A Kind of Parallel Robot Design

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Abstract

Parallel robot is widely used in many industrial fields such as food, medicine, electronics and so on. It has high rigidity, high precision and high load. They complement the current widely used series robots and greatly promote the development of industrial robots and industrial Productivity. In this paper, through the analysis of the structure of parallel robots, the kinematics and dynamics models was established. According to the operating range of the joystick, the closed-loop constraint equation of the robot is established and the kinematic inverse formula of the robot is solved. The relation between the three-dimensional coordinate of the crop space and the rotation angle of the three servo motors is obtained, which provides a theoretical basis for controlling the robot. The numerical solution of the positive solution verifies the correctness of the derivation of the inverse position.

Keywords

Robot, delta, kinematics.

1. Introduction

Parallel mechanism is a multi-channel closed-loop mechanism composed of two or more branches in parallel. Parallel robot is currently the most widely used parallel mechanism, first proposed by the professor in 1985. The main feature is that all branches can get the input of the driver at the same time. The movement of all the branches together determines the final output. Three-degree-of-freedom parallel robots are three groups of closed-loop rod group connected fixed platform and moving platform space agencies, the fixed platform and moving platform through three identical, 120° angle each other into the kinematic chain, Each kinematic chain has a parallelogram closed loop composed of four ball hinges and rod groups; one end of the driving arm is connected with the closed loop, one end of the parallelogram is connected with a fixed platform through rotating pairs; three parallelogram-shaped mechanisms ensure that the fixed platform and the movable platform The parallel robot always has the parallelism and eliminates the freedom of rotation of the moving platform and retains the three plane degrees of freedom of the space. The parallel robot can only couple the three plane degrees of freedom of the space due to the three branches, that is, Due to the freedom of rotation, the freedom of rotation in the Z direction must be obtained for the end effector to perform rotation and grasping. Therefore, it is proposed that the end effector be rotated by installing a motor-driven retractable shaft on a fixed platform.

2. Parallel Robot Design

2.1 Structure Design

According to the structure shown in Fig. 1, the virtual prototype model of the parallel robot is established by using the 3D software, as shown in Fig.2. Robot mainly by the fixed platform, moving platform, drive arm, driven arm, servo motor, harmonic reducer, ball hinge, spline shaft, cross joint and other components. One end of the driving arm is connected with the motor and the other end is hinged with the Hooke hinge through a thread; the telescopic shaft is respectively connected with a stepping motor fixed on a static platform and an end effector under a moving platform through a cross universal joint. The body consists of three sports branches, And evenly distributed on the static platform, each movement has an active arm and a closed loop, this closed loop is composed of the slave boom and four spherical hinge parallelogram closed structure, the structure of the ball through the hinge and active Arm and moving platform connection. The three groups of uniformly distributed parallelogram closed-loop structures ensure that the static platform and the movable platform can only maintain relative parallel motion, and eliminate the three rotational degrees of freedom of the movable platform and retain the translational freedom in the three directions of the movable platform.

