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Design and Analysis of a Three-DOF Assembly Robot

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Abstract. The paper designs a Three-DOF assembly robot based on the planar quadrilateral mechanism. It is mainly used for the handling and assembly of parts, featuring small size, low cost and simple transmission principle. The robot combined with the characteristics of the planar quadrilateral mechanism, a detailed kinematic analysis is carried out and the forward and inverse solutions are obtained. The paper use MATLAB to analyze its end working space and motion trajectory according to the constraint equation. Finally, the motion simulation is carried out using ADAMS, which verifies the effectiveness of the design and provides a theoretical basis for the kinematics research and structural optimization of the assembly robot.

1. Introduction

In the manufacturing industry, the assembly robot as a wide-ranging application of the device to get the attention of a growing number of researchers [1].Assembly robot on an assembly line is mainly used for handling and assembly of parts, and therefore requires a larger operating space, so most of the assembly in series of the robot mechanism, so that the robot can be guaranteed and a certain precision in continuous operation for a long time, while ensuring product quality Stability 。

With the increasing production efficiency of industrial automation, people have put forward higher requirements on the precision, speed and robustness of robot motion control[2].In this research, a parallelogram mechanism was used in the design of the manipulator, which has the characteristics of simple structure, large working space, and good performance[3], and due to its special geometric relationship, no more complicated coordinate transformation is required, which reduces Calculate the difficulty of robot kinematics.

In order to improve the dynamic performance of the parallelogram robots, efficiency and robustness in the design stage of its dynamic modeling, analysis, optimization and simulation, through the robot dynamics simulation can improve its design performance, reduce design costs and product Development cycle [4].

In this paper, a three-degree-of-freedom assembly robot based on a planar four-bar mechanism is designed, and its kinematics is analyzed and the forward and inverse solutions are obtained. It has the characteristics of small size, low cost and simple transmission. Analyze the working space and motion trajectory of its end by MATLAB according to the constraint equation. Finally, ADAMS was used to simulate to verify the effectiveness of the design and provide a theoretical basis for the kinematics research and structural optimization of the robot.

2. Described mechanical structure

As shown in Figure 1, it is a simplified structure diagram of a 3-DOF assembly robot mechanism. It is composed of a plane quadrilateral mechanism and a waist turning mechanism. The plane quadrilateral mechanism has two degrees of freedom, including 8 movable rods, 3 composite hinges, and 5 hinges. The mechanism is simple and flexible. The DC geared motor drives a driving rod respectively as the driving part of the parallel transmission structure. The driven rod is driven by the hinge structure to realize the up and down motion of the end effector. The last three rods are fixedly connected together and always move in parallel to ensure the stability of the entire working process.

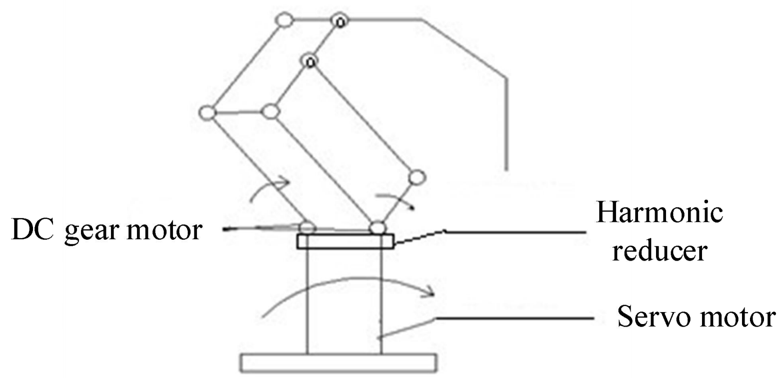


Figure 1. Schematic diagram of assembly robot structure

3. Robot kinematics analysis

Robot kinematics refers to establishing the relationship between the joint angle of each joint and the position and posture of the end effector by establishing a coordinate system for the robot[5]. In the research process of robot kinematics, it can be divided into two types of basic problems, forward kinematics and inverse kinematics of robots. Among them, the forward kinematics is to know the rod parameters and joint angles, and the position and posture of the end effector are solved through matrix transformation; inverse kinematics is the conditions for the known robot rod parameters and the position and posture of the end effector, through matrix transformation Solve the joint angle of each joint[6].

