Research on Trajectory Planning of Columnar Object Loading Robot

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Abstract: In order to effectively solve the problem of continuous and stable work and obstacle avoidance of the columnar object loading robot, the obstacle avoidance trajectory planning of the loading robot is carried out, and the angular displacement, angular velocity, and angular acceleration of each joint of the loading robot are simulated. The analysis results show that the cubic B-spline interpolation method can quickly generate obstacle avoidance trajectory and the trajectory has good motion characteristics, and can complete the loading work continuously without sudden changes, which verifies the feasibility of automatic loading of columnar object loading robots.

Keywords: robot; automatic loading; obstacle avoidance; trajectory planning

1. Introduction

With the development of modern industrial technology towards intelligence and unmannedness, the use of robots to complete the filling of columnar objects is the main development direction. Trajectory planning of the loading process is one of the key technologies in the loading robot design. Commonly used trajectory planning methods include fifth-order polynomial interpolation and cubic B-spline interpolation [1]. Obstacles in the workspace will hinder the normal operation of the robot, which is a key issue in robot design. The aim of this work is to effectively improve the performance of continuous and stable work and obstacle avoidance of the loading robot [2]. Therefore, in this work, we plan the trajectory of the loading process, analyze the simulation results, and verify the feasibility of automatic loading of the cylindrical robot.

2. Robot Loading Trajectory Planning

Robot loading trajectory planning refers to the method of robot loading trajectory generation in kinematics and dynamics [3]. When planning the loading trajectory, the problem of obstacle avoidance needs to be considered. Set n obstacle avoidance key points in the workspace according to work requirements. The robot is required not only to meet the position and speed requirements at the starting and ending points, but also to pass obstacle avoidance key points. Moreover, the trajectory is smooth and continuous, the sudden changes of speed and acceleration are unacceptable [4].

2.1. Fifth-Degree Polynomial Trajectory Planning of Loading Robot

In this model, the initial and ending angular displacement values of each joint are known, and the angular velocities of the head and end are both 0, and the acceleration is a fixed value. Substituting into equation (1), the fifth-order polynomial coefficient is shown as:

$$\theta(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3 + a_4 t^4 + a_5 t^5 \quad (1)$$

The fifth-degree polynomial spline trajectory planning is to express the trajectory with a fifth-degree polynomial containing 6 unknowns, and its trajectory function is:

$$\begin{cases} a_0 = \theta_0, a_1 = \dot{\theta}_0, a_2 = \frac{\ddot{\theta}_0}{2} \\ a_3 = \frac{20\theta_n - 20\theta_0 - (8\dot{\theta}_n + 12\dot{\theta}_0)t_n - (3\ddot{\theta}_0 - 2\ddot{\theta}_n){t_n}^2}{2{t_n}^3} \\ a_4 = \frac{30\theta_0 - 30\theta_n + (14\dot{\theta}_n + 16\dot{\theta}_0)t_n + (3\ddot{\theta}_0 - 2\ddot{\theta}_n){t_n}^2}{2{t_n}^4} \\ a_5 = \frac{12\theta_0 - 12\theta_n - (6\dot{\theta}_n + 6\dot{\theta}_0)t_n + (\ddot{\theta}_0 - \ddot{\theta}_n){t_n}^2}{2{t_n}^5} \end{cases} \quad (2)$$

Where, t_0 is the starting time, θ_0 is the initial angle value of the joint, t_n is the time to reach the position n, and θ_n is the angle value of the joint at the position *n*.

2.2. Cubic B-Spline Trajectory Planning for Loading Robot

In this model, the information of key points is obtained through discretization and kinematics solution. Afterwards, the smooth function is finally obtained by interpolation [5]. The expression of the cubic B-spline function is:

$$\mathrm{P}(t) = \sum_{i=0}^{3} d_i F_{i,3}(t) \quad (3)$$

$$(\mathrm{t} \in [0,1] \;\; d_i = i = 0,1,2,3)$$

Where,

$$\begin{cases} F_{0,3}(t) = 1/6(-t^3 + 3t^2 - 3t + 1) \\ F_{1,3}(t) = 1/6(3t^3 - 6t^2 + 4) \\ F_{2,3}(t) = 1/6(-3t^3 + 3t^2 + 3t + 1) \\ F_{3,3}(t) = \frac{1}{6}t^3 \end{cases} \quad (4)$$

