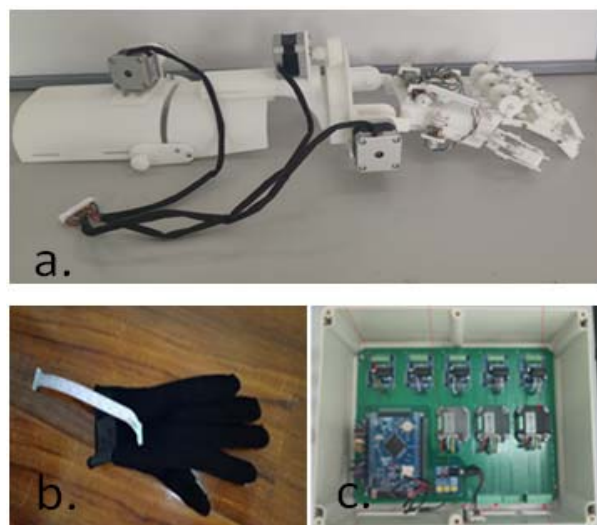


Fig. 2 Structure of rehabilitation robot system: a .The rehabilitation robot; b .Data glove ; .c. Control system;

However, Existing upper limb rehabilitation training robot can only carry on the elbow and wrist, and also is not very convenient to wear and the patients in the process of the training is easy to cause certain harm to human body, Inability to train for people with shoulder joint loss .so in this paper, the design of a wearable structure, increase the shoulder stretch of degrees of freedom, and optimize the structure of the elbow, reduce the burden of the patients.

III. DESIGN OF THE ROBOT STRUCTURE

A. Shoulder Joint Design

The driving methods commonly used in upper limb rehabilitation robots include hydraulic driving, motor driving, and pneumatic driving. In this paper, we adopt the method of motor drive. Due to the large driving torque required by the shoulder joint, the weight of the driving motor and reducer used is heavier. If it is directly installed on the joint of the robot, it will increase the burden of the patient, so in this paper, the motor and reducer are placed on the back of the robot for more even weight distribution throughout the robot. The output shaft of the motor is equipped with a worm gear reducer, which realizes the self-locking of the joint at any position, and the motor transmits the torque to the winch through the gear reducer and drives the movement of the wire rope. The power of the motor is transmitted to the joints of the robot via Bowden cable, which drives the joints of the robot to rotate.

The shoulder joint of the human body has three degrees of freedom, two of which were chosen for the study. including adduction/abduction and flexion/extension. The back structure is designed to provide support for the entire robot, as well as for the placement of motors and drives, which can be secured to the robot by straps. Determine the length of the individual parts with reference to the average size of the upper limbs of the human body. Moreover, in order to adapt to the wearing length range of the upper arm of different populations, adjustable upper arm length range is: 283mm~313mm.

B. Elbow Joint Design

The elbow joint of the human body has one degree of freedom, the body of the drive motor is attached to the upper arm support of the robot, and the motor power output shaft is connected to the The forearm section, in turn, drives joint movement. This design avoids the instability of line drives. In addition, the curved limit slot is designed so that the robot's angle of motion is in line with that of the human elbow joint, thus providing protection to patients. In addition, the length of the forearm is adjustable to suit the use of different people. Adjustable range is:203~237mm

C. Design of Wrist Joint and Hand

The wrist structure has two degrees of freedom, including internal/external rotation, extension/bending, the drive motor is a stepper motor, and is cleverly combined with the hand to achieve the connection with the hand, allowing the patient's upper extremity to perform rehabilitation training with the hand, improving the efficiency of rehabilitation training. The hand module has a total of 14 degrees of freedom, including two degrees of freedom of the thumb. The other four fingers have three degrees of freedom and five fingers are driven by five stepper motors, which can realize the individual movement of each finger and help the patient complete the hand rehabilitation training.

Overall structure and wearing diagram of the robot show in Fig.3 and Fig.4. Angle range of motion of each joint of the robot show in Table 1.

