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Design of a Control system Based on Beck Hoff TwinCAT Nursing Robot

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Abstract. Aiming at the requirement of multi-axis coupling linkage control operation of dual-arm nursing robot, a new method based on Beck Hoff TwinCAT3 design PLC control program and electronic gear function to realize multi-degree-of-freedom coupling control was proposed. A set of human-like double-arm care robot was developed. Control system. The improved D-H modeling method was used to establish the mathematical model of the shoulder, elbow and wrist joints of the arms of the nursing robot, and the forward and inverse kinematics analysis was carried out. The inverse kinematics solution was solved according to the set of the end position pose of the arms, and the left and right arms were obtained. The torsion angle of the joints; the communication between the driver, the motor and the controller is completed by using the EtherCAT bus technology, and the PLC motion control program is written based on the host computer software and the relevant function blocks are called. Focusing on the design of the electronic gear function, the coupling angle of the master-slave axis and the electronic gear is designed according to the torsion angle of the six arms of the two arms calculated by inverse kinematics analysis, so that the joint axes can run according to the calculated torsion angle and reach the set position. Through the on-site debugging experiment and the software real-axis monitoring module, the actual running speed and position waveform of each joint axis are obtained. Through the graphical analysis, the arms of the nursing robot can reach the designated position. The experimental results verify the effectiveness of the design of the nursing robot software control system.

Keywords: bus technology, coupled control, dual robotic arm, improved D-H modeling, nursing robot

1 Introduction

At present, the research on humanoid dual-arm care robots with the ability to transfer patients has received more and more attention [1]. However, due to the complex kinematics and control constraints in the coordination of the arms and the waist, the control system analysis and precision control of the nursing robot is quite difficult [7]. At present, the nursing robots developed by foreign institutions such as the United States and Japan can realize simple displacement, robotic grabbing, intelligent sweeping, etc. Robots have less freedom and usually only complete simple work [2-3, 8], so for the elderly and the disabled, there is no real function of nursing. Therefore, according to the actual needs of the old and weak disabled population, this paper designs a humanoid double robotic arm care robot with twelve degrees of freedom. The nursing robot has ten degrees of freedom in both arms, and the waist joint has two degrees of freedom. The physical model of the nursing robot was established according to the principle of humanity. In order to make the nursing robot have greater driving force, the freedom of the joints of the two arms is selected by the AC servo motor, and the coordinated movement of the two robot arms is the key to the control design [9].

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In summary, this paper is to study the control system of the nursing robot's dual-armed function [4]. The research focus of the control system is based on the computer's Beck Hoff control technology and the PLC software control program design using the PC software TwinCAT3. The main function of the electronic gear is to realize the linkage control between the waist spindle and the two-arm slave axis, so that the nursing robot has arms and joints. The shafts cooperate with each other and operate according to the planned path [5] to realize the function of nursing.

2 Arm Care Robot Structure

The main structure of the nursing robot consists of a bottom moving platform, a waist, and a double robot arm.

The bottom is moved by the omnidirectional wheel to move the platform, and it can move in multiple directions. The waist has two degrees of freedom. Because of the large load, the design is driven by a high-power servo motor. The two arms are identical in structure and have five structures. The mechanical arm of the degree of freedom is used as the left and right arms of the nursing robot. The overall structure of the nursing robot is shown in Fig. 1:

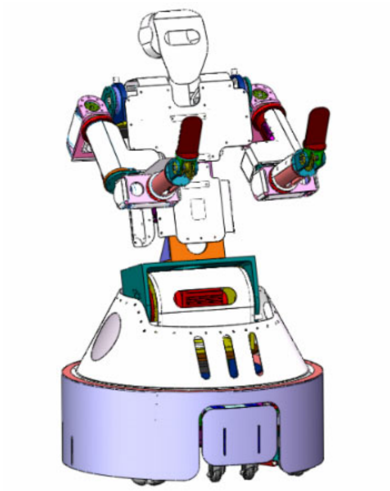

Fig. 1. Overall structure of the nursing robot

The single robot arm of the nursing robot has five degrees of freedom, the front and rear swinging degrees of freedom and the left and right swinging degrees of freedom at the shoulder joints; the inside and outside rotation degrees of the boom; the elbow joints for the lower arm lifting degrees; the wrist joints The degree of freedom for the robot is lifted. The servo motor drive with the power matching the maximum load is selected for each degree of freedom. In order to achieve precise and flexible control, each servo motor is equipped with a reducer for deceleration processing. The structure of a single arm is shown in Fig. 2 below:

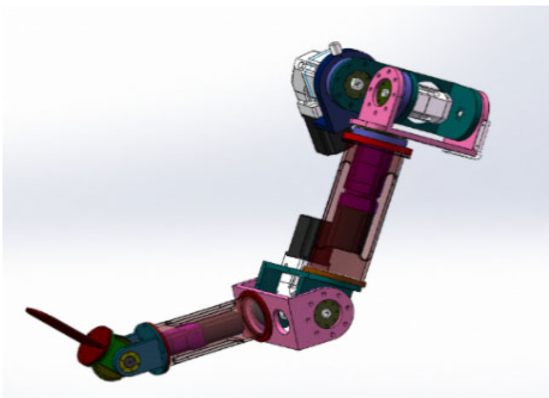

Fig. 2. Mechanical arm structure

3 Kinematic Analysis

The end position and attitude representation of the dual robotic arm care robot is typically described in a matrix format. In the Cartesian space coordinate system, the operating angles of the joints of the robot arm are not necessarily the same, but the end position and the pose are likely to be the same, so the forward and inverse kinematics analysis of the robot is a re-radiation relationship. It can be determined that the joint coordinates obtained by the end pose of the nursing robot have multiple sets of solutions. In the following, we use the analytical method to perform inverse kinematics analysis on the dual robotic posture of the nursing robot [6]. This design is mainly to study the realization of the lifting motion of the dual-mechanical arm nursing robot. Therefore, in the inverse kinematics analysis, the three joints of shoulder joint lifting, elbow joint lifting and wrist joint lifting are mainly discussed. It is analyzed that the movements of the three joints of the single robot arm of the nursing robot are the movements in the two-dimensional sitting plane, so the Z-axis coordinate can be specified as a fixed value, and the joint motion can be analyzed in the XY coordinate system. According to the numerical analysis method, the schematic diagram of the initial position and end position coordinates of the single arm of the nursing robot is as shown in Fig. 3: (Unit: mm)

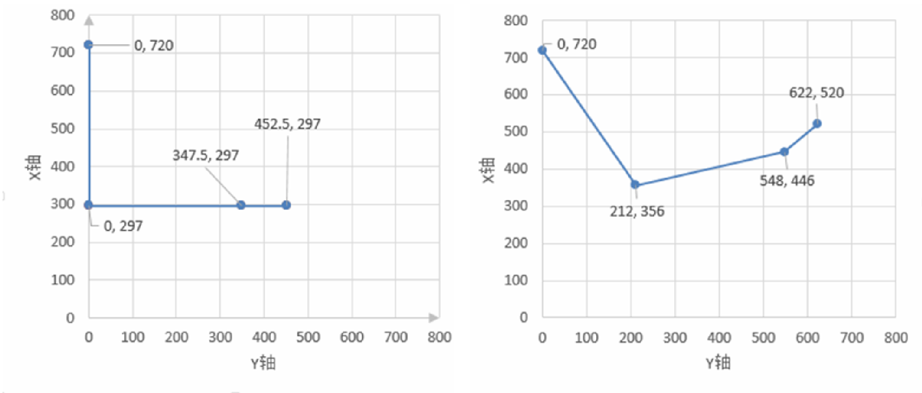

Fig. 3. Initial position and end position coordinates

According to the figure, the position coordinates of the end position of the robot end arm in the Cartesian coordinate space are:

$$\begin{cases} P_L = [p_x, p_y, p_z] = [520, 622, 208] \\ P_R = [p_x, p_y, p_z] = [520, 622, -208] \end{cases} \quad \textbf{(1)}$$