Knowing that the trajectory speed and acceleration of the loading robot are continuous, and the trajectory starting point speed and ending speed are 0. Then, the control points of the cubic B-spline curve can be obtained.

$$\frac{1}{6}\begin{bmatrix} -3 & 0 & 3 & 0 & \cdots & 0 & 0 & 0 \\ 1 & 4 & 1 & 0 & 0 & \cdots & 0 & 0 \\ 0 & 1 & 4 & 1 & 0 & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & \cdots & 0 & 1 & 4 & 1 & 0 \\ 0 & 0 & 0 & \cdots & 0 & 1 & 4 & 1 \\ 0 & 0 & 0 & \cdots & 0 & -3 & 0 & 3 \end{bmatrix}\begin{bmatrix} p_0 \\ p_1 \\ p_2 \\ \vdots \\ p_{i-1} \\ p_i \\ p_{i+1} \end{bmatrix} = \begin{bmatrix} 0 \\ M_1 \\ M_2 \\ \vdots \\ M_{i-1} \\ M_i \\ 0 \end{bmatrix} \quad (5)$$

Where, $M_1, M_2 \cdots M_i$ are the middle key point of the joint trajectory, and $p_0, p_1 \cdots, p_i$ are the control point of the cubic B-spline trajectory. Substituting the control points into equation (3), the cubic B-spline curve is obtained:

$$P_i(t) = 1/6\begin{bmatrix} t^3 & t^2 & t & 1 \end{bmatrix}\begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix}\begin{bmatrix} p_{i-1} \\ p_i \\ p_{i+1} \\ p_{i+2} \end{bmatrix} \quad (6)$$

3. Simulation Verification

The operation of the loading robot is the robot transports the materials from the storage position to the loading position. The storage position is the starting point of the trajectory M1, and the loading position is the end point M5. In order to enable the end effector to effectively avoid obstacles, three key points are set in the middle of the trajectory [5], which is shown in Table 1 (M2, M3, M4).

Table 1. Joint variables of key points of the robot

Key points	T(s)	θ_1	θ_2	θ_3	θ_4	θ_5	θ_6
M_1	0	-0.880	-0.995	2.114	-1.119	0.691	1.571
M_2	1	-1.435	-1.334	2.669	-1.335	1.707	1.571
M_3	2	-2.374	-2.244	2.583	-0.339	0.768	0
M_4	3	-2.642	-1.931	2.259	-0.328	2.070	0
M_5	4	-2.867	-1.390	1.779	1.182	1.571	0.275

3.1. Fifth-Degree Polynomial Trajectory Planning Simulation

Substituting the key point joint variables in Table 1 into equation (2), setting the first and end angular accelerations as 0, the fifth-order polynomial trajectory function is solved, and the trajectory curves of the joint angles, angular velocities, and angular accelerations of the loading robot are obtained, which is shown in Figure 1-Figure 3.