As shown in Figure 2, create a homogeneous coordinate system according to the right-hand rule, and derive the kinematics equations of the robot's planar quadrilateral mechanism. The schematic diagrams of the bars and joints and the final coordinate system are shown in Figure 3.

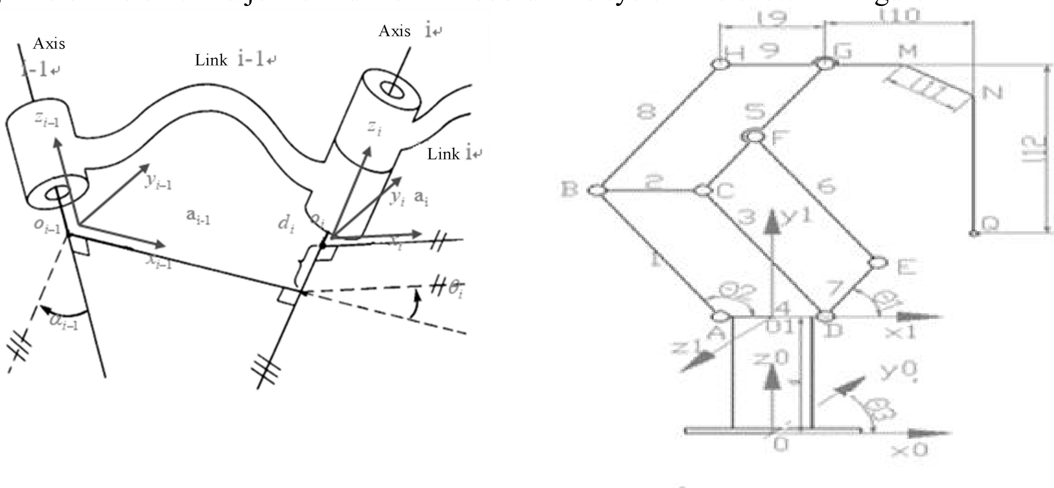


Figure 2. The establishment of homogeneous (left); The establishment of homogeneous (right)

Homogeneous coordinate matrix according to the relevant principles of "left to right" multiplied.

$$ {}^{i-1}_{i}T=\mathrm{Rot}(z_{i-1},\theta_i)\mathrm{Trans}(z_{i-1},d_i)\mathrm{Trans}(x_i,l_i)\mathrm{Rot}(x_i,\alpha_i) \quad (1) $$

Get the connecting rod transformation matrix ${}^{i-1}_{i}T$:

$$ {}^{i-1}_{i}T=\begin{bmatrix} cos\theta_i & -sin\theta_i cos\alpha_i & sin\theta_i sin\alpha_i & l_i cos\theta_i \\ sin\theta_i & cos\theta_i cos\alpha_i & -cos\theta_i sin\alpha_i & -l_i cos\alpha_i \\ 0 & sin\alpha_i & cos\alpha_i & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2) $$

Among : l_i — along x_i axis,the distance from the intersection of z_{i-1} axis and x_i axis to 0_i;

α_i — around the θ_i axis, the angle from z_{i-1} to z_i;

d_i — along the z_{i-1} axis, the distance from z_{i-1} axis and x_i to the origin of the 0_{i-1} coordinate system;

θ_i — around the z_{i-1}axis, the angle from z_{i-1} to x_i;

Bypass substitution parameters , l_i=0; α_i=90°; d_i= d; θ_i=θ_3

The pose transformation matrix ${}^0_1T$ between the base coordinate o-$x_0y_0z_0$ and the coordinate system o_1-$x_1y_1z_1$ is:

$$ {}^0_1T=\begin{bmatrix} cos\theta_3 & 0 & sin\theta_3 & 0 \\ sin\theta_3 & 0 & -cos\theta_3 & 0 \\ 0 & 1 & 0 & d \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (3) $$