The inverse kinematics analysis of the spatial position of the end of the nursing robot arm is carried out to obtain the torsion angle of the three joints of the arms, and then the software control programming and algorithm design are performed according to the joint rotation angle. First, as shown in Fig. 4 below, the three coordinate axes of the main joint degrees of freedom of the dual robots of the nursing robot are established. According to the coordinate system, the D-H parameters of each link can be obtained as shown in Table 1 below:

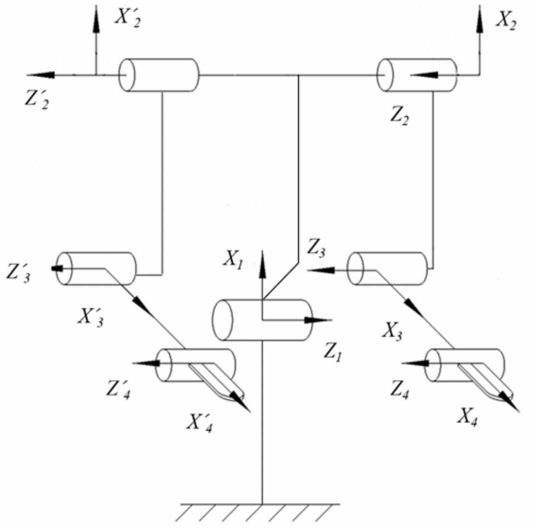

Fig. 4. Link attached coordinate system

Table 1. Nursing robot kinematics linkage parameter table (zero position)

Order Number	Joint i	Parameter			
		α_{i-1}	a_{i-1}	d_i	θ_i
I	1	0	0	0	0
II	2	-0.2°	723	313.0	θ_2
	3	84.6°	425	105.0	θ_3
	4	0	347.5	0	θ_4
III	2	-0.2°	723	313.0	θ_2'
	3	84.6°	425	105.0	θ_3'
	4	0	347.5	0	θ_4'

In summary, the inverse kinematics analysis of the dual-mechanical arm nursing robot is mainly based on the lumbar joint pitch freedom degree. Here, in order to simplify the modeling figure, the 0 coordinate system and the 1 coordinate system are coincident. The lumbar joint is the connecting rod C_1, the lumbar joint and the shoulder joint are the connecting rod C_2, the shoulder joint and the elbow joint are the connecting rod C_3, and the elbow joint and the wrist joint are the connecting rod C_4, and the three are the main moving joints. Perform inverse kinematic position and pose analysis. According to formula (2) and the link parameter table 1, the transformation matrix of the three links of the left arm [10] can be obtained: see the following formulas (3) to (8):

$$^{i-1}T_i = A_{i-1} = Trans(a_{i-1}, 0, 0)Rot(x_{i-1}, \alpha_{i-1})Trans(0, 0, d_i)Rot(z_i, \theta_i) \tag{2}$$

$$A_1 = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$A_2 = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & a_1 \\ 0 & 0 & 1 & d_2 \\ -\sin\theta_2 & -\cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$A_3 = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & a_2 \\ 0 & 0 & 1 & d_3 \\ -\sin\theta_3 & -\cos\theta_3 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$$A_4 = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & 0 \\ 0 & 0 & -1 & -d_4 \\ \sin\theta_4 & \cos\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

The left arm kinematics equation is obtained by the link transformation matrix:

$$T_L = A_1 A_2 A_3 A_4 \tag{7}$$

The end pose equation of a given nursing robot is expressed by equation (3-24), and the analytic method is used to solve the inverse kinematics, and the values of θ_2, θ_3 and θ_4 of the rotation angles of the joints of the left arm of the nursing robot are obtained.

$$T_L = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_x \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8}$$