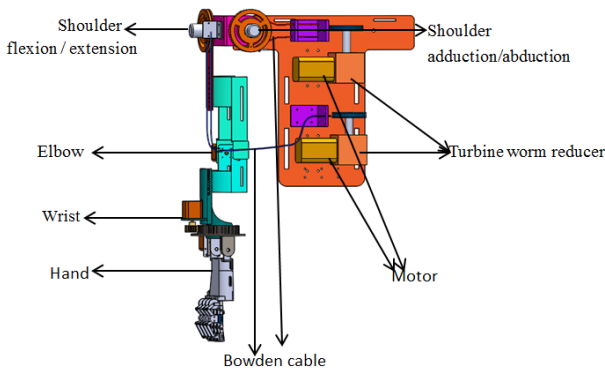


Fig. 3 The 3D model of the upper limb rehabilitation robot

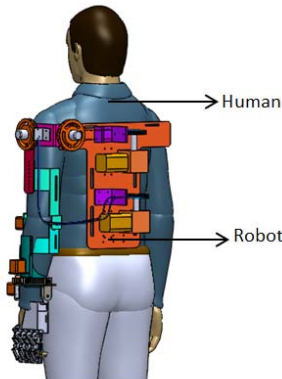


Fig. 4 The 3D model of upper limb rehabilitation robot that worn by human

TABLE I MOTION ANGLE RANGE OF EACH JOINT OF THE ROBOT

Joint	Movement	Angle Range	
Shoulder	Flexion/Extension	0~90°	
	Adduction/Abduction	0~85°	
Elbow	Flexion/Extension	0~110°	
Wrist	Flexion/Extension	-60°~80	
	Internal/External Rotation	-90°~90°	
Thumb	MCP	Flexion/Extension	0~50°
	DIP	Flexion/Extension	0~80°
Other Finger	DIP	Flexion/Extension	0~80°
	PIP	Flexion/Extension	0~90°
	MCP	Flexion/Extension	0~85°

It should be noted that Table 1 is a theoretical range of angles for each of the robot's joints, which may differ from the actual situation in actual use, and we will test the actual situation in the follow-up of the robot.

IV. KINEMATIC ANALYSIS OF THE ROBOT

Currently, The DH model is a type of robot modelling proposed by Denavit and Hartenberg in the 1950s[13]. method, which can be used in any configuration independent of the robot's structural order and complexity, making it the most popular method for modern robots. Robots generally consist of connecting rods and joints where they can rotate and slide, by determining the current connecting rod and the next connecting rod. of the parameters, you can determine their transfer matrix, and so on, and you can derive the transfer matrix for the entire robot. It is represented as show in Fig.5.

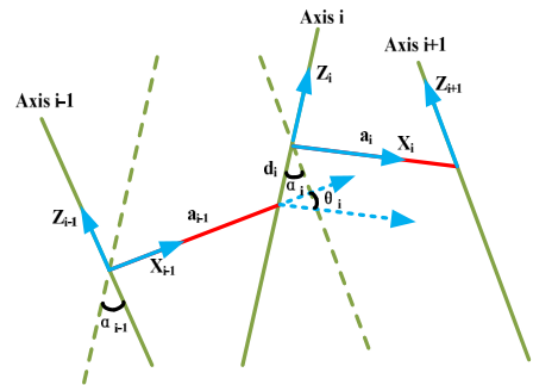


Fig. 5 Diagram of the Denavit-Hartenberg Notation

The relationship between two adjacent links is represented by four parameters: joint Angle θ , link offset d , link length a and twist Angle α .

The pose relation of adjacent connecting rod $i + 1$ and connecting rod i can be expressed by the homogeneous

coordinate transformation matrix between the coordinate systems of the phase adjacent connecting rod .

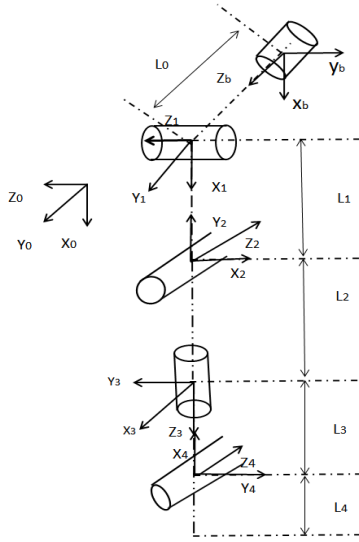


Fig. 6 Diagram of coordinate system of upper limb rehabilitation robot

In Fig.5 Coordinate system 0 overlaps with coordinate system 1. Simplified coordinate system of the robot from Fig. 5 allows to build the D-H parameter table of the robot, show in Table II .