The position of the end point in the coordinate system o1-x1y1z1 is:

$$ \begin{bmatrix} x_{Q1} \\ y_{Q1} \\ z_{Q1} \end{bmatrix}=\begin{bmatrix} l_3cos\theta_2 + l_5cos\theta_1 + 0.5l_4 + l_{10} \\ l_3sin\theta_2 + l_5sin\theta_1 - l_{12} \\ 0 \end{bmatrix} \quad (4) $$

The position matrix of the end point relative to the base coordinate system o-x0y0z0 (Positive solution):

$$ \begin{bmatrix} x_{Q0} \\ y_{Q0} \\ z_{Q0} \end{bmatrix}={}^0_1T * \begin{bmatrix} x_{Q1} \\ y_{Q1} \\ z_{Q1} \end{bmatrix}=\begin{bmatrix} cos\theta_3 * (l_3cos\theta_2 + l_5cos\theta_1 + 0.5l_4 + l_{10}) \\ sin\theta_3 * (l_3cos\theta_2 + l_5cos\theta_1 + 0.5l_4 + l_{10}) \\ l_3sin\theta_2 + l_5sin\theta_1 - l_{12} + d \end{bmatrix} \quad (5) $$

The equation can be solved θ_3、θ_1、θ_2 (Inverse solution) :

$$ \theta_3=arctan2(Y_{Q0}, X_{Q0}) \quad (6) $$

$$ \theta_1=\arctan\left(\frac{2Z-\sqrt{-(X^2+Z^2)*(X^2+Z^2-4)}}{X^2+2X+Z^2}\right) \quad (7) $$

$$ \theta_2=\arctan\left(\frac{2Z+\sqrt{-(X^2+Z^2)*(X^2+Z^2-4)}}{X^2+2X+Z^2}\right) \quad (8) $$

Among: $X=\frac{X_{Q0}}{Lcos\theta_3}-\frac{l_4}{2L}-\frac{l_{10}}{L}$; $Z=\frac{Z_{Q0}}{L}-\frac{l_{12}}{L}-\frac{d}{L}$; $L=l_3=l_5$;

Based on the previous forward and inverse kinematics, the linear mapping relationship between the linear velocity of the end effector and the joint angular velocity is studied. This relationship can be represented by the Jacobian matrix[7]. The Jacobian matrix of the manipulator, which is a partial derivative matrix, and its element in the i-th column and j-th row is:

$$ J_{ij}(q)=\frac{\partial X_i(q)}{\partial q_i} \quad (9) $$

Among: X − Generalized velocity of the end in the coordinate space

q − Joint torsion angular velocity

Find the derivation of both sides of equation (3) at the same time, that is, the Jacobian matrix:

$$ J=\begin{bmatrix} \dot{x_Q} \\ \dot{y_Q} \\ \dot{z_Q} \end{bmatrix}=\begin{bmatrix} -l_3cos\theta_3sin\theta_2 & -l_5cos\theta_3sin\theta_1 & P \\ -l_3sin\theta_3sin\theta_2 & -l_5cos\theta_3sin\theta_1 & Q \\ l_3cos\theta_2 & l_5cos\theta_1 & 0 \end{bmatrix}\begin{bmatrix} \dot{\theta_1} \\ \dot{\theta_2} \\ \dot{\theta_3} \end{bmatrix} \quad (10) $$

Among: $P=-sin\theta_3 * (0.5l_4 + l_3cos\theta_2 + l_5cos\theta_1 + l_{10})$

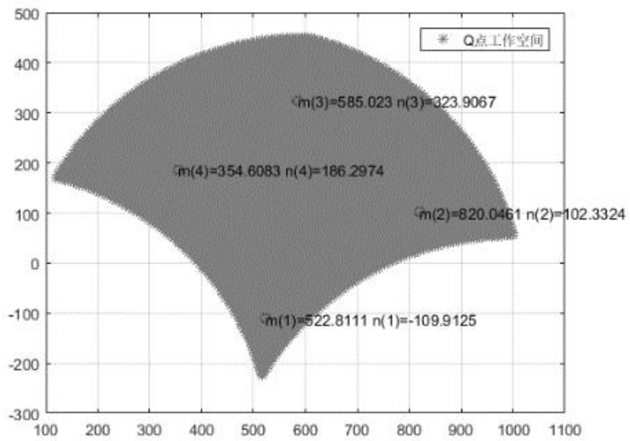
$Q=cos\theta_3 * (0.5l_4 + l_3cos\theta_2 + l_5cos\theta_1 + l_{10})$

