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Design of five axis welding robot based on leadshine control system

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Abstract. The five-axis welding robot based on leadshine control system can accomplish various welding tasks in industry, and can accomplish arc welding and linear welding and other welding types. When welding, the machine has small chattering and high welding accuracy. In this paper, the D-H linkage coordinate system and kinematics forward and inverse solutions of the robot are analyzed, and the reachable space of the robot is calculated by Monte Carlo method. The hardware system of the robot is also summarized in more detail in this paper. Using SimMechanics tools to model the robot. Then using MATLAB function to validate the model, recording the difference between theoretical data and simulation data, and judging the correctness of the theory according to the difference.

1. Introduction

As we all know, the industrial robot manipulator plays an important role in today's industrial production. The terminal manipulator is programmed to move along the prescribed Cartesian space[1-2]. In order to obtain the trajectory of the end manipulator, its inverse kinematics must be solved. For welding robot, the most important part is to analyze the kinematics of the robot and then to model and simulate the robot[3]. However, for many welding robot mechanisms, the inverse kinematics can not get the solution of the joint angle, or there are many solutions, which brings many problems to the path planning of the welding robot[4-5].

In this topic, the hardware connection of the robot is completed and the teaching device is compiled.After analyzing the D-H link coordinate system[6], the forward and inverse kinematics solutions are obtained. It is convenient to plan the path of robots later[7]. In solving the inverse kinematics of the robot, the algebraic method and the geometric method are combined, and the robot model is modeled and simulated by the tools of MATLAB and SolidWorks[8]. Monte Carlo method is applied to display the motion space of the robot[9-10]. After several cycles of the end position, the points are displayed in three-dimensional space, so that the reachable space of the end of the robot can be perceived intuittively. At the same time,using matlab function to validate the robot model established by SimMechanics toolbox, and determine the correctness of the forward and inverse solutions of the robot by error.

2. Design of Welding Robot

Firstly, this paper will introduce the whole control system of the robot in detail, as shown in Fig. 1 is the control connection diagram of each module of the five-axis welding robot in this project. The control system can complete the motion control and manual teaching function of the robot. Among them, the motion controller is the core, coding various instructions and controlling the movement. Other paragraphs are indented (BodytextIndented style).
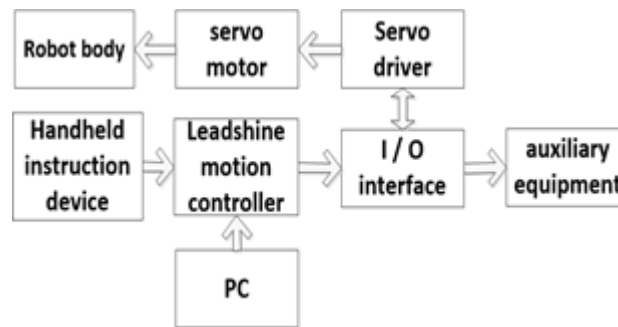
Figure 1. Control chart of robot system

Because before modeling and simulation, we must have a more detailed understanding of the various mechanical structures and parameters of the robot, in order to ensure the accuracy of the later data, so this paper introduce the robot ontology used in this project by means of charts.

Table1. A slightly more complex table with a narrow caption.

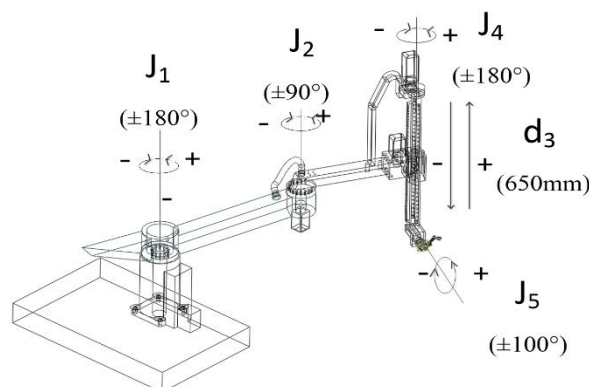| Performance	quota
Outline size and weight	1940mm×1240mm×610mm；150kg；
Maximum uniaxial speed	1#：≥112°/s；2#：≥112°/s；3#：≥750mm/s；4#：≥850°/s；5#：≥120°/s
Rated load	6kg
Welding speed per minute	Vmin≤450mm/min；Vmax≥5000mm/min
Basic motion control mode	Computer entry mode
work space	Rmax：1420±10mm；Hoax：650±10mm
Trajectory repeatability	Under the no-load speed of 9000 mm/min, the robot runs 500 times along the set trajectory, and the deviation between the trajectories does not exceed 0.15 mm.

