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Trajectory Planning Research of the Filter Shell Special Arc Welding Robot

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Abstract. The detailed analysis of the structure and parameters of the connecting rod is put forward by using the improving D-H method to establish the link coordinate system and the kinematics equation, based on the special filer shell arc welding robot with six degrees of freedom designed. Therefor, the correctness of the kinematics equation is verified though the simulations of Matlab function with the robotics toolbox. The analysis simulation results show that the rationality of the robot structure that based on the kinematics analysis is feasible.

Introduction

Due to the domestic development of automotive industry, its related manufacturing industry has also been a rapid development opportunity. Particularly, the filter industry that is called the "lung" of the car engine has developed rapidly. The application of arc welding robot plays a decisive role during the process from traditional hand-made to the assembly line of automation manufacturing. It is well known that the applications of the robot overcome the problems of low production and unstable quality exist in traditional manual work, that greatly improves the quality of efficiency filter production and the whole development of industry. The aim of the arc welding robot is mainly about welding under related shape trajectory set before[1,2], which requires the analysis of welding trajectory in advance i.e., trajectory planning, relevant information obtaining of trajectory[3,4], the input control system and control the robot welding work. Therefore, the trajectory planning has the key role of the quality in welding robot, which is an important component of the welding robot control system.

The Structure of the Robot and the Link Parameters

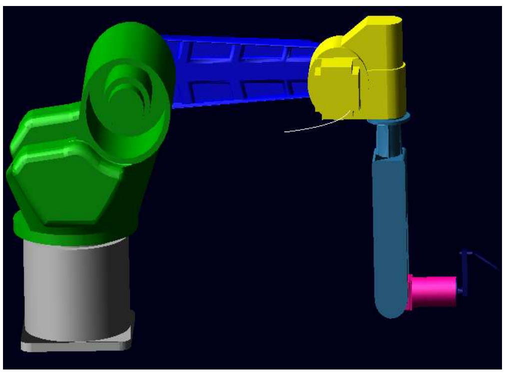

Fig. 1 Filter shell special arc welding robot structure

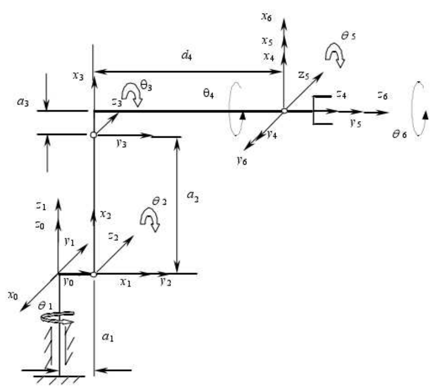

Fig. 2 Robot base coordinate system and the connecting rod coordinate system

The structure of the robot has shown in Fig.1, and the Robot base coordinate system and the connecting rod coordinate system have shown in Fig.2. In the both figures, the shape characteristics and kinematics of the robot has been fully demonstrated. The link coordinate system and kinematics equations are established with D-H method. Table 1 shows the link parameter of the filter shell special arc welding robot.

Table 1 The link parameter of the filter shell special arc welding robot

Joints	Joint angle θ_i	Offset d_i	Rod length a_{i-1}	Twist angle a_{i-1}
1	θ_1	0	0	0
2	θ_2	0	a_1	-90
3	θ_3	0	a_2	0
4	θ_4	d_4	a_3	-90
5	θ_5	0	0	90
6	θ_7	0	0	-90
a_1=250mm; a_2=650mm; a_3=50mm; d_4=594mm				

Robot Kinematics Analysis

The kinematics problem is solving the pose of end connecting rod coordinate system relative to the base coordinate system, based on the parameters and joint variables of the robot bar geometric. The kinematics equation of the position and the attitude from the i coordinate system and the i-1 coordinate systems are builded by homogeneous transformation matrix. The principle of coordinate system based on the improved method D-H, is established as follows:

$$
{}^{i-1}_{i}T = \begin{bmatrix} \cos\theta_i & -\sin\theta_i & 0 & a_{i-1} \\ \sin\theta_i\cos\alpha_{i-1} & \cos\theta_i\cos\alpha_{i-1} & -\sin\alpha_{i-1} & -d_i\sin\alpha_{i-1} \\ \sin\theta_i\sin\alpha_{i-1} & \cos\theta_i\sin\alpha_{i-1} & \cos\alpha_{i-1} & d_i\cos\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}
$$