TABLE II D-H PARAMETER TABLE OF THE ROBOT

i	a_{n-1}	α_{n-1}	d_n	θ_n
1	0	0°	0	θ_1
2	0	-90°	0	θ_2
3	L_1	-90°	0	θ_3
4	0	90°	L_2+L_3	θ_4
5	0	-90°	0	θ_5

According to the D-H notation, the transformation of coordinates between adjacent coordinate systems can be seen that the transformation of coordinate system $n-1$ with respect to coordinate system n is:

$${}^{n-1}T_n = R_{ot}(\alpha_{n-1})T_{rans}(a_{n-1})R_{ot}(\theta_n)T_{rans}(d_n) \quad (1)$$

$$= \begin{bmatrix} \cos\theta_n & -\sin\theta_n & 0 & a_{n-1} \\ \sin\theta_n \cos\alpha_{n-1} & \cos\theta_n \cos\alpha_{n-1} & -\sin\alpha_{n-1} & -\sin\alpha_{n-1}d_n \\ \sin\theta_n \sin\alpha_{n-1} & \cos\theta_n \sin\alpha_{n-1} & \cos\alpha_{n-1} & \cos\alpha_{n-1}d_n \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Set the B coordinate system for the base coordinate system. From B coordinate system to 0 coordinate system is to move L_0 in the positive direction of the z-axis, and then

rotate 90° counterclockwise around the x-axis. The conversion matrix is:

$${}^B T_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 1 & 0 & L_1 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Substitute the parameters of Table II into equation (1)

$${}^0 T_1 = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^1 T_2 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_2 & -\cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^2 T_3 = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & L_1 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_3 & -\cos\theta_3 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad {}^3 T_4 = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & 0 \\ 0 & 0 & -1 & -(L_2+L_3) \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$${}^4 T_5 = \begin{bmatrix} \cos\theta_5 & -\sin\theta_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_5 & -\cos\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

The transformation matrix from the 4th coordinate system to the end of the robot is:

$${}^5 T_{end} = \begin{bmatrix} 1 & 0 & 0 & L_4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Therefore, the pose matrix of the robot end coordinate system relative to the base coordinate system is:

$${}^B T_0 {}^0 T_1 {}^1 T_2 {}^2 T_3 {}^3 T_4 {}^4 T_5 {}^5 T_{end} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

Kinematic positive solution is:

$$n_x = c_1 c_2 c_3 c_4 c_5 - s_4 c_1 c_2 c_5 - s_5 (c_1 c_2 c_3 + s_1 c_3)$$

$$n_y = c_5 (s_1 c_2 c_3 c_4 - s_1 s_2 s_4) - s_1 c_2 s_3 s_5$$

$$n_z = (s_2 c_3 s_4 + c_2 s_4) c_4 + s_2 s_3 s_5$$

$$o_x = -s_5 (c_1 c_2 c_3 c_4 - c_1 s_2 s_4) - c_5 (c_1 c_2 c_3 + s_1 c_3)$$

$$o_y = -(s_2 c_3 c_4 + c_2 s_4) s_5 - s_2 s_3 c_5$$

$$o_z = -s_5 (s_1 c_2 c_3 c_4 - s_1 s_2 s_4) - s_1 c_2 s_3 c_5$$

$$a_x = c_2 c_4 - s_2 c_3 s_4$$

$$a_y = -s_1 c_2 s_3 - c_1 c_3$$

$$a_z = -s_1 c_2 c_3 s_4 - s_1 s_2 c_4$$

$$\begin{aligned}
P_x &= (L_2 + L_3)(c_1c_2s_3 + s_1c_3) + L_1c_1c_2 \\
&+ L_4(c_1c_2c_3c_4c_5 - s_4c_1c_2c_5 - s_5(c_1c_2c_3 + s_1c_3)) \\
P_y &= L_4(c_5(s_1c_2c_3c_4 - s_1s_2s_4) - s_1c_2s_3s_5) \\
&+ (s_1s_2s_3)(L_2 + L_3) \\
P_z &= -(L_3 + L_2)s_2s_3 - s_2L_1 + L_0 + L_4(c_2c_4 - s_2c_3s_4)
\end{aligned}$$