Figure 2. Robot parameter diagram

According to the above figure, it can clearly seen that the robot belongs to a series structure robot with five joints, four of which are rotating joints and one is moving joints. In addition, when analyzing the welding joints of the robot in Chapter 3, it is necessary to establish a coordinate system to analyze the fixed welding joints trajectory.

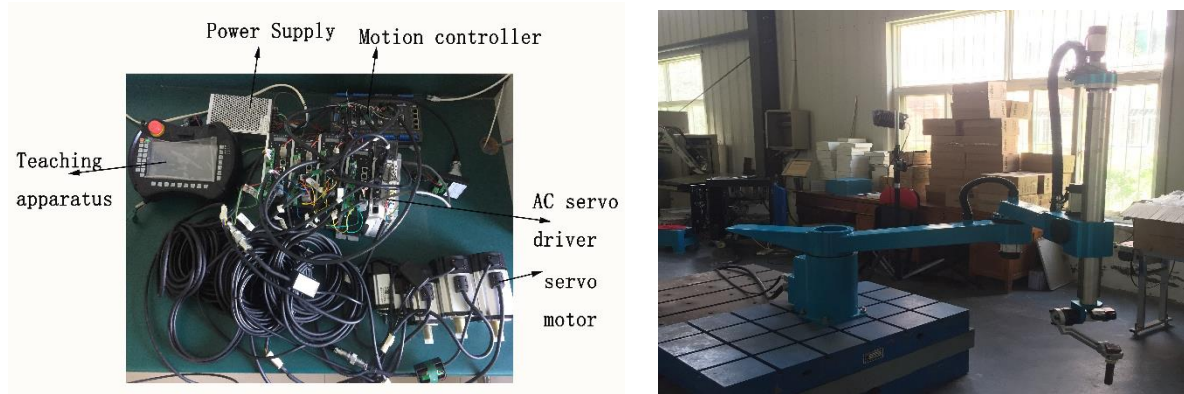The hardware control system and robot ontology are as follows:

Figure 3. Physical diagram of the hardware connection and robot ontology map

3. Kinematics analysis of robot

In this chapter, analyzing the forward and inverse solutions of the robot in detail. The forward solutions can help us get the position and attitude of the end of the robot conveniently, and the inverse solutions can help us get the joint variables of each joint according to the position and attitude. Firstly, the D-H linkage coordinate system is established according to the robot. Because it involves the end-effector welding joint, this paper build it in two parts. But because the coordinate system established in the welding joint is fixed, we will not do more research once.

The D-H link coordinate system is shown below. The origin of 0 and 1 coordinate systems coincide, and the origin of 3, 4 and 5 coordinate systems coincide.