Respectively, i={1,6}. We can get the connecting rod transformation matrix in turn as follows:

$$
{}^{0}_{1}T = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & 0 \\ \sin\theta_1 & \cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}
$$

$$
{}^{1}_{2}T = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & a_1 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_2 & -\cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}
$$

$$
{}^{2}_{3}T = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & a_2 \\ \sin\theta_3 & \cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}
$$

$$
{}^{3}_{4}T = \begin{bmatrix} \cos\theta_4 & -\sin\theta_4 & 0 & a_3 \\ 0 & 0 & 1 & d_4 \\ -\sin\theta_4 & -\cos\theta_4 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}
$$

$$
{}^{4}_{5}T = \begin{bmatrix} \cos\theta_5 & -\sin\theta_5 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ \sin\theta_5 & \cos\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}
$$

$$
{}^{5}_{6}T = \begin{bmatrix} \cos\theta_6 & -\sin\theta_6 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin\theta_6 & -\cos\theta_6 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7}
$$

Then robot kinematics equation can be gotten as follows:

$$
{}^{0}_{6}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T\,{}^{4}_{5}T\,{}^{5}_{6}T = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8}
$$

Now let us consider C_i is $\cos\theta_i$, S_i is $\sin\theta$, C_{ij} is $\cos(\theta_i+\theta_j)$ and S_{ij} is $\sin(\theta_i+\theta_j)$. With multiplication principle of matrix combined with powerful calculation ability of Matlab matrix, we can get the result as follows:

$$\begin{cases}
n_x = c_1[c_{23}(c_4c_5c_6 - s_4s_6) - s_{23}s_5c_6] + s_1(s_4c_5c_6 + c_4s_6); \\
n_y = s_1[c_{23}(c_4c_5c_6 - s_4s_6) - s_{23}s_5c_6] - c_1(s_4c_5c_6 + c_4s_6); \\
n_z = -s_{23}(c_4c_5c_6 - s_4s_6) - s_{23}s_5c_6; \\
o_x = c_1[c_{23}(-c_4c_5c_6 - s_4c_6) + s_{23}s_5s_6] - s_1(s_4c_5s_6 - c_4c_6); \\
o_y = c_1(s_4c_5c_6 - c_4s_6) + s_1[c_{23}(-c_4c_5s_6 - s_4c_6) + s_{23}s_5s_6]; \\
o_z = s_{23}(c_4c_5s_6 + s_4c_5) + c_{23}s_{23}s_6; \\
a_x = -c_1(c_{23}c_4s_5 + s_{23}c_5) - s_1s_4s_5; \\
a_y = -s_1(c_{23}c_4s_5 + s_{23}c_5) + c_1s_4s_5; \\
a_z = s_{23}c_4s_5 - c_{23}c_5; \\
p_x = c_1(c_{23}a_3 - s_{23}d_4 + c_2a_2 + a_1); \\
p_y = s_1(c_{23}a_3 - s_{23}d_4 + c_2a_2 + a_1); \\
p_z = -s_{23}a_3 - c_{23}d_4 - s_2a_2
\end{cases} \tag{9}$$

The Robot Kinematics Simulation

Robot Objects Modeling

The model program will be as follows:

L {1} = link ([0 0 0 0 0],'mod'); L {2} = link ([-pi/2 0.25 0 0 0],'mod');
L {3} = link ([0 0.65 0 0 0],'mod'); L {4} = link ([-pi/2 0.05 0 0.594 0],'mod');
L {5} = link ([pi/2 0 0 0 0],'mod'); L {6} = link ([-pi/2 0 0 0 0],'mod');
r=robot ({L {1} L {2} L {3} L {4} L {5} L {6}}); r.name='arc welding robot'; drivebot (r)