The coordinate matrix at the end of the robot:

$$R = \begin{bmatrix} n_x & o_x & a_x \\ n_y & o_y & a_y \\ n_z & o_z & a_z \end{bmatrix} \quad (3)$$

Robot posture matrix:

$$P^T = [P_x, P_y, P_z]^T \quad (4)$$

V. KINEMATIC AND DYNAMIC SIMULATION OF THE ROBOT

A. Simulation Process

Adams is virtual prototype simulation software developed by American Mechatronics that allows users to easily perform static, kinematic and dynamic analyses of virtual mechanical systems, but Adams is capable of drawing simple parts and cannot design more complex structures. After the model is imported, the original constraints between the parts will disappear, so you need to add constraints to the robot first. If there is no degree of freedom between the two links, add a fixed pair between the two members to view them. It is a degree of freedom. If there is a degree of freedom between two members, add a rotating pair between the two members, and then add material properties to the part. Users can also customize the quality of the part. Finally, add corresponding driving functions to each joint of the robot. After the above steps are set, the robot can be simulated in motion.

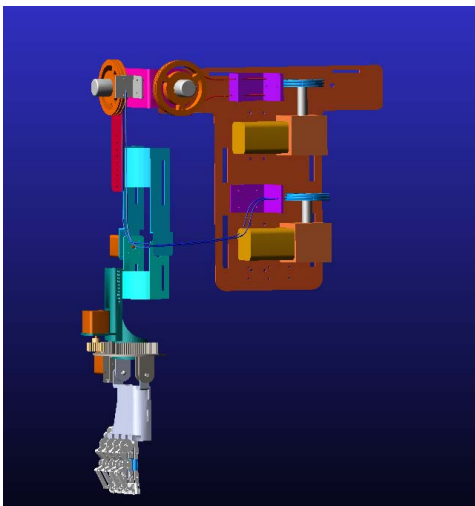


Fig. 7 Adams simulation model of the robot

In this paper, only the elbow joint and shoulder joint were simulated, and the hand and wrist joint were regarded as a single freedom. After adding the rotating vice, adding the driver to the rotating vice and set the driver function. Set the shoulder joint flexion/extension drive function to: STEP (time, 0, 0, 10, 90d)+ STEP (time, 10, 0, 20, -90d). Set the elbow drive function to: STEP (time, 0, 0, 10, 110d)+ STEP (time, 10, 0, 20, -110d) and Set the shoulder joint abduction/adduction drive function to STEP (time, 0, 0, 15, 85d)+ STEP (time, 10, 0, 20, -85d).

B. Simulation Result

Using the ADAMS Postprocessor module, we can obtain motion simulation results for the elbow and shoulder joints.

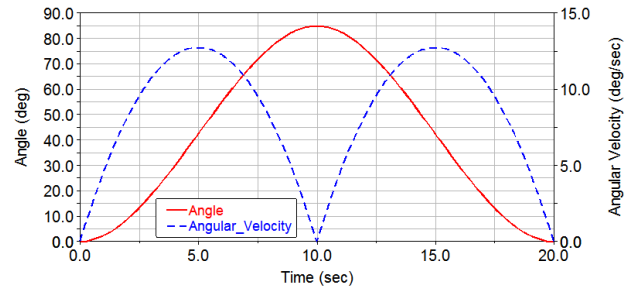


Fig. 8 Angle displacement and angular velocity change curve of shoulder joint abduction/adduction

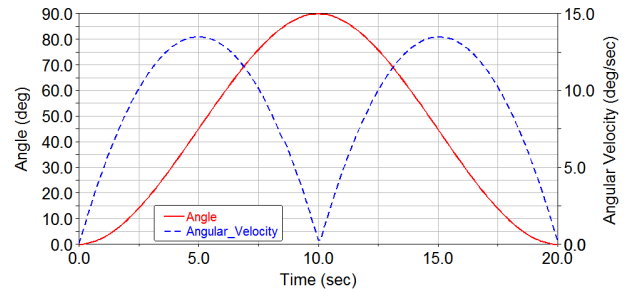


Fig. 9 Angle displacement and angular velocity change curve of shoulder joint flexion/extension