Analyze the equation according to the numerical analysis method, substitute the coordinates of the end point P and the relevant link parameter values, and then, according to the requirements of the joint motion range of the dual-arm mechanism of the nursing robot, round off the non-conforming value and determine the left arm of the nursing robot. The torsion angle of each joint at the end position is:

$$\theta_2 = 29.67°; \theta_3 = -16.2°; \theta_4 = 44.7° \tag{9}$$

Similarly, the torsion angle of each joint of the right arm of the nursing robot at the end position is:

$$\theta_2^{'} = 29.67°; \theta_3^{'} = 163.8\,(\text{舍掉}) - 16.2; \theta_4^{'} = 44.7° \tag{10}$$

4 Hardware Control System Design

The hardware system of the nursing robot control system is mainly composed of Beck Hoff controller, driver, servo motor, planetary reducer and the like. Multiple motor drives and controllers are connected in series topology via an industrial real-time Ethernet EtherCAT bus communication protocol. The EtherCAT bus technology with excellent high-speed transmission performance, flexible topology, simple and durable openness, it is executed once with the servo axis for 100µs for actual position and status update [12]. The hardware diagram and physical map of the nursing robot are shown in Fig. 5 below:

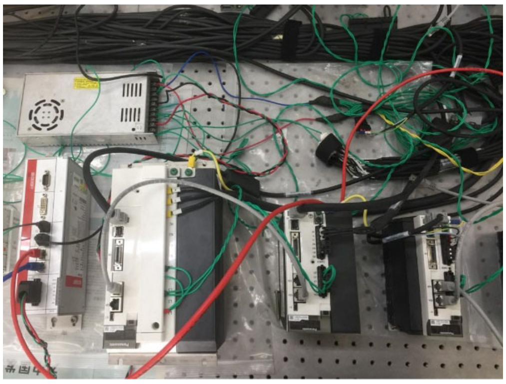

Fig. 5. Hardware system physical map

5 Software Control System Design

Software control is the core of the entire robot control system by software programming the motor driver to send signals to control the motor. The TwinCAT3 based on Beck Hoff controller is used as the upper computer software of the nursing robot control system. It can realize motion control through the NC configuration interface, and can also realize logic control through PLC programming. Based on the inverse kinematics analysis and solution of the end position of the double manipulator of the front nursing robot, the values of the joint torsion angles of the three main joints running to the end position during the nursing process are obtained. Joint torsion angle, writing control program and design algorithm, so that the three main joint axes of the nursing robot's one arm can run according to the calculated torsion angle, so that the arms reach the set end position, and complete the nursing robot software control system design.

5.1 NC Motion Control

The control of the NC axis of the TwinCAT3 software interface is pure software control based on the computer software interface, motion control is the basis of PLC program control. In actual control, the NC axis feeds the status position of the drive to the PLC axis, while the PLC axis writes the data of the function block to the NC axis [11]. In the debugging of the NC axis, the distance between the motor and the actual rotation of the motor is set to be equal, that is, 360 mm is run in the program, and the motor actually rotates 360 degrees. The NC axis control does not require motion programming. The defined NC axis interface operation enables multiple operating mode settings such as motor shaft enable operation, single axis JOG operation, and specified position operation. The software operation interface of the NC axis of the motor is shown in Fig. 6 below:

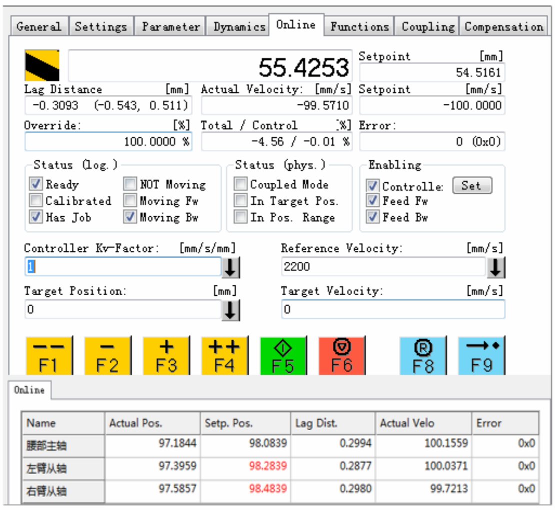

Fig. 6. NC axis motion control interface

5.2 PLC Main Program Design

TwinCAT3 software has a powerful database and supports PLC, C++ and other programming languages. The main program design mainly adopts modular PLC motion control program. After adding the function library, it can be written in the MAIN window under PLC. The PLC program calls the relevant function block. The control program design of the six joint axes of the dual-mechanical arm of the nursing robot is the same, so the design is described by one single-arm design. The design of the PLC main control program is mainly to write function block call instructions, such as motor enable, jog operation, relative position operation, set, electronic gear design, etc. After the required function block call is completed, the parameter design is completed in the function writing window.

5.3 Electronic Gear Design

The electronic gear function is called by PLC command to realize the correspondence between the coupling of the master-slave axis and the nonlinear position and speed. The design of the nursing robot control system software sets the precise electronic gear ratio and coupling speed through the analysis of the running torsion angle of the joint shaft, so that the three joint axes of the nursing robot can run according to the calculated torsion angle and reach the set end point. The position, the care action of the nursing robot is carried out. The electronic gear function block diagram is shown in Fig. 7 below:

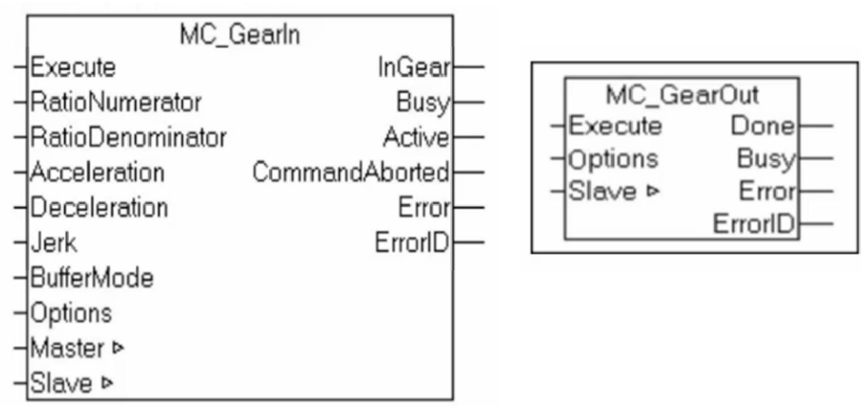

Fig. 7. Electronic gear function block

The control system is designed to facilitate the control of the program, as well as the collection of experimental data during operation and commissioning.

(1) Nursing robot freedom specification: the left arm shoulder joint is the 1st axis, the elbow joint is the 2nd axis, the wrist joint is the 3rd axis; the right arm shoulder joint is the 4th axis, the elbow joint is the 5th axis, the wrist joint it is the 6th axis.

(2) All joint axis lifting motions of the dual manipulators are in the positive direction, and the joint axis is moved in the negative direction.

(3) In the electronic gear design, the No. 1 axis is the main axis, and the rest are the slave axes.

According to the joint torsion angle, the left and right arm joint axis motor of the nursing robot needs to run in the TwinCAT3 software control system: the running distance between the No. 1 axis and the No. 4 axis at the shoulder joint is 29.67 mm, and the No. 2 axis at the elbow joint is The running distance of the 5th axis is -16.2mm, that is, 16.2mm in the opposite direction; the running distance of the 3rd axis and the 6th axis at the wrist joint is -44.7mm. The coupling coefficient of the motor gear is designed according to the actual running distance of the two-arm joint motor. The running distance of No. 1 axis and No. 2 axis and No. 5 axis is close to 2/1; the running distance ratio of No. 1 axis to No. 3 axis and No. 6 axis is close to 2/3; the running distance between No. 1 axis and No. 4 axis is close to 1. Therefore, in the design of the electronic gear, the coupling coefficient of the electronic gear of the No. 1 axis and the No. 4 axis is set to 1; the coupling coefficient of the electronic gear of the No. 1 axis, the No. 2 axis, and the No. 5 axis is set to 1/2; The coupling coefficient of the electronic gear of the number axis with the 3rd axis and the 6th axis is 3/2. Set the electronic gear coupling coefficient parameters as follows:

```
/ / Electronic gear master-slave coupling coefficient setting
gearin2 (
Master: = axis1,
Slave: = axis4,
Execute: = gearin2_do,
Ratio Numerator: = 1,
Ratio Denominator: = 1,
gearin3 (
Master: = axis1,
Slave: = axis2, axis5,
Execute: = gearin3_do,
Ratio Numerator: = 1,
Ratio Denominator: = 2,
gearin4 (
Master: =axis1,
Slave: =axis3, axis6,
Execute: = gearin4_do,
Ratio Numerator: = 3,
Ratio Denominator: =2,
```