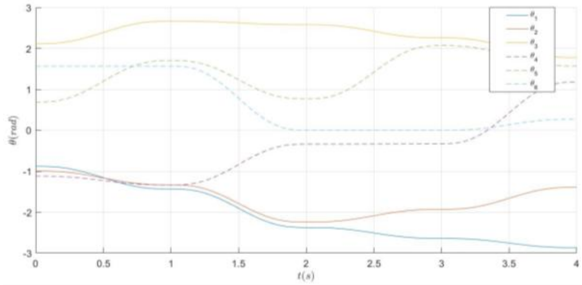

Figure 1. The changes of the angle of the end joint of the robot over time

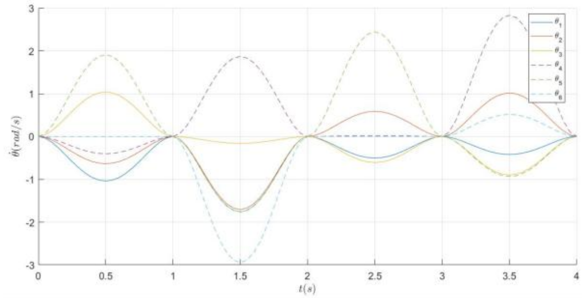

Figure 2. The changes of the angular velocity of robot end joint over time

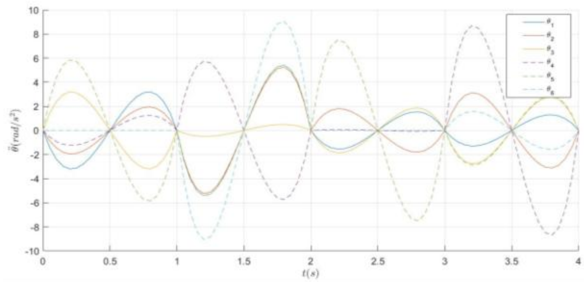

Figure 3. The changes of the angular acceleration of robot end joints over time

3.2. Cubic B-Spline Trajectory Planning Simulation

Substituting the angle value of the key points into equation (5), the control points of the cubic B-spline curve are solved. Substituting the angle of the end joint into equation (6), the cubic B-spline trajectory of the end joint is solved, and the trajectory curve of each joint angle, angular velocity, and angular acceleration of the robot is shown in Figure 4- Figure 6.

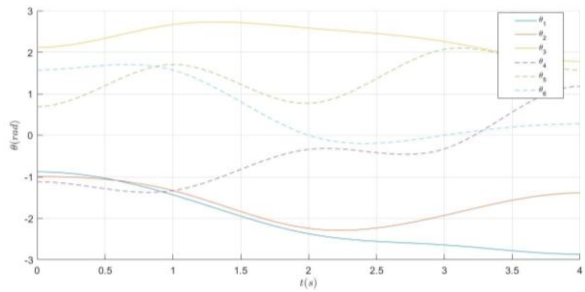

Figure 4. The angle-time relationship diagram of the robot end joint

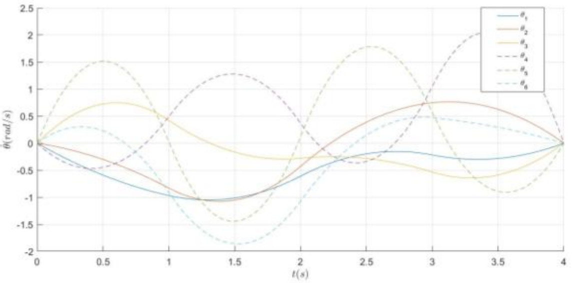

Figure 5. The relationship between angular velocity and time of robot end joint

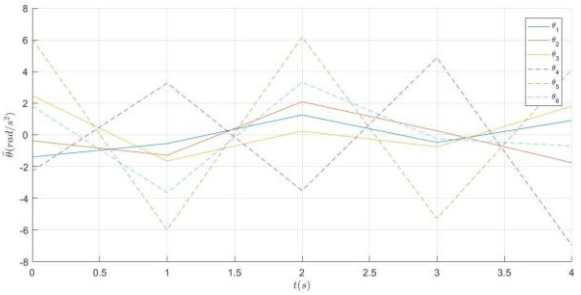

Figure 6. The relationship between angular acceleration of robot end joints and time

Figure 1 and Figure 4 shows the two trajectories of the end joints of the loading robot planned by the two models, respectively. They are both continuous and smooth. In the two results, all key points of obstacle avoidance have been passed as required, and there is no sudden position change. It can be seen from Figure 2 and Figure 5, that the two joint angular velocity curves also remain smooth and continuous, and there is no sudden change in speed. However in Figure 3 and Figure 6, although the angular acceleration of the fifth-order polynomial curve is continuous, the rate of change is not a constant value, indicating that the joint torque is changing over time. In addition, the impact on the joints at the obstacle avoidance point is also greater, which is difficult to achieve [6].

The angular acceleration of the joint in the trajectory curve obtained by the cubic B-spline method remains linear and continuous, indicating that the joint torque output is stable. Although the angular acceleration turns when the joint passes the key point, it has little effect on the joint trajectory.

In summary, for the simulation of the joint space trajectory of the loading robot, the cubic B-spline trajectory planning method not only meets the obstacle avoidance requirements of the loading robot, but also ensures its high-performance of motion function.

4. Summary

For the loading process of the loading robot, the five-degree polynomial interpolation method and the cubic B-spline interpolation method are used to plan the obstacle avoidance trajectory of the robot loading, and the joint motion trajectory is simulated. The joint angle, angular velocity and angular acceleration curves are obtained. The results show that the kinematics characteristics of cubic B-spline interpolation trajectory planning are good, the joint torque output is stable without sudden changes in speed and acceleration. The feasibility of automatic loading is verified, and technical support is provided for unmanned loading operations.

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