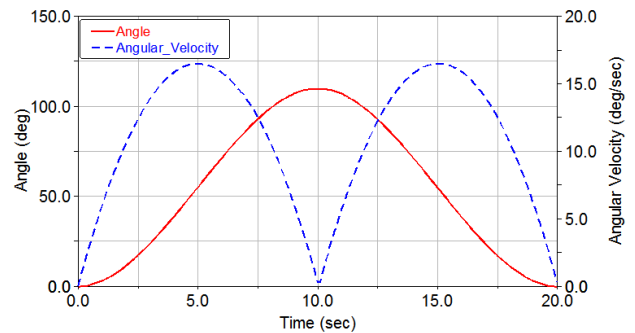


Fig. 10 Angle displacement and angular velocity change curve of elbow joint

It can be seen from Fig.8, 9 and 10 that the rehabilitation robot is driven by the motor, the motion range of shoulder joint flexion/extension movement and abduction/adduction movement range is 0~90° and 0~85°, and the elbow joint flexion and/extension movement range is 0~110°. The movement curve of the three joints is smooth, the speed is gentle, and there is no sudden change of position and speed,

which is consistent with the way people move, and meets the relevant requirements of rehabilitation training .

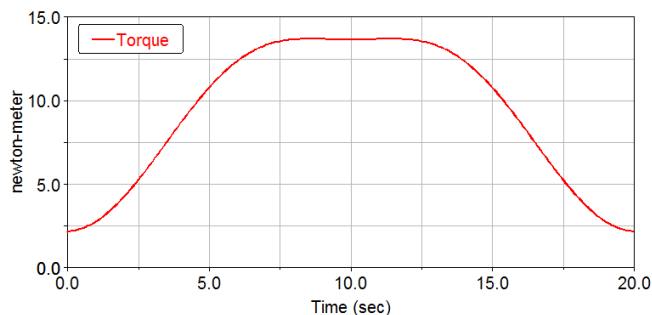


Fig. 11 Torque change curves of shoulder joint abduction/ adduction

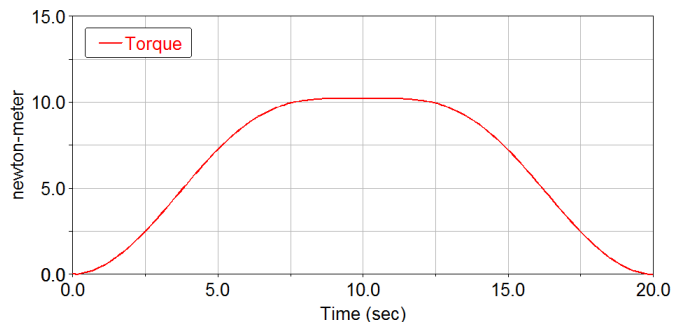


Fig. 12 Torque change curves of shoulder joint flexion/extension

As can be seen from Fig.11, the maximum driving torque of the shoulder joint abduction/ adduction is 13N/M . As can be seen from Fig.12, the maximum driving torque of the shoulder joint flexion/extension is 10.2N/M. It also can be seen from the Fig.11 and Fig.12 that the curve of variation of joint moments is also smooth, without joint forces moment mutations, which also protects the patient to some extent. It provides the basis for the selection of motor in the future.

VI. CONCLUSION

At present, most of the upper limb rehabilitation robots at home and abroad have complex structures, the volume is larger, the price is expensive, can only be in the hospital for treatment, upper limbs rehabilitation robot light-duty, facilitation, obviously is the development trend of the future, In this paper, according to the research status of upper limb rehabilitation robots at home and abroad, based on the principle of modular design, Reasonable selection of joint degrees of freedom. using SOLIDWORKS completed a wearable upper limbs rehabilitation robot structure design, After completing the design of the robot, the spatial coordinate system of the robot was established using the DH parameter method, the D-H parameters were determined, and the kinematic positive solution of the robot lays a theoretical foundation for future robotics research, and finally, the ADAMS simulation software is used for the robot performs motion simulation. The simulation results show that the motion curve of the robotic elbow and shoulder joints is smooth, without position mutations, and can be effective for patients' rehabilitative training

In the future, the structure of rehabilitation robots can be further optimized to help patients complete their daily

behavioural activities, adding sensors to capture the patient's behavioural intentions and enhance human-computer interaction capabilities.