According to the coupling factor set by the program, when the speed of the main shaft is 60m/s, the speed of the slave axis No. 4 should be 60 m/s; the speed of the slave axis No. 2 and the No. 5 axis should be 30 m/s; The speed of shaft 3 and axis 6 should be 45m/s. The design control program is verified by the on-site debugging experiment and the software oscilloscope monitoring module.

6 Field Debugging and Graphic Output Monitoring

After the design of the nursing robot based on PLC programming and calling the electronic gear module control system is completed, the Scope View graphical output tool of TwinCAT3 software is applied to verify the designed PLC program and the electronic gear function to realize the correct coupling of the master-slave speed. The actual running speed and position change curve of each axis can be monitored in the Scope View function, as shown in Fig. 8, Fig. 9, and Fig. 10 below:

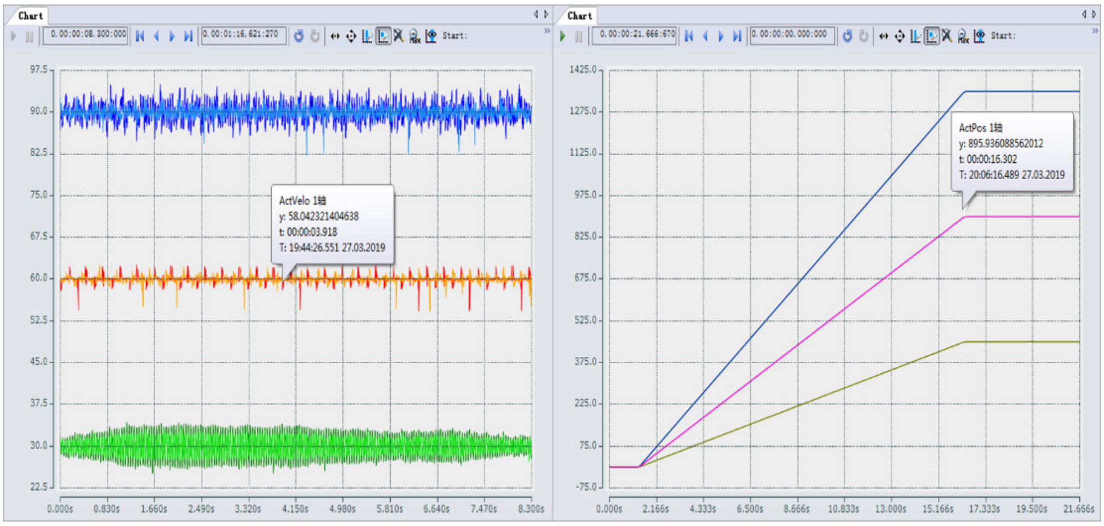

Fig. 8. No. 1 spindle speed and displacement curve

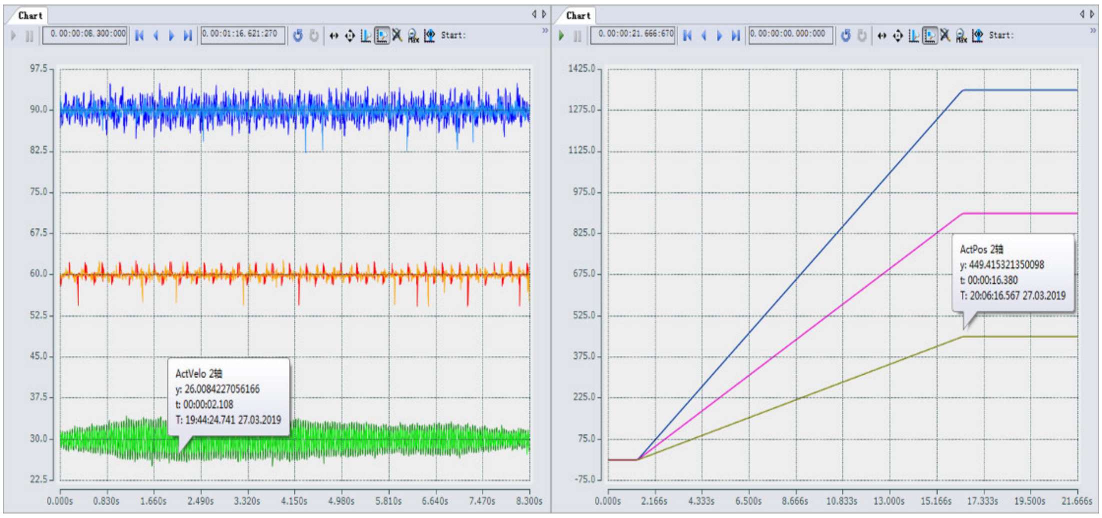

Fig. 9. No. 2 slave axis speed and displacement curve

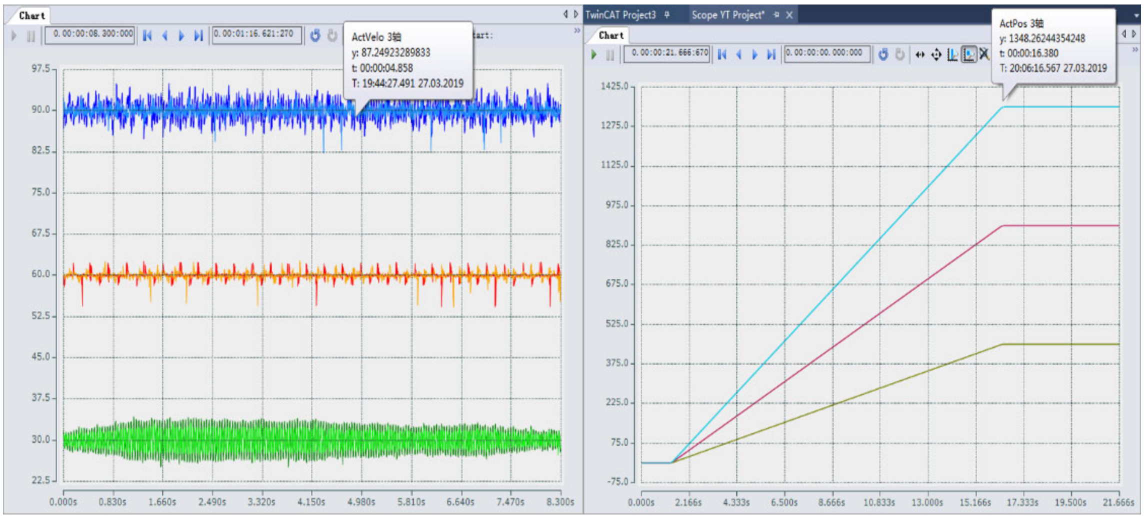

Fig. 10. No. 3 slave axis speed and displacement curve

The on-site commissioning results shown in the above figure show that the actual running speed of the No. 1 and No. 4 axes of the nursing robot arms is 58 mm/s; the actual running speed of the No. 2 and No. 5 axes is 26 mm/s; the actual running speed with the 6th shaft is 87m/s. After running for 15s, the running distance between the No. 1 and No. 4 axes is 900mm; the running distance