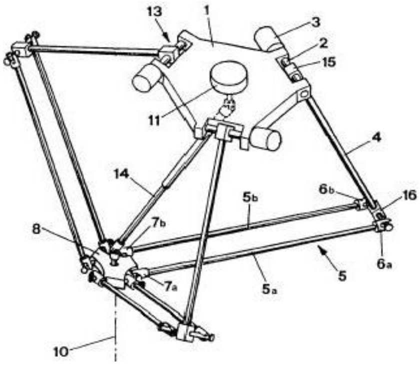

Fig. 1 Delta parallel robot

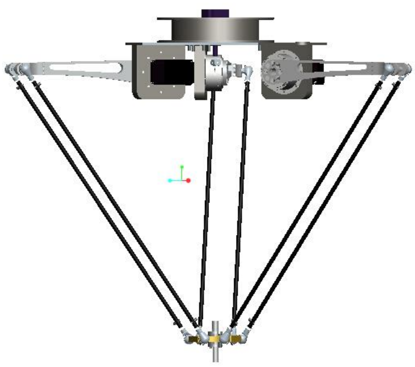

Fig. 2 Delta parallel robot 3D model

2.2 Kinematics analysis

Robot kinematics is the basis of robotics and describes the changes in the joints and end effectors during the movement of the robot. It involves two aspects: the robot is the kinematics and inverse kinematics. Robot positive kinematics is the known robot's link parameters and various joint variables, to solve the position and attitude of the robot end-effector; the inverse kinematics of the robot is the position and attitude of its end-effector, solving the robot's Each joint variable. Therefore, solving the positive and negative solution of the robot position is particularly important for controlling the robot motion and subsequent visual positioning and grasping. For the parallel mechanism, the kinematic inverse solution is relatively simpler than the positive solution. It is easy to get the analytic expression of the end effector position parameter relative to the driver input, but the positive solution is more difficult. For the complex structure, the analytic expression can not be obtained , Only the numerical solution can be obtained, and the numerical solution can be obtained by analyzing the parallel mechanism correctly.

2.2.1 Position inverse analysis

In order to solve the spatial relationship of mechanism, firstly, the mechanism was simplified and the virtual rod model was introduced. Three virtual links were introduced into the middle of the upper and lower sides of the three groups of parallelograms. For the three groups of closed-loop rod group, the quadrilateral frame in the three kinematic chains is a plane quadrangle because the moving platform has only three directions of translation freedom as shown in FIG.3. Under this condition, the motion of the virtual rod is exactly the same as that of the slave boom, so that the mechanism is simplified as shown in FIG.4 when performing inverse kinematics analysis of the robot.

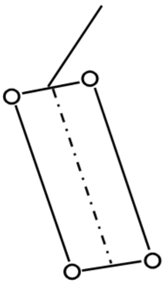

Fig. 3 The introduction of virtual branches

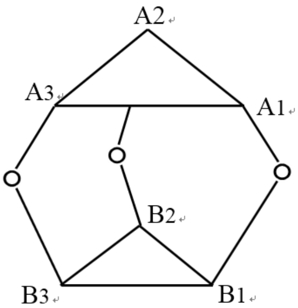

Fig.4 Simplified Delta mechanism

2.2.2 Analysis of the inverse solution

The robot connects the upper and lower platforms through three branch chains, the driving arm makes a certain angle of repeated swinging under the driving of the motor, and then makes the moving platform make a certain translational movement through the parallelogram closed-loop mechanism. The specific content of the inverse solution analysis is to give the coordinate value of the geometric center of the moving platform in the static coordinate system, and to solve three sets of motor rotation angles, that is, the motor's opening angle to the static platform. The inverse analysis of the robot provides a theoretical basis for the follow-up control robot to perform the picking and packing actions, which is a key step to solve the robot kinematics problem. Specific analysis is as follows:

The organization's single branch diagram is shown in Fig. 5. The static coordinate system $O-XYZ$ is established by using the geometric center of the static platform as the origin of coordinates, and the dynamic coordinate system $O^{'}-X^{'}Y^{'}Z^{'}$ is established by taking the geometric center of the movable platform as the origin. The radius of the static platform is R, the radius of the movable platform is r, the driving arm length is La, , The angle between the three driving arms relative to the X-axis direction of the static coordinate system is $\alpha_1,\alpha_2,\alpha_3$, and the opening angles relative to the static platform is $\theta_1,\theta_2,\theta_3$.

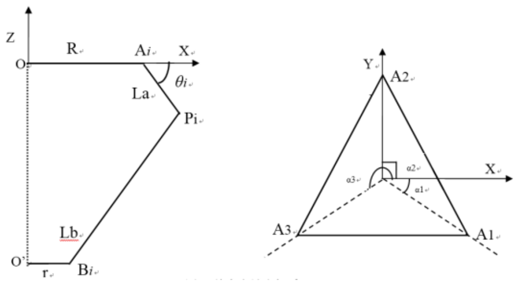

Fig.5 Single branched coordinate system

A is the position where the driving joint is located. In the static coordinate system, the vector OA can be expressed as:

$$\begin{Bmatrix} \cos\alpha_1 & \cos\alpha_2 & \cos\alpha_3 \\ \sin\alpha_1 & \sin\alpha_2 & \sin\alpha_3 \\ 0 & 0 & 0 \end{Bmatrix} \tag{1}$$

The vector AP of the driving arm can be expressed as:

$$\begin{Bmatrix} La\cos\theta_1\cos\alpha_1 & La\cos\theta_2\cos\alpha_2 & La\cos\theta_3\cos\alpha_3 \\ La\cos\theta_1\sin\alpha_1 & La\cos\theta_2\sin\alpha_2 & La\cos\theta_3\sin\alpha_3 \\ -La\sin\theta_1 & -La\sin\theta_2 & -La\sin\theta_3 \end{Bmatrix} \tag{2}$$

