Research on trajectory planning of dual-arm cooperative robot

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Abstract. To meet the requirements of the market for complex and diverse operation tasks, the reasonable trajectory planning of the manipulator plays an important role in the completion of the task, which affects the motion accuracy and operation efficiency of the manipulator, the trajectory planning of the manipulator needs to meet the smooth change of motion parameters and no sudden change to ensure the smooth operation of the system. In this paper, the method of middle point interpolation is used to calculate and analyze the linear interpolation trajectory planning and arc interpolation trajectory planning of 7-DOF(degrees of freedom) redundant manipulator, and to realize the accurate trajectory planning of the end position of the dual-arm cooperative robot.

1. Introduction
Improving the level of intelligent manufacturing is the inevitable requirement of scientific and technological progress[1]. The cooperation of dual-arm greatly reduces the difficulty of operation and improves the feasibility of operation task. The coordination of both arms, not only to avoid external obstacles, but also to their own coordination anti-collision. Therefore, the spatial trajectory planning of dual-arm cooperative robot is of great significance and is the necessary guarantee to realize the safe operation of the system[2-4].

ZHANG J et al. proposed a trajectory planning based on position feedback[5]. WU T et al. proposed a trajectory planning method for error minimization based on least squares[6]. ZHU Y F et al. used the fifth B spline interpolation and the seventh polynomial interpolation to plan the trajectory of the 6-DOF manipulator, the results show that B spline interpolation has better adaptability to the trajectory planning of the manipulator[7]. ZHOU S simulated the different docking position of the end-effector, analyzed the fluctuation of the average acceleration of the end-effector, and obtained the position parameters under the optimal dynamic precision[8].

In this paper, the trajectory planning of dual-arm cooperative robot is studied. Firstly, the dual-arm D-H model is established in the MATLAB according to each joint parameter of the dual-arm cooperative robot. Secondly, the trajectory planning of the dual-arm cooperative robot is carried out in cartesian space to analyze the motion effect of the linear interpolation trajectory planning and arc
interpolation trajectory planning in the operation space, which provides a reliable kinematics planning for the coordinated motion of the dual-arm.

2. Establishment of dual-arm cooperative robot model
This section describes the position and coordinates of the robot, and designs a dual-arm cooperative robot model, which has a base, left arm and right arm, and the left arm and right arm contain seven degrees of freedom[9].

2.1. Basic Position Description and Coordinate Transformation for Kinematics Modeling
The establishment of the manipulator connecting rod coordinate system is shown in Fig. 1.

![Coordinate system parameters of the connecting rod of manipulator](image)

The length of the link \( a_n \) represents the distance measured along the \( x_n \) from the \( z_n \) to \( z_{n+1} \), \( \alpha_{n-1} \) represents the angle of rotation along the \( x_n \) from \( z_n \) to \( z_{n+1} \), \( d_n \) represents the distance along the \( z_n \) from the \( x_{n-1} \) to \( x_n \), the joint angle \( \theta_n \) represents the angle from \( x_{n-1} \) to \( x_n \) around the \( z_n \)[10-11], \( \theta_{min} \) is the minimum value of \( \theta_n \), \( \theta_{max} \) is the maximum value of \( \theta_n \), \( n=1,2,\ldots,7 \).

2.2. Establishment of motion D-H model of dual-arm cooperative robot
According to the joint model of human arm, the D-H parameters of the 7-DOF dual-arm cooperative robot with shoulder joint are designed as shown in Table 1.

| Left arm joint/i | \( \alpha_{i-1}/^\circ \) | \( a_i/mm \) | \( d_i/mm \) | \( \theta_{min}/^\circ \) | \( \theta_{max}/^\circ \) |
|------------------|-----------------|-----------|-----------|-----------------|-----------------|
| 1                | -90             | -185      | 0         | -120            | 120             |
| 2                | 90              | 113       | 0         | -45             | 150             |
| 3                | -90             | 109       | 0         | -180            | 180             |
| 4                | 90              | 75        | 0         | -90             | 90              |
| 5                | -90             | 105       | 0         | -180            | 180             |
| 6                | 90              | 71        | 0         | -120            | 120             |
| 7                | -90             | 32        | 0         | -180            | 180             |

