Double-robot coordination workspace Analysis based on Matlab

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Abstract: Aiming at the requirements of dual robot collaborative operation, a dual robot cooperation system model is established in SolidWorks2012 software to study the dual robot cooperation space. The D-H parameters are established, and the kinematics positive solution equation is obtained. The dual robot cooperative kinematics model is given. Based on the Monte Carlo method, the workspace of the dual robot is solved. The extreme value theory method is used to analyze and calculate, so as to extract the precise boundary contour of the common area of the dual robot workspace, and the collaborative space boundary surface and limit position of the dual robot are determined. The optimal coordinated working space of the dual robot end effector is obtained, which lays a theoretical foundation for the coordinated trajectory planning of the dual robot.

1 Introduction

The research on the workspace problem of multi-robot collaborative work is one of the difficult problems in the research of multi-robot system [1]. Collaborative space is a common area that can be achieved by multiple robots (represented by dual robots). It is an important kinematic indicator for measuring the working ability of dual robots [2]. Comprehensive research literature at home and abroad has made little research on the collaborative space of dual robots, mostly focusing on single-industry robots, less degrees of freedom, and working spaces of parallel robots [3]. The research of collaborative workspace has a very important role in the design, path planning, collision avoidance research and optimal operation configuration of dual robots [4].

In this paper, Monte Carlo method is used. Monte Carlo is a numerical method for solving mathematical problems by means of random sampling. This method is easy to implement computer graphics display function, and the calculation speed is fast and the error and dimension are irrelevant [6]. The collaborative workspace of the dual robot collaborative operation system is analyzed [7].

2 Modeling of dual robot collaborative operation system

A two-robot collaborative system consisting of two six-degree-of-freedom industrial robots is the research object. The system model adopts the layout of the main robot 1 (left) and the slave robot 2 (right), and the distance between the two robots is 2L. The structural model of the dual robot collaborative operation system is shown in Figure 1.

3 Kinematics analysis of robots

3.1 Establishment of coordinate system and determination of D-H parameters

The description of the kinematics of the robot requires two coordinate systems [5]. One is the local coordinate system of a single robot. The coordinate system representing the main robot is O₁X₁Y₁Z₁, which represents the coordinate system of the slave robot is O₂X₂Y₂Z₂; the other is global. The coordinate system OXYZ, the local coordinate system of the master robot and the slave robot are symmetric about the global coordinate system. Figure 2 is the D-H coordinate system of the dual robot.
3.2 Kinematics positive solution

The kinematic positive solution is to determine the position of the end pose based on the value of the known joint variable. The homogeneous coordinate transformation between adjacent joints is sequentially performed by the formula (1), and the end effector is multiplied by the formula (2) to obtain the end effector coordinate. The link transformation matrix is:

\[
T_i = \begin{bmatrix}
    c_i & -s_i & 0 & a_i \\
    s_i & c_i & 0 & d_i \\
    0 & 0 & 1 & 0
\end{bmatrix}
\]

The relative coordinate system in the reference coordinate system:

\[
\begin{bmatrix}
    p_x \\
    p_y \\
    p_z
\end{bmatrix} = \begin{bmatrix}
    c_1(a_2c_3 + a_3c_2 - d_2s_2) - a_1s_1 \\
    s_1(a_2c_3 + a_3c_2 - d_2s_2) + a_1c_1 \\
    -a_2s_2 - a_3c_2 - d_3s_3
\end{bmatrix}
\]

(4)

As can be seen from (4), the position coordinates of the robot end effector are known in the case where the various parameters of the robot are known.

4 Solution and Simulation of Double Robot Collaboration Space

4.1 Derivation of Mathematical Model Equations for Dual Robot Cooperative Workspace

From the point set formula (5), the end trajectory workspace of a single robot in the local coordinate system can be obtained. The working space set of the main robot 1 is defined as p1, and the working space of the robot 2 is set to p2, and the working space in the local coordinate system is down-converted to the world coordinate system according to the formula (5), and the main robot 1 and the slave robot 2 are obtained. The working space equation in the world coordinate system is:

\[
p^1 = \begin{cases}
    x = f_1(\theta^1_1, \theta^1_2, \theta^1_3) \\
    y = f_1(\theta^1_1, \theta^1_2, \theta^1_3) \\
    z = f_1(\theta^1_1, \theta^1_2, \theta^1_3)
\end{cases}
\]

(6)

