MOTION TRAJECTORY PLANNING AND SIMULATION OF 6-DOF MANIPULATOR ARM ROBOT

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ABSTRACT: In order to better study the trajectory of robot motion, a motion trajectory planning and simulation based on 6-DOF manipulator arm robot is designed. Three and five polynomial methods are adopted to plan motion trajectories. The advantages and disadvantages of the three and five polynomial trajectory planning are summarized. The trajectory planning in the right angle space can make the robot arm work according to the prescribed movement path, and realize the continuous and controllable movement path. Thus, the study of six DOF robot arm and mobile robot has broad application fields. The experimental results show that the intelligent robot is the highest performance of mechatronics, and it continues to be active in the field of scientific and technological development. Based on the above finding, it is concluded that the five -polynomial trajectory planning can guarantee the continuous angular acceleration of the joint, make the steering gear run smoothly and reduce the mechanical wear of the motor.

KEY WORDS:6-DOF; manipulator arm robot; motion trajectory; planning; simulation

1 INTRODUCTION

Robotics is a discipline specializing in robotic engineering. In the rapid development and continuous innovation of the global computer technology, multi-sensor fusion technology, artificial intelligence technology and electronic technology, the development of robot technology is also in full swing. The mobile intelligent robot has the functions of path dynamic programming, environment interaction, decision-making, control behavior and so on. At the same time, multi-disciplinary research results show that the intelligent robot is the highest performance of mechatronics, and it continues to be active in the field of scientific and technological development [1].

Through the research of the mobile robot technology and the kinematics of the 6-DOF manipulator arm, the function and the advantage between the two are reasonably combined, and the ability of grasping the space object of the manipulator is brought into full play. The robotic arm runs autonomously to the desired area to grab the target. Therefore, a modular robot with six degrees of freedom is presented on the platform of autonomous mobile robot, which can make the robot have the function of autonomous movement and grasping operation [2]. The mobile robot using the scheme can perform the action of approaching the target, the arm extension, the clamping object, and the arm reset. In industrial production and indoor security, the robot car can accomplish the task of grasping and transporting. At the same time, it can also replace the manual to deal with dangerous things found in the room to ensure personal safety.

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The trajectory planning of robot arm is analyzed in this study. In the joint space, three polynomial and five polynomial functions are used to carry out arm trajectory planning, and the advantages and disadvantages between the two are analyzed. After that, the trajectory planning in the right angle space can make the robot arm work according to the fixed motion path, and realize the continuous and controllable movement path [3].

2 METHOD

This chapter mainly analyzes the trajectory planning problem of robot arm, and analyzes the problem of choosing different methods from one position to the other at the end of manipulator.

2.1 Overview of manipulator trajectory

As for the trajectory planning of robot arm, the joint angle of the manipulator is controlled by the control system. Thus, the end grab of the mechanical arm moves in accordance with a predetermined route, thereby ensuring that the robot arm completes the specified action in the working space smoothly [4]. By specifying a number of intermediate points in the trajectory, the degree of articulation of each set of points corresponding to each point in the joint space is represented [5]. At the same time, the kinematics equations of each point are established, and then the interpolation is performed by the kinematics equations of each joint. In this way, the trajectory planning of the robot arm can be achieved. Figure 1 is a schematic diagram of a robotic arm performing a task.

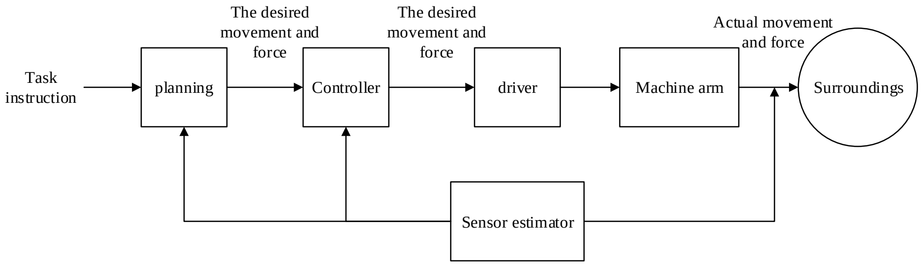

Fig. 1. Schematic diagram of manipulator control principle

2.2 Trajectory planning in joint coordinate space

A method for controlling the motion of the joints of a mechanical arm can be adopted for trajectory planning of the joint space of a robot arm. Therefore, the trajectory of each joint is very smooth, so that the whole movement of the robot arm can be stabilized, and the task of spatial operation can be completed steadily.