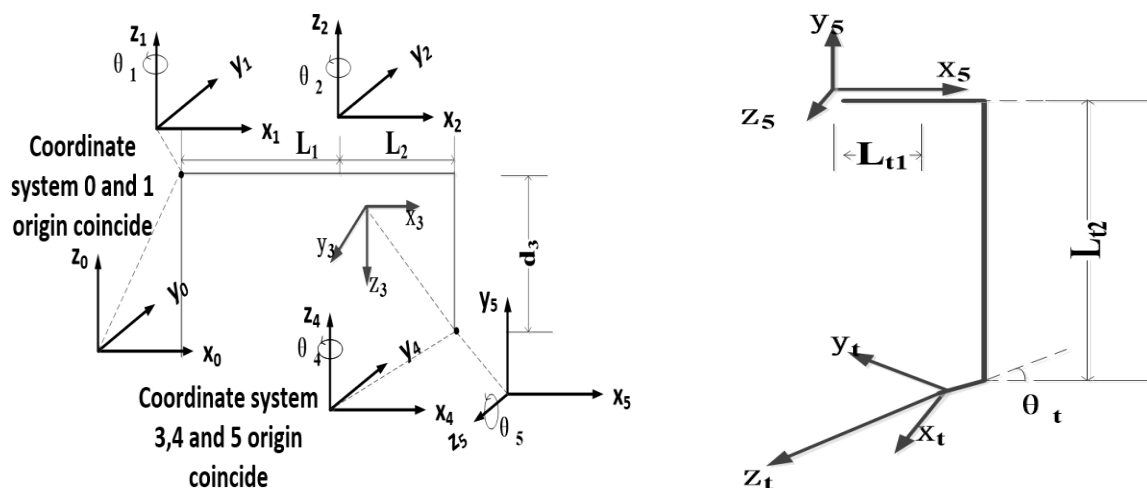

Figure 4. Connecting Rod Coordinate System of Robot Body and Welding Joint

Z_t is aligned with the normal end of the welding torch, pointing to the workpiece. X_t and Z_5 are in the same direction, the origin is at the end of the welding torch.

The following table is an introduction to the parameters of D-H connecting rod. And the positive and negative solutions will be displayed.

Table 2. D-H connecting rod parameters

i	a_{i-1}	α_{i-1}	d_i	θ_i	offset
1	0	0	0	θ_1	0
2	L_1	0	0	θ_2	0
3	L_2	$180°$	d_3	0	0
4	0	$180°$	0	θ_3	0
5	0	$90°$	0	θ_4	0

The following formula is a demonstration of the positive solution of kinematics.

$$_5^0T = {}_1^0T {}_2^1T {}_3^2T {}_4^3T {}_5^4T = \begin{bmatrix} T_{5\_11} & T_{5\_12} & T_{5\_13} & T_{5\_14} \\ T_{5\_21} & T_{5\_22} & T_{5\_23} & T_{5\_24} \\ s\theta_5 & c\theta_5 & 0 & -d_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$
\begin{aligned}
T_{5\_11} &= c\theta_1 c\theta_2 c\theta_4 c\theta_5 - c\theta_1 s\theta_2 s\theta_4 c\theta_5 - s\theta_1 c\theta_2 s\theta_4 c\theta_5 - s\theta_1 s\theta_2 c\theta_4 c\theta_5 \\
T_{5\_12} &= c\theta_1 s\theta_2 s\theta_4 s\theta_5 - c\theta_1 c\theta_2 c\theta_4 s\theta_5 + s\theta_1 c\theta_2 s\theta_4 s\theta_5 + s\theta_1 s\theta_2 c\theta_4 s\theta_5 \\
T_{5\_13} &= c\theta_1 c\theta_2 s\theta_4 - s\theta_1 s\theta_2 s\theta_4 + c\theta_1 s\theta_2 c\theta_4 + s\theta_1 c\theta_2 c\theta_4 \\
T_{5\_14} &= L_1 c\theta_1 + L_2 c\theta_1 c\theta_2 - L_2 s\theta_1 s\theta_2 \\
T_{5\_21} &= c\theta_1 c\theta_2 s\theta_4 c\theta_5 + c\theta_1 s\theta_2 c\theta_4 c\theta_5 + s\theta_1 c\theta_2 c\theta_4 c\theta_5 - s\theta_1 s\theta_2 s\theta_4 c\theta_5 \\
T_{5\_22} &= -c\theta_1 c\theta_2 s\theta_4 s\theta_5 - c\theta_1 s\theta_2 c\theta_4 s\theta_5 - s\theta_1 c\theta_2 c\theta_4 s\theta_5 + s\theta_1 s\theta_2 s\theta_4 s\theta_5 \\
T_{5\_23} &= c\theta_1 s\theta_2 s\theta_4 + s\theta_1 c\theta_2 s\theta_4 + s\theta_1 s\theta_2 c\theta_4 - c\theta_1 c\theta_2 c\theta_4 \\
T_{5\_24} &= L_1 s\theta_1 + L_2 c\theta_1 s\theta_2 + L_2 s\theta_1 c\theta_2
\end{aligned}
\tag{2}
$$