Therefore, the coordinates of the P point on the driving arm in the static coordinate system can be expressed as:

$$\overrightarrow{OP}=\overrightarrow{OA}+\overrightarrow{OP}= \begin{Bmatrix} \mathrm{R}\cos\alpha_1+La\cos\theta_1\cos\alpha_1 & \mathrm{R}\cos\alpha_2+La\cos\theta_2\cos\alpha_2 & \mathrm{R}\cos\alpha_3+La\cos\theta_3\cos\alpha_3 \\ R\sin\alpha_1+La\cos\theta_1\sin\alpha_1 & R\sin\alpha_2+La\cos\theta_2\sin\alpha_2 & R\sin\alpha_3+La\cos\theta_3\sin\alpha_3 \\ -La\sin\theta_1 & -La\sin\theta_2 & -La\sin\theta_3 \end{Bmatrix} \tag{3}$$

From the boom end point B in the active coordinate system $O^{'}$ can be expressed as

$$\overrightarrow{O'B}=r\times\begin{Bmatrix} \cos\alpha_1 & \cos\alpha_2 & \cos\alpha_3 \\ \sin\alpha_1 & \sin\alpha_2 & \sin\alpha_3 \\ 0 & 0 & 0 \end{Bmatrix} \tag{4}$$

Set the geometric center of the platform in the static coordinate system coordinates were R_X、R_y、R_z, the point B in the coordinate system O can be expressed as:

$$\overrightarrow{OB}=\overrightarrow{OO'}+\overrightarrow{O'B}= \begin{Bmatrix} R_x+\cos\alpha_1 & R_x+\cos\alpha_2 & R_x+\cos\alpha_3 \\ R_y+\sin\alpha_1 & R_y+\sin\alpha_2 & R_y+\sin\alpha_3 \\ R_z & R_z & R_z \end{Bmatrix} \tag{5}$$

Because of the boom length is certain, the model of PB is Lb:

$$\left\|\overrightarrow{OP}-\overrightarrow{OB}\right\|^2=Lb^2 \tag{6}$$

The simultaneous equations (3), (5), (6) have equations:

$$\begin{cases} Lb^2=(R_x+\cos\alpha_1-R\cos\alpha_1-La\cos\theta_1\cos\alpha_1)^2 \\ +(R_y+\sin\alpha_1-R\sin\alpha_1-La\cos\theta_1\sin\alpha_1)^2+(R_z+La\sin\theta_1)^2 \\ Lb^2=(R_x+\cos\alpha_2-R\cos\alpha_2-La\cos\theta_2\cos\alpha_2)^2 \\ +(R_y+\sin\alpha_2-R\sin\alpha_2-La\cos\theta_2\sin\alpha_2)^2+(R_z+La\sin\theta_2)^2 \\ Lb^2=(R_x+\cos\alpha_3-R\cos\alpha_3-La\cos\theta_3\cos\alpha_3)^2 \\ +(R_y+\sin\alpha_3-R\sin\alpha_3-La\cos\theta_3\sin\alpha_3)^2+(R_z+La\sin\theta_3)^2 \end{cases} \tag{7}$$

Simplify the equation:

$$I_i\cos\theta_i-J_i\sin\theta_i-K_i=0 \tag{8}$$

The angle of rotation of the driving arm can be obtained by multiplying the angle formula. The analytical expression of the coordinate of the geometric center of the moving platform (the singularity is eliminated if the discriminant is less than 0):

$$\theta_i=2\arctan\left(\frac{-J_i-\sqrt{J_i^{\,2}+I_i^{\,2}-K_i^{\,2}}}{K_i+I_i}\right) \tag{9}$$

