Joint Trajectory Time Optimization of Cobot Based on Particle Swarm Optimization

Cheng Zhenyi¹,*

¹School of Mechanical and Automotive Engineering, Shanghai University Of Engineering Science, Shanghai, China

*E-mail:447337499@qq.com

Abstract: In order to improve the working efficiency of the robot and make the welding quality of the part of skin group improved greatly. We researched on the end trajectory of the Cobot. In the application scenario of Friction Stir Welding (FSW) test bench, an algorithm of joint space trajectory is proposed according to the kinematics characteristics of the robot and the practical application needs. Based on particle swarm optimization (PSO), the motion trajectory of robot joint is fitted by high order polynomial interpolation. While ensuring the end trajectory, the stability of the joint motion is guaranteed. The simulation experiment is carried out by using MATLAB software. The joint space optimal motion planning is realized. The comparison algorithm is verified by experiments. According to the experimental results, the particle swarm optimization algorithm improves the efficiency of the cooperative robot significantly. It is helpful to the end stability of friction stir welding robot.

1. Introduction
In recent years, friction stir welding (FSW) has developed rapidly in the world. Under the background of China’s industry 4.0, major research institutes have begun to vigorously develop the technology of FSW[1]. Our school’s Intelligent Robot Research and Development Center focuses on the development of friction stir welding robots. When studying the related control problems, it encounters the problems of jitter and uneven axial force[2, 3]. After referring to the feed-forward control and other solutions[4], it decides to optimize the joint arms of the cooperative robot first. Robot trajectory planning is the key of robot control. At present, there are two optimization directions: one is to optimize the time, the other is to optimize the energy of the system. Compared with the working efficiency of the robot, the friction stir welding robot is not sensitive to the change of system energy, so the motion time is chosen as the optimization object. In order to improve the performance of the robot, reduce the jitter of the robot in work and the change of the axial force in welding. In this paper, particle swarm optimization (PSO) is used to optimize the trajectory of the robot joint.

There are several ways to optimize the time of trajectory planning, such as genetic algorithm. At present, most of the research on robot joint trajectory at home and abroad adopt genetic algorithm[5]. Particle swarm optimization is still in the exploratory stage, but it also has a considerable research foundation[6]. At the same time, it has many shortcomings and limitations.

This paper chooses UR5 cooperative robot as the research object, and studies the trajectory planning time of point-to-point (PTP). In the simulation experiment, the end trajectory of the robot for friction stir welding arc workpiece was optimized by using high order polynomial interpolation and particle swarm optimization. The practicability and expected results of the research results are verified.
by the combination of actual test and simulation experiments. Experiments show that this method can not only optimize the trajectory planning time, shorten the time of robot joint movement, but also can be applied in practice. For friction stir welding test, it can greatly shorten the welding cycle, improve work efficiency and increase the life of the stirring head.

2. **Kinematics Analysis of Collaborative Robot**

UR5 cooperative robot is used in this experiment, which is a 6-DOF robot. According to the specifications, the size diagram (Figure 1) is obtained. According to the D-H parameters (shown in Table 1), the robot model can be constructed, and the forward and inverse solutions and singular values [7] can be obtained. Forward and Inverse kinematics. According to the manual of the Cobot UR5 (Figure 2), the DH parameters of the robot in table 1 are obtained.

Table 1 - D-H parameters of the UR5

| Connecting rod | Torsion Angle | Around corner | Distance | Length |
|----------------|--------------|---------------|----------|--------|
| n              | α_i / rad    | θ_i / rad     | d_i / mm | a_i / mm |
| 1              | π/2          | θ_1          | 89.459   | 0      |
| 2              | 0            | θ_2          | 0        | 425    |
| 3              | 0            | θ_3          | 0        | 392.5  |
| 4              | π/2          | θ_4          | 109.15   | 0      |
| 5              | -π/2         | θ_5          | 94.65    | 0      |
| 6              | 0            | θ_6          | 82.3     | 0      |

The kinematics principle and simulation of the UR5 robot are analyzed [8]. Combining with MATLAB robot simulation library, the forward and inverse kinematics solutions of the cooperative robot can be obtained. In order to plan the joint space motion of the robot, it is necessary to find the position points of the joint motion. According to the inverse kinematics characteristics of the robot, the position points of the joint motion can be obtained.