$\dot{x_Q}\ \dot{y_Q}\ \dot{z_Q}$ − The projection of the velocity of the end point Q on each coordinate axis;

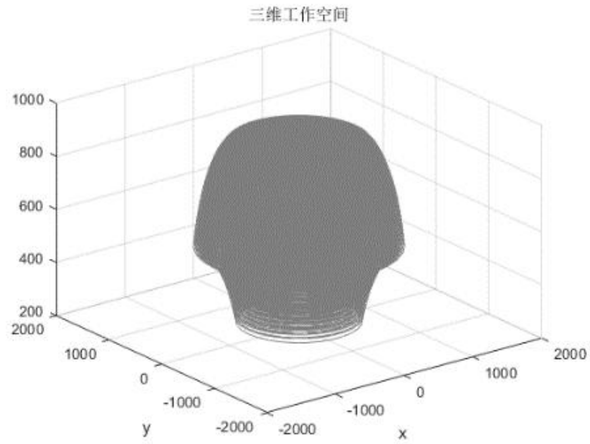
$\dot{\theta}_1\ \dot{\theta}_2\ \dot{\theta}_3$ – The angular velocity of the joint input variable.

4. Robot simulation analysis

The limit range that the robot mechanism can reach in the working process is restricted by conditions such as rod length and rotation angle [8]. Analyze the position of the mechanism in MATLAB, given the constraint range of the input corner, and then calculate the working space. The working plane and three-dimensional working space of the end effector are shown in Figure 3.



a.



b.

Figure 3. Working plane at the end of the actuator (a) ; Three-dimensional working space (b)

When creating a robot structural model, you first need to create various parts. Then by using the kinematic joint constraint library to constrain each component, determine the connection and positional relationship between the components. Finally, various loads are applied to the model to make it simulated according to the design requirements. Figure 4 shows the model diagram of the assembly robot in ADAMS.

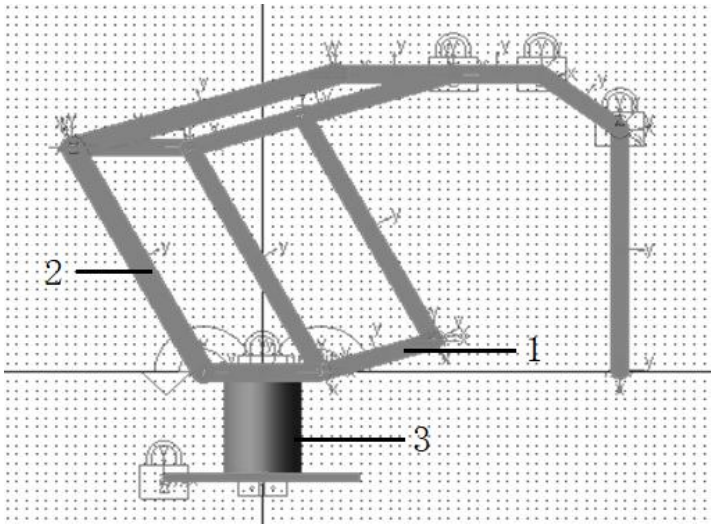


Figure 4. Model diagram of assembly robot in ADAMS

A motion simulation test was performed on the model in the above figure, and the effectiveness of the design scheme was verified by testing the performance of the system model. Then, by optimizing and adjusting the parameters, the results are further analyzed to obtain the motion law of the robot.

Figure 5-8 shows the measurement curve output after the robot motion simulation, including the velocity, angular velocity and angular acceleration curves, which proves that the planar quadrilateral mechanism is stable in motion and does not interfere with each other.