Similarly, the working space equation from Robot 2 is:

\[
p^2 = \begin{cases}
    x = f_2(\theta^2_1, \theta^2_2, \theta^2_3) \\
    y = f_2(\theta^2_1, \theta^2_2, \theta^2_3) \\
    z = f_2(\theta^2_1, \theta^2_2, \theta^2_3)
\end{cases}
\]

(7)

The simultaneous (6), (7) can establish the workspace set M of the common area of the dual robot cooperative welding system, that is as:

\[
M = \begin{cases}
    x = x^1 = x^2 \\
    y = y^1 = y^2 \\
    z = z^1 = z^2
\end{cases}
\]

(8)

4.2 Simulation analysis of dual robot collaborative space
The workspace cloud map is established according to Monte Carlo numerical analysis. First, in the Matlab environment, use the random joint variable:
\[ \theta_i = \theta_{i\text{ min}} + (\theta_{i\text{ max}} - \theta_{i\text{ min}}) \times \text{Rand}(N,1), i = 1 \ldots 3 \]

Discrete the joint angles of the two robots, then, according to the positive kinematics equation (4) and the intersection set of the two-robot cooperative space points (8), the spatial coordinate value of the end effector, that is, the workspace [8] is obtained. The superimposed area is a common area of the dual robot working space, that is, a collaborative space. As shown in Figure (3).

4.3 Drawing the boundary curve of the collaborative space and analyzing the numerical results

In order to obtain the boundary curve of the collaborative workspace [6], the boundary value curve of the collaborative workspace is extracted by the extreme value theory and the search region method [10]. The graph of the two-dimensional workspace is shown in Figure (4). The common area is the boundary outline of the collaborative workspace, as shown in Figure 5.

From the above solution method, the spatial region of the dual robot cooperative workspace and the key points of the extreme position and joint angle are solved based on the Matlab numerical solution method. The results are shown in Table 2 - Table 4.

| Extreme-position (mm) | \( \theta_1 \) (rad) | \( \theta_2 \) (rad) | \( \theta_3 \) (rad) |
|-----------------------|---------------------|---------------------|---------------------|
| \( X_{\text{max}} \)  | 1872.67              | -0.6786             | -0.4586             |
| \( X_{\text{min}} \)  | -1870.46             | -1.7753             | -0.0843             |
| \( Y_{\text{max}} \)  | 1880.29              | -1.0753             | -2.4059             |
| \( Y_{\text{min}} \)  | -1880.29             | 2.8471              | -2.9142             |
| \( Z_{\text{max}} \)  | 1880.38              | 0.0109              | -1.3511             |
| \( Z_{\text{min}} \)  | -1880.38             | 0.1097              | -1.6486             |

| Extreme-position (mm) | \( \theta_1 \) (rad) | \( \theta_2 \) (rad) | \( \theta_3 \) (rad) |
|-----------------------|---------------------|---------------------|---------------------|
| \( X_{\text{max}} \)  | 1872.67              | 0.6786              | -0.4586             |
| \( X_{\text{min}} \)  | -1870.46             | -1.7753             | -0.0843             |
| \( Y_{\text{max}} \)  | 1880.29              | -1.0753             | -2.4059             |
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| \( Z_{\text{max}} \)  | 1880.38              | 0.0109              | -1.3511             |
| \( Z_{\text{min}} \)  | -1880.38             | 0.1097              | -1.6486             |

Table 2. Single Robot Workspace Limit Position and Joint Variable Parameters

Table 3. Collaborative workspace limit position and master robot 1 joint variable parameters
Table 4. Collaborative workspace limit position and slave 2 joint variable parameters

| Extreme-position/mm | $\theta_2^2$/rad | $\theta_2^2$/rad | $\theta_2^2$/rad |
|---------------------|-----------------|-----------------|-----------------|
| X_{max}            | 2102.56         | 1.6466          | -1.8479         |
| X_{min}            | 900.872         | -0.8271         | 0.0521          |
| Y_{max}            | 1112.33         | 1.7758          | 0.4004          |
| Y_{min}            | -1112.33        | 0.5134          | -2.8906         |
| Z_{max}            | 1290.78         | 0.9147          | -0.5308         |
| Z_{min}            | 1290.78         | 0.8041          | -2.5421         |

5 Conclusion

In this paper, a two-robot kinematics model is established. The workspace is solved based on Monte Carlo method, and the collaborative space boundary curve is drawn by the extreme value search domain method. The common area shape of the dual robot cooperation space and the collaborative space in space are obtained. The limit position lays a theoretical foundation for the subsequent research on the coordinated path planning of the collaborative operation of the two robots, the optimization of the robot's mechanism parameters and the cooperative collision avoidance problem.

References

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