(1) The Jacobian matrix of the robot

The linear transformation of the speed of the robot end and its joint speed is the Jacobian matrix of the robot, which can also be understood as the transmission ratio of the movement speed from the joint space to the operation space. For a parallel robot, the velocity relationship between the end effector and the joint can be expressed by equation (10)

$$x=J(\theta)\theta \tag{10}$$

Express (6) in matrix form:

$$\left\{\begin{matrix} R_x+\cos\alpha_1-R\cos\alpha_1-La\cos\theta_1\cos\alpha_1 & R_y+\sin\alpha_1-R\sin\alpha_1-La\cos\theta_1\sin\alpha_1 & R_z+La\sin\theta_1 \\ R_x+\cos\alpha_2-R\cos\alpha_2-La\cos\theta_2\cos\alpha_2 & R_y+\sin\alpha_2-R\sin\alpha_2-La\cos\theta_2\sin\alpha_2 & R_z+La\sin\theta_2 \\ R_x+\cos\alpha_3-R\cos\alpha_2-La\cos\theta_3\cos\alpha_3 & R_y+\sin\alpha_3-R\sin\alpha_3-La\cos\theta_3\sin\alpha_3 & R_z+La\sin\theta_3 \end{matrix}\right\}^2 = Lb^2 \quad (11)$$

The overall Jacobian matrix of the parallel mechanism is:

$$J = B^{-1}A = \begin{bmatrix} \frac{m_{11}}{n_{11}} & \frac{m_{12}}{n_{11}} & \frac{m_{13}}{n_{11}} \\ \frac{m_{21}}{n_{22}} & \frac{m_{22}}{n_{22}} & \frac{m_{23}}{n_{22}} \\ \frac{m_{31}}{n_{33}} & \frac{m_{32}}{n_{33}} & \frac{m_{33}}{n_{33}} \end{bmatrix} \quad (12)$$

3. Solution of singularity

When the robot's Jacobian matrix is 0, the Delta mechanism will have a singularity [5]. When any one of the matrix determinants in Equation 5-3-5 is equal to 0 or equal to 0 at the same time, the robot will have a strange shape . Therefore, referring to *Gosselin* et al.'s definition of singularity of parallel mechanism, the singularity is divided into three types: positive kinematics singularity, inverse kinematics singularity and combination singularity. When the matrix B is irreversible, the mechanism appears positive kinematic singularity; when the matrix A is irreversible, the mechanism appears inverse kinematics singularity; when the matrix A, B are irreversible at the same time, the mechanism will appear combination singular state.

(1) Positive kinematics singularity: When the body appears positive kinematics singularity, all the joints of the organization are dead, unable to exercise, but the end effector can still move, institutions have uncontrollable degree of freedom, for example, as shown in Figure 6 As shown.

(2) Inverse kinematics singularity: When an inverse kinematics problem occurs in an institution, the end effector of the institution can not move. The input of the driver does not determine the output of the institution, and the institution loses one or more degrees of freedom. For example, Show.

(3)Combination of singular: When the combination of strange institutions, the drive input does not determine the institutions throw the output throw. There will be the following two situations: First, the driver input is 0 end of the actuator can still do a small swing; Second, the driver has The input but the end effector can not move, ie the output changes to 0, as shown in Figure 9 for example.

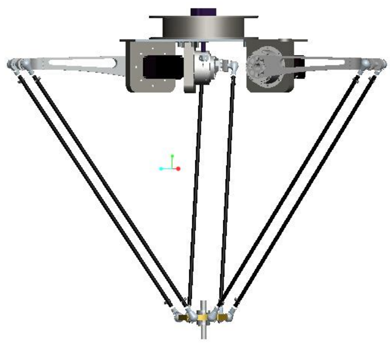

Fig.6 Non-singular, normal posture

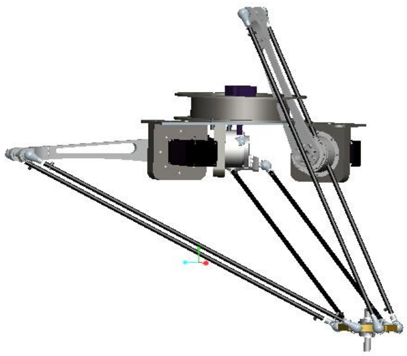

Fig.7 Kinematic singularity

Fig.8 Inverse kinematics singularity

Fig.9 Combination of strange

4. Conclusion

For the parallel mechanism, the kinematic inverse solution is relatively simpler than the positive solution. It is easy to get the analytic expression of the end effector position parameter relative to the driver input, but the positive solution is more difficult. For the complex structure, the analytic expression can not be obtained. Only the numerical solution can be obtained, and the numerical solution can be obtained by analyzing the parallel mechanism correctly.

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