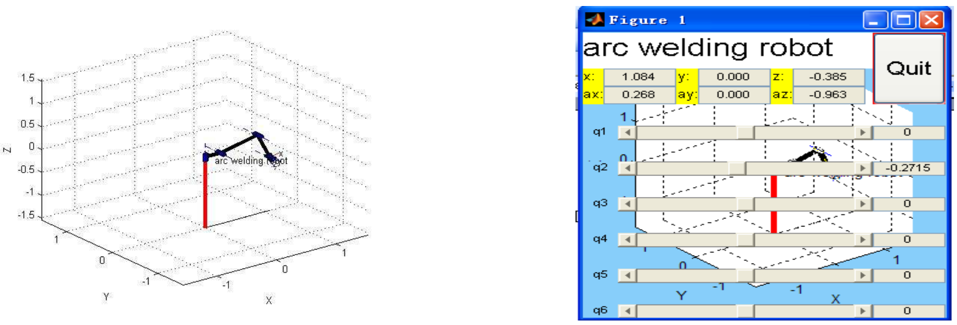

Fig. 3 The model of manipulator

The Fig. 3 shows that the six joint of the robot rotate smoothly, when the driven block bring along the robot. The movement of former three joint has been decided by the working space[5,6], and the different attitudes of the wrist been decided by the exercise of following three joint.

Test Results of Kinematics Simulation

The fkine () function of robot kit (robotics toolbox) is used to solve the forward kinematics. Its format is as following:

TR = FKINE (ROBOT, Q)

The "ROBOT" is ROBOT object, TR is forward kinematics of positive solution defined by Q. For the reason that the relative zero, when we establish the D-H coordinate joint type coordinate system is qz = [PI/2 -PI/2 0 0 0 0], call function fkine (r, qz) will return to the translational homogeneous change matrix of mechanical arm end effectors, then the operation results are as follows:

Fkine (r, qz); ans =(0.0000, 1.0000, 0, 0.0000); (0.0000, 0, 1.0000, 0.8440); (1.0000, -0.0000, -0.0000, 0.7000); (0, 0, 0, 1.0000)

The last column of matrix represents the moving distance of robot is a_1+d_4 in the direction of Y_0, in the direction of Z_0 the moving distance a_2+a_3, that the situations are completely consistent with the simulations Fig. 2 shows. So the results of forward kinematics calculation are completely correct. So the results of forward kinematics calculation are completely correct.

Trajectory Planning Simulation

The sequences of operations and actions have been formulated on the basis of the requirements of the task of the robot. And the trajectory planning simulation can be more detailed visual description of the industrial robot motion process. The planning could been computed in joint space within the also in the Cartesian space. The trajectory planning and divided into point to point movement and continuous path movement, the former only need rules starting point and end point, the latter should regulation starting point and end point, and to indicate some middle path point[7].

Joint Space Trajectory Planning

The point to point planning was been adopted in the trajectory simulation of the joint space. Therefore, the main research first three joint to the influence of the robot movement, set starting point and end point, and in two places at the beginning of the manipulator. Then, the velocity is zero, the regulation movement time for 2s. The program in the Matlab with robot kit is as follows:

qz = [PI / 2 - PI / 2 0 0 0 0]; % starting point joint vector;
qr = [- PI / 3 PI / 4 PI / 3 0 0 0]; % end point joint vector;
T = drew. 056:2; % simulation time is 2s, sampling interval is 0.056s;
Q = jtraj (qz, qr, t); % build path command; Plot (r, q)

The results showed the process of the robot from the initial point to the end point of the motion characteristics. In order to obtain more intuitive understanding of the motion process of various joint changes, the robot kit of velocity, acceleration function should be invoked as follows:

[q, qd, QDD] = jtraj (qz, qr, t); % joint trajectory planning
Plot (t, q (:, I)); % draw each joint angular displacement curve
Plot (t, qd (:, I); % draw each joint velocity curve
Plot (t, (QDD (:, I)); % draw each joint acceleration curve. Now let consider i=1 and 3.