Then the formula for welding head is analyzed.

$$_t^5T = \begin{bmatrix} & & & L_{t1} \\ R_Z(\theta_t) R_Y(-90°) & & -L_{t2} \\ & & & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} 0 & -s\theta_t & -c\theta_t & L_{t1} \\ 0 & c\theta_t & -s\theta_t & -L_{t2} \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$_t^0T = {}_5^0T {}_t^5T \tag{4}$$

Next we will analyze the inverse kinematics solution. When $x_{5o}{}^2 + y_{5o}{}^2 = (L_1 + L_2)^2$, θ_1 and θ_2 have one sets of solutions. Here applying the geometric solution.

$$\begin{cases} \theta_1 = A\tan 2(y_{5o}, x_{5o}) \\ \theta_2 = 0 \end{cases} \tag{5}$$

When $(L_1 - L_2)^2 \le x_{5o}{}^2 + y_{5o}{}^2 < (L_1 + L_2)^2$, θ_1 and θ_2 have two sets of solutions.

$$\begin{cases} \theta_1 = A\tan 2(y_{5o}, x_{5o}) - A\cos(\dfrac{x_{5o}^2 + y_{5o}^2 + L_1^2 - L_2^2}{2L_1\sqrt{x_{5o}^2 + y_{5o}^2}}) \\[3mm] \theta_2 = A\cos(\dfrac{x_{5o}^2 + y_{5o}^2 - L_1^2 - L_2^2}{2L_1 L_2}) \\[3mm] \theta_1 = A\tan 2(y_{5o}, x_{5o}) + A\cos(\dfrac{x_{5o}^2 + y_{5o}^2 + L_1^2 - L_2^2}{2L_1\sqrt{x_{5o}^2 + y_{5o}^2}}) \\[3mm] \theta_2 = -A\cos(\dfrac{x_{5o}^2 + y_{5o}^2 - L_1^2 - L_2^2}{2L_1 L_2}) \end{cases} \tag{6}$$

Before solving θ4 and θ5, we first set the analytical formula of the tool coordinate system as follows. Among them, $^0_t T =\,^0_G T$.

$$^0_G T = \begin{bmatrix} g_{11} & g_{12} & g_{13} & g_{14} \\ g_{21} & g_{22} & g_{23} & g_{24} \\ g_{31} & g_{32} & g_{33} & g_{34} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}$$

According to θ_1、 θ_2 and θ_t, I can get θ_4 and θ_5 analytic formula.

$$\begin{cases} \theta_4 = A\tan 2(g_{11}c(\theta_1 + \theta_2) + g_{21}s(\theta_1 + \theta_2), \\ \qquad g_{11}s(\theta_1 + \theta_2) - g_{21}c(\theta_1 + \theta_2)) \\ \theta_5 = A\tan 2(-g_{32}s\theta_t - g_{33}c\theta_t, g_{32}c\theta_t - g_{33}s\theta_t) \end{cases} \tag{8}$$

So two sets of inverse solutions can be obtained. Secondly, because $\pm 180°$ is actually a position in programming, we all consider these four joint variables to be within the range of ($-180°$ ~ $+180°$].

4. Model simulation
This chapter will introduce the simulation of a five-axis welding robot. Firstly, using Monte Carlo method to visually display the workspace of the robot, and then using SolidWorks to model the robot and cooperate with MATLAB to verify whether the forward and inverse solutions in Chapter 3 are correct. Finally, I will make an error in the theory and simulation.

4.1. Robot workspace
In this figure, showing the three-dimensional view of the workspace as well as its face view, overhead view and side view.
   Since MATLAB is mainly used for simulation, this paper have shown the following steps:
   1) Generating random variables of joints and moving pairs.
   2) The joint variable value is substituted in the wrist coordinate system relative to the 0 coordinate system.
   3) Search for random points in each tier and column.
   4) Ten new random points are generated near each searched boundary point, and the generated data are stored in the matrix of the boundary point in sequence.