between No. 2 and No. 5 axes is 450mm; and the running distance between No. 3 and No. 6 axes is 1350mm. In summary, the displacement proportional relationship of the three main joint axes of the single arm is consistent with the inverse kinematic solution of the torsion angle ratio, and the actual running speed and displacement values of each axis are collected by the Scope View monitoring module. Compliance, and the error between the actual running speed and the set speed value does not exceed 5%, which is a reasonable error range. Therefore, the on-site debugging experiment verifies the correctness, feasibility and stability of the software control system design.

The program design makes the nursing robot dual-arms cycle the cues, and the actual running speed and position changes of the six joint-axis motors are shown in the following Fig. 11:

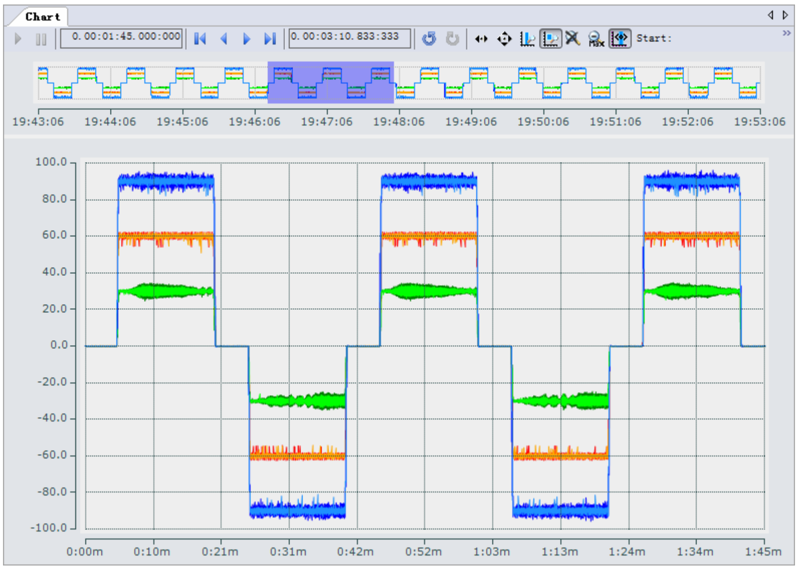

Fig. 11. Speed waveform of each axis cyclic operation

7 Conclusion

In order to realize the design of the humanoid double-arm care robot control system, the PLC program is completed by using the Beck Hoff controller and the host computer software TwinCAT3. The mechanical structure of the main body of the nursing robot and the two arms is introduced. According to the mechanical structure, the positive kinematic model of the six joint axes of the shoulder joint, the elbow joint and the wrist joint of the double mechanical arm is established by using the improved DH modeling method and the arms are set. The end pose matrix is obtained by inverse kinematics to obtain the torsion angle of the three joints of the left and right arms. The hardware platform of the control system is completed based on the EtherCAT bus communication protocol. The software interface of the NC axis is implemented by the TwinCAT3 PC software of Beck Hoff controller. Design with PLC motion control program. PLC motion control realizes multi-axis coupling linkage control by writing motion control code, and calling function blocks such as enable, relative position setting and electronic gear. The key design electronic gear function block is solved according to inverse kinematics analysis. The torsion angle of the joints is designed to couple the primary and secondary shafts to the electronic gear. Based on the design of the PLC control program, each joint axis can be operated according to the calculated torsion angle, so that the arms of the nursing robot can reach the set position. Finally, the on-site debugging of the nursing robot was completed and the oscilloscope graphical output module of the Scope View of the PC software TwinCAT3 was used to verify the effectiveness of the software control system design. The nursing robot arms were run to the set end position according to the calculated joint torsion angle. The experimental results are in line with the expected design, and the dual-arm care robot realizes the care action of the person. The control method of electronic gear coupling using PLC programming makes the control of the robot easier and more precise, and is innovative in the control of multi-degree of freedom nursing robot.

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