2.1 **Planning of End Position**

According to the actual welding requirements of the workpiece, an arc trajectory of FSW is planned based on high order interpolation [9]. In case of fixed end trajectory, there are innumerable inverse solutions. According to the simulation experience of the inverse solution of the joint robot [10], the solutions of the four path points of the joint are obtained. According to Cartesian transformation of the solve function, the definition of coordinate system and worktable coordinate system can be applied to basic inverse kinematics. The base is the first joint point. The solution is shown in Table 2 below.
Table 2 The Inverse kinematics of each joint at the path point

| Joint/Path Point | 1      | 2      | 3      | 4      |
|------------------|--------|--------|--------|--------|
| 1                | 87.55° | 90.51° | 120.62°| 171.23°|  
| 2                | -67.52°| -67.02°| -67.04°| -46.14°|  
| 3                | 82.26° | 77.45° | 79.09° | 54.46° |  
| 4                | -193.77°| -190.6°| -190.5°| -190.5°|  
| 5                | -54.21°| -57.72°| -86.10°| -86.33°|  
| 6                | -81.72°| -80.21°| -81.72°| -81.72°|  

3. Experimental design based on particle swarm optimization

3.1. Solution of Position, Velocity and Acceleration

There are many interpolation methods for trajectory planning of joint points, such as high-order polynomial interpolation, low-order polynomial interpolation, Hermite interpolation, spline interpolation and so on. However, the high-order polynomial interpolation may be unstable; the low-order polynomial interpolation has poor smoothness, and the first derivative does not exist near the interpolation node; the piecewise three-order Hermite interpolation has better smoothness than the low-order polynomial, but it does not have the second-order smoothness in the interpolation interval. In this paper, the high-order spline interpolation function is used to interpolate the control points and optimize the joint trajectory of the cooperative robot based on friction stir welding.

High-order spline interpolation is used to interpolate the spatial motion of robot joints. In the experiment, the path of joint space motion is divided into three intervals. Let the position of joint motion be, and the time of different intervals be. The relationship between joint spatial motion position and time is as follows:

\[
\begin{align*}
q_1 &= a_1f_1^3 + a_2f_2^2 + a_3f_3 + a_4 \\
q_2 &= a_5f_2^4 + a_6f_2^3 + a_7f_2^2 + a_8f_2 + a_9 \\
q_3 &= a_{10}f_3^3 + a_{11}f_3^2 + a_{12}f_3 + a_{13}
\end{align*}
\]  

(1)

According to the above formula, the formulas for calculating the velocity and acceleration of each point in the motion of each joint of the robot can be obtained. The velocity is as follows:

\[
\begin{align*}
q_1 &= 3a_1f_1^2 + 2a_2f_2 + a_3 \\
q_2 &= 5a_5f_2^3 + 4a_6f_2^2 + 3a_7f_2 + a_8 \\
q_3 &= 3a_{10}f_3^2 + 2a_{11}f_3 + a_{12}
\end{align*}
\]  

(2)

The acceleration is shown as follows:

\[
\begin{align*}
q_1 &= 6a_1f_1 + 2a_2 \\
q_2 &= 20a_5f_2^2 + 12a_6f_2 + 6a_7f_2 + 2a_8 \\
q_3 &= 6a_{10}f_3 + 2a_{11}
\end{align*}
\]  

(3)

According to the known conditions, the following three groups of formulas can be obtained from the path points passed at different times and the motion state of the robot joints at different times. Let the value of four path points and the motion time of three intervals be. The formulas for solving parameters in the first interval are as follows:


The formulas for solving the parameters of the second interval are as follows:

\[
\begin{align*}
Q(2) &= a_{10} \\
Q(3) &= a_{23}t(2)^5 + a_{24}t(2)^4 + a_{25}t(2)^3 + a_{26}t^2 + a_{20} \\
a_{21} &= 3a_{13}t(1)^2 + 2a_{12}t(1) + a_{11} \\
a_{22} &= 6a_{13}t(1) + 2a_{12} \\
a_{23} &= 5a_{23}t(2)^4 + 4a_{24}t(2)^3 + 3a_{25}t(2)^2 + 2a_{26}t(2) + a_{21} \\
a_{24} &= 20a_{23}t(2)^3 + 12a_{24}t(2)^2 + 6a_{25}t(2) + 2a_{22}
\end{align*}
\]

The formulas for solving the parameters of the third interval are as follows:

\[
\begin{align*}
Q(3) &= a_{30} \\
Q(4) &= a_{33}t(3)^3 + a_{32}t(3)^2 + a_{31}t(3) + a_{30} \\
0 &= 3a_{33}t(3)^2 + 2a_{32}t(3) + a_{31} \\
0 &= 6a_{33}t(3) + 2a_{32}
\end{align*}
\]

According to the above formulas, the parameters of higher order polynomials can be obtained. Thus, the trajectory formula, velocity formula and Acceleration Formula of joint space motion can be obtained. The position, velocity and acceleration at any time can be calculated according to the formula.

### 3.2 Optimization of particle swarm optimization

In order to optimize joint space trajectory planning based on PSO, several examples need to be selected as optimization objects. In the experiment, a three-dimensional example is formed by the time taken to complete the motion of three intervals, and 20 groups of particles are generated randomly. The mean of the particles is between. The fitness function of the example is shown in equation (7):

\[
\text{fitness} = t_1 + t_2 + t_3
\]

The fitness value of particles is calculated according to fitness function. The smallest fitness of a single particle is selected as the local optimal particle and the smallest fitness of all particles is selected as the global optimal particle.