5)   Find the next boundary point and repeat the first four steps with the boundary point until the end of the cycle number or the random points of the boundary change little.
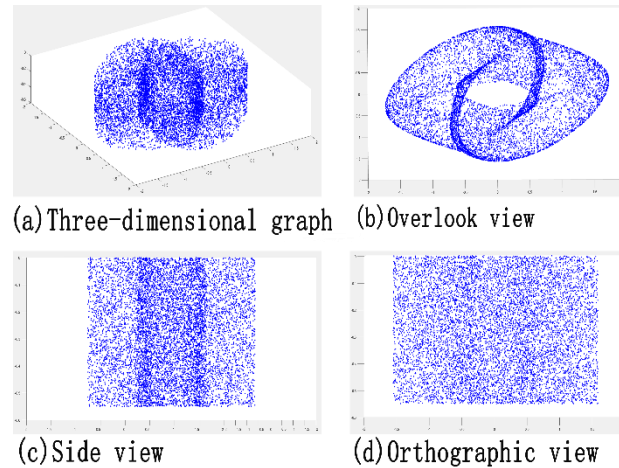

(a)Three-dimensional graph   (b)Overlook view

(c)Side view   (d)Orthographic view

Figure 5. Motion space illustration

4.2. Modeling and combining with MATLAB to verify the correctness of positive and negative solutions.

The quality of SolidWorks modeling determines the degree of integration when the model matches MATLAB in the later stage. Through the actual measurement of the robot, the three-dimensional views of each workpiece and the overall framework of the robot are drawn, and then the three-dimensional views are presented in SolidWorks.
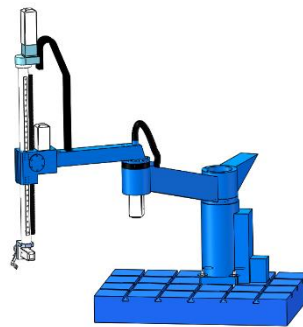

Figure 6. Three dimensional simulation of robot

The robot model is imported into MATLAB and connected with the model established by SimMechanics. Then, the joint angle obtained by theoretical calculation is input into the model, and then the model is moved to see if the final movement is beyond the workspace. If all arrival positions are within the workspace after further verification, it shows that the previous theoretical calculation is correct and conforms to the structure of the robot.

When the model is established, the types of joints (moving or rotating joints) are considered firstly, and then the parameters of each manipulator are defined in the program, the corresponding input parameters are set and the model is run. The obtained data are stored in the corresponding modules for later processing and comparison.

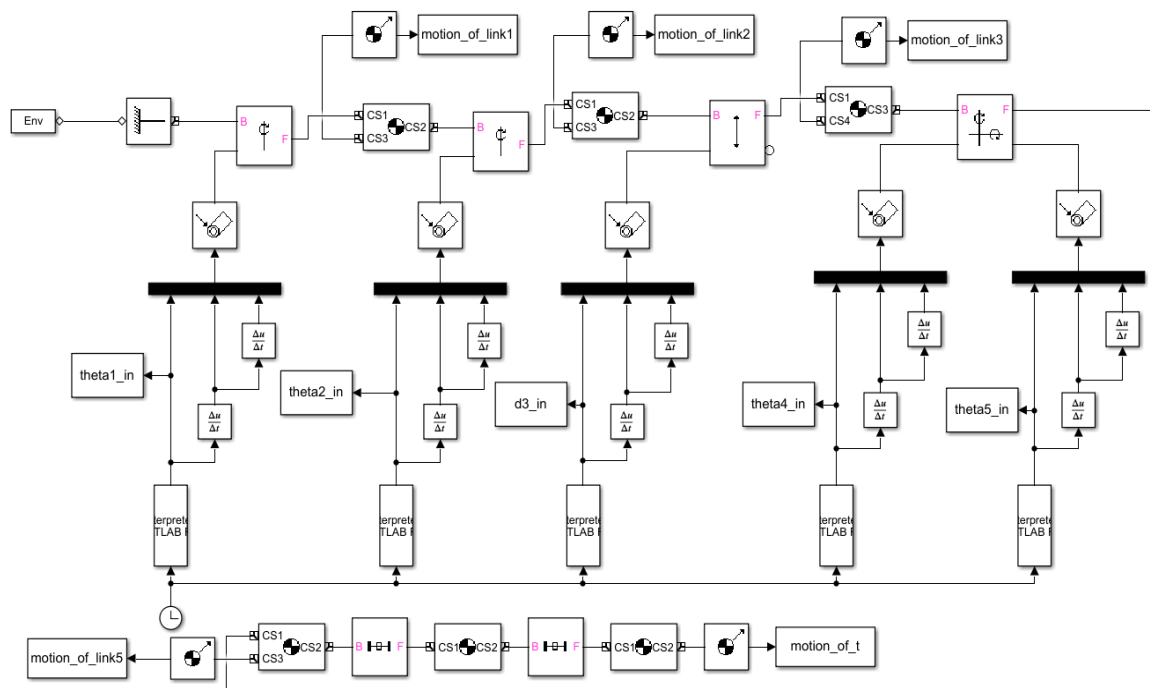Specific model building is shown in Figure 7.