ACKNOWLEDGMENT

This research is supported by National Natural Science Foundation of China (61703305) ; Key Research Program of the Natural Science Foundation of Tianjin (18JCZDJC38500) and Innovative Cooperation Project of Tianjin Scientific and Technological Support (18PTZWHZ00090).

REFERENCES

- [1] Ying Mao, Sunil Kumar Agrawal, "Design of a Cable-Driven Arm Exoskeleton (CAREX) for Neural Rehabilitation," *IEEE Transaction on Robotics*, Vol. 28, No. 4 ,pp. 922-931,2012
- [2] Chen Ji , and P. S. Lum , "Pilot testing of the spring operated wearable enhancer for arm rehabilitation (SpringWear)," *Journal of Neuroengineering & Rehabilitation*, Vol. 15, No. 1, 2018.
- [3] Yi Liu, Shuxiang Guo, Hideyuki Hirata, Hidenori Ishihara, Takashi Tamiya, "Development of a powered variable-stiffness exoskeleton device for elbow rehabilitation", *Biomedical Microdevices*, Vol.20, No.3, 2018.
- [4] Tasuku Otsuka, Ko Kawaguchi, Hiroaki Kawamoto, Yoshiyuki Sankai. "Development of upper-limb type HAL and reaching movement for meal-assistance," *International Conference on Robotics and Biomimetics*, Vol. 15, No. 1, pp: 883–888, 2011.
- [5] Florian G, Georgios N, Alireza G, "Compensation or Restoration: Closed-Loop Feedback of Movement Quality for Assisted Reach-to-Grasp Exercises with a Multi-Joint Arm Exoskeleton," *Frontiers in Neuroscience*, Vol. 36, No. 10, 2016.
- [6] WB Chen, CH Xiong, RL Sun. "A 10-degree of freedom exoskeleton rehabilitation robot with ergonomic shoulder actuation mechanism". *International Journal of Humanoid Robotics*, Vol. 8, No. 1, pp:47–71, 2011.
- [7] Lulu Wang, Xin Hu, "Design, kinematics simulation and dynamic analysis of the wearable upper-limb rehabilitation robot," *Beijing Biomedical Engineering*, Vol. 36, No. 2 , 2017.
- [8] Nina Robson, Gim Song Soh , "sGeometric design of eight-bar wearable devices based on limb physiological contact task", *Mechanism and Machine Theory* ,Vol.100, No.8. pp:358–367, 2016.
- [9] Zongjiu Zhang, Longde Wang, "Report on Stroke Prevention and Treatment in China 2018". October 2018.
- [10] Thieme H, Mehrholz J, Pohl M, et al, "Mirror therapy for improving motor function after stroke". *Stroke* , Vol.44, No.1, 2013.
- [11] Denavit, J. R. S. Hartenberg. " A Kinematic Notation for Lower-Pair Mechanisms Based on Matrices ," *Journal of Applied Mechanics*, Vol.44, No.1, p: 215-221, 1955
- [12] Shuxiang Guo, Zhi Wang, Jian Guo, Qiang Fu and Nan Li, "Design of the Speech Control System for a Upper Limb Rehabilitation Robot Based on Wavelet De-noising," *International Conference on Mechatronics and Automation*, pp.2300-2305, 2018.
- [13] Shuxiang Guo, Zhi Wang, Jian Guo, "Study on Motion Recognition for a Hand Rehabilitation Robot Based on sEMG Signals" *International Conference on Mechatronics and Automation*, pp. 1061-1066, 2019.
- [14] Shuxiang Guo, Jian Guo, Jiange Gao, "The LabVIEW -Based Control System for the Upper Limb Rehabilitation Robot", pp. 1732-1737, 2017.
- [15] Shuxiang Guo, Nan Li, Jian Guo, "A VR-based Upper Limb Rehabilitation Hand Robotic Training System" *International Conference on Mechatronics and Automation*, pp.2364-2369, 2018.