In addition to the fitness function, the parameters (8) in the updated particle velocity formula need to be determined. The inertia weight, maximum and minimum, decreases as the number of iterations increases, as shown in formula (10). Learning factors. The random factors are random numbers between them, which are generated by the function of MATLAB.

\[
v[m] = w \cdot v[m] + c_1r_1(pBest[m] - present[m]) + c_2r_2(pBest[m] - present[m])
\]

\[\text{present}[m] = \text{present}[m] + v[m]
\]

\[W = W_{\text{max}} - (W_{\text{max}} - W_{\text{min}})(n/N)
\]

In this experiment, besides the general constraints, the constraints of joint space motion must be satisfied, that is, the joint motion speed and acceleration can not exceed the prescribed maximum speed and acceleration. From the formula (11), the maximum velocity and large acceleration of different particles can be obtained.
\[ |V| \leq V_{\text{max}} \quad |\dot{a}| \leq a_{\text{max}} \]  

Particle swarm optimization (PSO) with constraints is used to optimize the time of joint space trajectory, and the shortest time of joint motion is obtained. In order to realize the optimization process, we first verify whether the particle meets the constraints in Formula (11). Satisfaction is calculated by formula (7), otherwise it is infinite. The fitness values of each particle are preserved. By comparing the fitness values of 20 particles, the minimum fitness value is selected, that is, the optimization is completed, as the global optimal particle. Through N iterations, the particle is updated continuously, even the fitness value, and the optimal particle is selected to obtain the optimal solution under constraints, that is, the shortest time of trajectory planning.

4. Simulation

In this paper, PSO based high order polynomial interpolation method is used to optimize the joint trajectory of cooperative robots. The joint trajectory is smooth and stable.

According to the beam-saving condition of the robot, the position-time relationship of the joint motion is obtained as shown in Figure 3. From the comparison of Figure 4 and Figure 5, it is obvious that polynomial of degree five interpolation can make the trajectory curve more flexible, especially the acceleration improvement at the end of the robot.

It is easy to find that Figures 6, 7, and 8 represent the iteration process. After about 30 iterations, the time tends to be stable. About a third of the time can be saved.

As can be seen from Table 3, the initial time to complete the specified trajectory is 6 seconds. After optimization, the time consumed by the robot can be shortened to about four seconds. This method not only ensures the smooth motion of the robot joint, but also improves the efficiency of the robot and enhances the axial force stability of friction stir welding.
Table 3. Joint optimization results.

|               | T1  | T2  | T3  | Total time |
|---------------|-----|-----|-----|------------|
| Initial time  | 2   | 2   | 2   | 6          |
| Optimization 1| 1.44| 1.36| 1.46| 4.26       |
| Optimization 2| 1.46| 1.36| 1.45| 4.27       |
| Optimization 3| 1.45| 1.38| 1.39| 4.32       |
| Optimization 4| 1.47| 1.36| 1.81| 4.64       |
| Optimization 5| 1.45| 1.36| 1.49| 4.30       |

5. Conclusion
The trajectory of the robot optimized by high-order interpolation and particle swarm optimization has good smoothness, greatly shortens the movement time, improves the efficiency of friction stir welding robot, and enhances the stability of welding.

In the experiment, the robot will have a short standstill after reaching a posture. I think the next work direction is the feed forward control of the robot's terminal trajectory to further improve the efficiency of the cooperative robot.

References
[1] Zhang hao, huang yongde. Research status of friction stir welding technology and process suitable for robot welding [J]. Materials review, 2018, 32(1):128-134.
[2] Wan minhong, zhou weijia. Design and motion control of high-precision and heavy-duty friction stir welding robot [J]. Robot, 2018, 40(6):817-824.
[3] Sun hongyu, zhou qi. Analysis of axial pressure change in friction stir welding [J]. Thermal processing technology, 2018(1):206-209.
[4] Tao zhengxin. Design and research of motion controller for friction stir welding robot [D]. Yanshan university, 2016.
[5] Xiong zhengwei. Trajectory planning of three-dimension feeding manipulator based on b-spline and multi-objective genetic algorithm[J].Mechanical transmission,2018,v.42; No.257(5):125-128.
[6] Feng Bin.Robot joint space based on particle swarm algorithm the optimal trajectory planning[J]. Journal of combination machine tools and automatic processing technology,2018, No.531(5):6-9.
[7] Guo xiaobao. Kinematics and singularity analysis of UR robot [J]. Equipment machinery, 2017(1).
[8] Ge jianbing, zhai xueqin. Kinematics simulation of robot based on MATLAB [J]. Machine design and manufacturing, 2008(9):168-169.
[9] Han jiang. Joint trajectory planning algorithm for industrial robots based on hybrid interpolation [J]. China mechanical engineering, 2018, 29(12):1460-1466.
[10] Lu jia-hao. Research on joint robot motion simulation based on MATLAB Robotic Toolbox [J]. Machine tool & hydraulics, 2017(17).