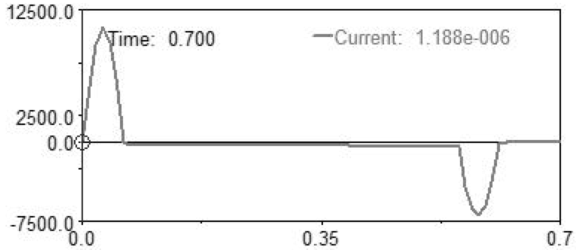


Figure 5. The speed curve of the end point Q with respect to the X axis

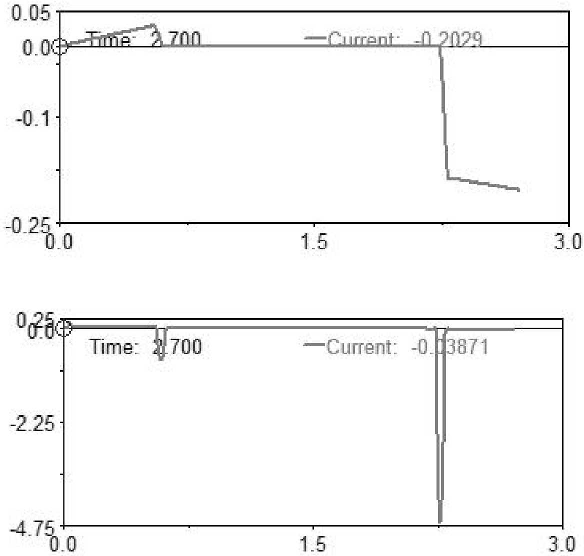


Figure 6. Angular velocity and angular acceleration curve of driving rod 1

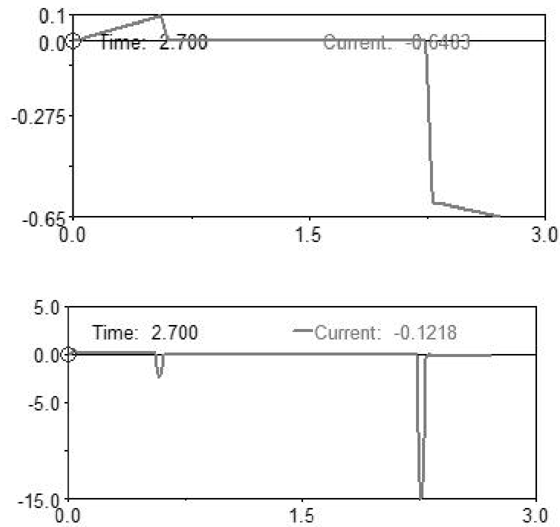


Figure 7. Angular velocity and angular acceleration curve of driving rod 2

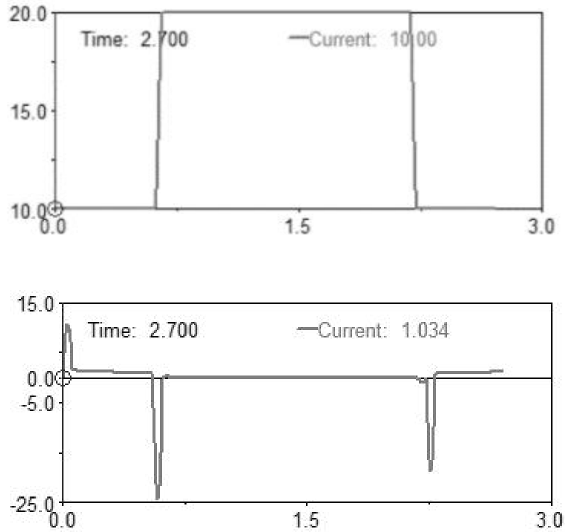


Figure 8. Angular velocity and angular acceleration curve of rotation position 3 (relative to the y axis)

Conclusion

This paper presents a relatively low cost, simple transmission principle, a wide range of applications 3 DOF assembly robot. Combining the characteristics of the planar quadrilateral mechanism, a detailed kinematic analysis is carried out and the forward and inverse solutions are obtained. Then analyzed using MATLAB workspace and its end trajectory according to the constraint equations. Finally, ADAMS is used to model and simulate the robot, and the experimental data and curves obtained from the simulation provide a theoretical basis for the kinematics research and structural optimization of the assembly robot.

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