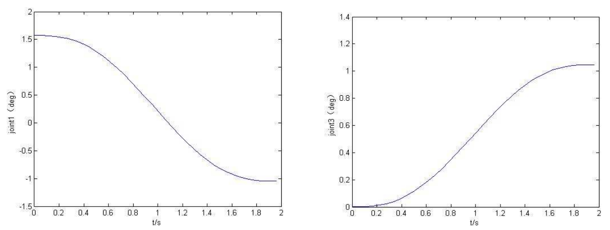

Fig. 4 The displacement curve of joint 1 and 3

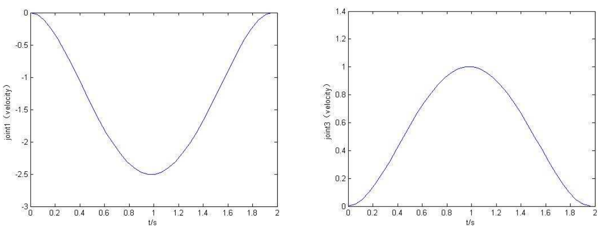

Fig. 5 The velocity curve of joint 1 and 3

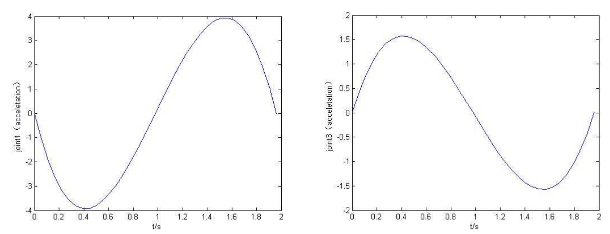

Fig. 6 The acceleration curve of join 1 and 3

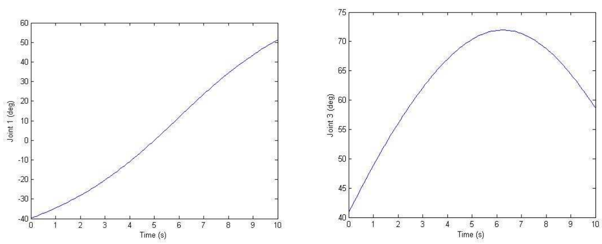

Fig. 7 The displacement curve of joint 1 and 3

The results show that the manipulator displacement curve is smoothing, speed and acceleration curve is continuous. And the whole structure would not generate large vibration, because of the specifies that the design of robot in this work to the process of running smoothly. Also, the result has complied with the requirements of design.

Cartesian Space Trajectory Planning

In welding process, we require motion trajectory of the robot in accordance with certain track continuous to specify a path, i.e. to reaches the specified destination, also in accordance with the desired path. So the Cartesian space robot trajectory planning is put forward to adopt [8].

The two Cartesian trajectory planning were discussed. And the program in Matlab with robot kit is as follows:

T = drew. "; Qz = [0 0 0 0 0 0];
T0 = transl (0.6, 0.5, 0); % initial position; T1 = transl (0.4, 0.5, 0.2); % final position;
R = jtraj (0, 1, t); TC = ctraj (T0 T1, r); Plot (t, transl (TC).

Now let consider t is time vector, and the initial qz is the robot pose, qr is the final position of the robot. The simulation results are as follows:

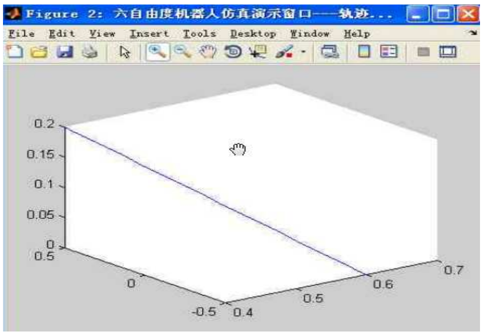

Fig. 8 The cartesian space trajectory planning curve

The Cartesian coordinate’s locus solves repeatedly the kinematics of the inverse problem by the trajectory update rate, in order to obtain a desired joint angle and joint angle. The results show that the cartesian space trajectory planning is expected to conform.

Conclusions

The structure of the filter shell special arc welding robot is more reasonable, no significant vibration in the course of the campaign. The results of the simulation prove the rationality of the design of the robot. Also the the improved D-H method is available for the calculate of the arc welding robot kinematics equation. And the Matlab environment combined with robot kit is made on the robot modeling and the kinematics simulation result can effectively prove the correctness of the structure of the movement.

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