Figure 7. Establishment of simulation model

4.3. Errors between simulation and theory

Firstly, we find a circular arc curve in the workspace, fix 10 points on the arc curve, get the coordinates of these 10 points through SolidWorks, and calculate the theoretical inverse solution through the position of these 10 points. Then the theoretical inverse solutions of these 10 points are brought into the model established by SimMechanics to get the position of the end effector, and then five joint variables are solved again through the end position. Finally, the five joint variables are compared.

point	theta_1	theta_2	d_3	theta_4	theta_5
1	-1.20477548284713	2.08525753107086	-0.86804	0.690314278571168	-1.110223e-16
2	-1.13168742779630	2.19452067827626	-0.86804	0.507963076314937	-1.110223e-16
3	-0.992150789991377	2.29473098772504	-0.86804	0.268216129061239	-1.110223e-16
4	-0.761207939378694	2.09968063987005	-0.86804	0.232323626303544	-1.110223e-16
5	-0.809282653405590	1.90445099283349	-0.86804	0.475627987366995	-1.110223e-16
6	-0.823382330926091	1.69723018994388	-0.86804	0.696948467777112	-1.110223e-16
7	-0.813043682659518	1.53331965839445	-0.86804	0.850520351059966	-1.110223e-16
8	-0.756865314679825	1.92457220109808	-0.86804	0.403089440376637	-1.110223e-16
9	-0.806485718806543	1.79309617486831	-0.86804	0.584185870733132	-1.110223e-16
10	-1.17425961283125	2.12864745151033	-0.86804	0.616408488115820	-1.110223e-16
1	-1.20374023682013	2.08572303567916	-0.86804	0.688813527935867	-1.110223e-16
2	-1.13419915326121	2.19391062395399	-0.86804	0.511084856102110	-1.110223e-16
3	-0.997232225061644	2.30177328901575	-0.86804	0.266255262840789	-1.110223e-16
4	-0.761207939378694	2.09968063987005	-0.86804	0.232323626303544	-1.110223e-16
5	-0.812664215986286	1.91396309907767	-0.86804	0.469497443703510	-1.110223e-16
6	-0.823382330926091	1.69723018994388	-0.86804	0.696948467777112	-1.110223e-16
7	-0.817426200945147	1.54250214450581	-0.86804	0.845720383234234	-1.110223e-16
8	-0.756376435993254	1.92299897470173	-0.86804	0.404173788086420	-1.110223e-16
9	-0.810434827746754	1.80299640725351	-0.86804	0.578234747288141	-1.110223e-16
10	-1.17664723526852	2.13294320724135	-0.86804	0.614500354822067	-1.110223e-16

Figure 8. Theoretical and simulation errors

5. Conclusion

In this topic, we have completed the basic kinematics analysis of the welding robot, obtained the correct forward and inverse solutions, and used SolidWorks and MATLAB to model the welding robot. The SimMechanics tool is used to simulate the motion and get the corresponding simulation data. According to the data analysis and theoretical analysis, the gap between simulation and theory is very small.

In future planning, hoping that the welding robot can complete more complex welding operations by changing the mechanical structure of the welding joint.

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