| Right arm joint/j | \( \alpha_{j-1}/^\circ \) | \( a_j/mm \) | \( d_j/mm \) | \( \theta_{min}/^\circ \) | \( \theta_{max}/^\circ \) |
|-------------------|-----------------|-----------|-----------|-----------------|-----------------|
| 1                 | -90             | 185       | 0         | -120            | 120             |
| 2                 | 90              | 113       | 0         | -150            | 45              |
| 3                 | -90             | 109       | 0         | -180            | 180             |
| 4                 | 90              | 75        | 0         | -90             | 90              |
| 5                 | -90             | 105       | 0         | -180            | 180             |
| 6                 | 90              | 71        | 0         | -120            | 120             |
| 7                 | -90             | 32        | 0         | -180            | 180             |
The D-H parameter model is established in MATLAB according to the D-H parameters of dual-arm as shown in Fig. 2.

![Fig. 2. D-H parameter model of dual-arm cooperative robot](image)

The D-H parameter model of dual-arm in the MATLAB meets the requirements of the designed connecting rod model, which is the basis for calculating and verifying trajectory planning of dual-arm.

### 3. Trajectory planning of cartesian space of dual-arm cooperative robot

Cartesian space trajectory is more convenient to observe the trajectory of the end of the manipulator than the visualization of the joint space trajectory[12-14]. The inverse kinematics solution of the manipulator is needed, although the amount of computation is large, cartesian space trajectory planning has higher motion accuracy, adaptability and stability for the scene of manipulator operation task.

#### 3.1. linear interpolation trajectory planning

Firstly, the linear trajectory planning of cartesian space with 7-DOF left arm is calculated, \( P_a(x_a, y_a, z_a) \) is the initial position of the left arm, \( P_b(x_b, y_b, z_b) \) is the terminal position, If 30 points are interpolated between the starting and ending points, the linear trajectory of the left arm moving in space can be calculated as shown in Fig. 3. By using the same calculation method, the linear trajectory of the right arm moving in space can be calculated as shown in Fig. 4.

![Fig. 3. Linear trajectory of left arm](image)

![Fig. 4. Linear trajectory of right arm](image)

For the convenience of observing the linear motion space trajectory of the left arm and the right arm, the cartesian space linear trajectory planning trajectory of the left arm and the right arm is calculated and simulated at the same time in the MATLAB, which can be expressed Fig. 5.
From the cartesian spatial trajectory planning of the left arm and the right arm, it can be seen that in the process of moving from the starting point to the end point, the path interpolation points are evenly distributed, the arms are kept in a uniform linear motion, and the running trajectory is relatively stable.

3.2. arc interpolation trajectory planning

The three-dimensional problem of circular arc trajectory planning in cartesian space is transformed into two-dimensional plane problem to solve the calculation, constraints on X, Y, Z plane are established respectively, uniform interpolation motion is used.

Firstly, the arc trajectory planning of the left arm is carried out, and the non-collinear three points in the space are selected A₁, B₁, C₁ to solve the arc trajectory, and the number of steps is 40, the cartesian space arc trajectory planning of the left arm is obtained by interpolation of 52 intermediate points between the A₁ of the starting point and the C₁ of the termination point. Simulation in MATLAB is shown in Fig. 6. By using the same calculation method, the cartesian space arc trajectory planning of the right arm is shown in Fig. 7.

It can be seen from the cartesian space trajectory of the left arm and the right arm, the velocity remains unchanged, and the trajectory is relatively smooth and stable. In order to observe the moving trajectory of cartesian space arc simultaneously, the arc trajectory of dual-arm is displayed in the MATLAB about the D-H model as shown in Fig. 8.
From the cartesian space arc trajectory of the dual-arm in Fig. 8. The motion range of the dual-arm is reasonable, and the motion trajectory is smooth and stable, which verifies the rationality of the motion of the dual-arm in cartesian space.

4. Conclusions
In this paper, 7-DOF redundant dual-arm cooperative robot model with shoulder joint is established, and on this basis, the linear interpolation trajectory planning and arc interpolation trajectory planning of dual-arm are calculated. The result shows that the trajectory of dual-arm in cartesian space is smooth and stable, avoiding the singularity of 7-DOF redundant dual-arm trajectory planning, which as a basic research for the rapid motion of dual-arm cooperative robot.

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