Usually, the trajectory planning of joint space contains the following two steps: First, each joint of the path is represented by a set of joint angles of the inverse kinematics [6]. Then, for a robot arm with 6 joints, 6 functions need to be built to ensure that each joint can smoothly pass through each point on the path, and finally reach the target position. In order to make each joint at the same time as the corresponding path, the motion time of each joint can be the same on the same path. Thus, the robot arm can operate at a predetermined path at each path point. At the same time, each joint is not directly related to the function constructed by other joints, but only specifies the time at which each joint run [7]. In addition, people will give the running time of each path in advance.

As shown in figure 2, the 3 curves represent 3 different trajectories of the same joint angle. The vertical axis represents the degree of joint angle Q (T), and the horizontal axis represents time t. The initial position is point A, and the termination position is point B. The robotic arm can move steadily to its desired position in accordance with the smooth trajectory 3. However, trajectory 1 and track 2 are running uneven, which will affect the stability of the robot arm. This trajectory is not conducive to the completion of the work of the robot arm. Therefore, we should ensure that the trajectory of each joint of the manipulator should be a smooth curve, in order to ensure the stability of the robot arm.

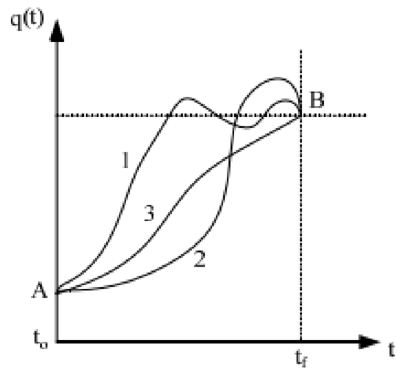

Fig. 2. Sketch map of 3 tracks of single joint

2.2.1 Trajectory planning of three polynomial functions

For manipulator, three function polynomial method is adopted for trajectory planning. The specific method is: when the initial position and posture of the robot arm are known, the 6 joint angles of the inverse kinematics of a set of manipulators are used to represent the ideal position of the robot arm at the target. It is possible to start with a single joint angle. At the initial moment t_i, the joint angle of the is θ_{t_i}, and at the moment t_f, the angle of the joint is θ_{t_f}. The end trajectory of the robot arm can be planned by matching the proper conditions with the end conditions and boundary conditions of the robot arm. The known condition is the angle θ_{t_i} of the end of the robot arm at the beginning of the movement and the angle θ_{t_f} at the end of the movement [8]. At the same time, the speed at which the end of the arm starts and the speed at which it ends is also known. The speed is usually 0 or a known value set by someone else. The angle of each point on the third-order polynomial trajectory is shown in table 1.

Table 1. The angles of each point on the three polynomial trajectory

Path point	Joint one (rad)	Joint two (rad)	Joint three (rad)	Joint four (rad)	Joint five (rad)	Joint six (rad)
A	1.1792	0	2.2581	-2.2639	2.2791	1.7831
B	1.0858	0	1.9965	-2.3713	2.2671	1.5841
C	0.6521	0	0.2471	-2.8613	2.3198	0.7831
D	0.3871	0	-0.8584	-pi	2.6413	0.1873

2.2.2 Trajectory planning of five polynomial functions

The starting point of the moving track at the end of the 6-DOF mechanical arm and the acceleration of the end point are specified in advance [9]. In the construction of the three polynomial, the boundary conditions of the starting point and the end joint, as well as the angular velocity, are added, so that there are 6 boundary conditions. In this way, the trajectory of the end of the robot arm can be planned by using the five polynomial method. In the five function polynomial interpolation method, the 6 joint angle data at each path point is shown in table 2:

Table 2. The angles of each point on the five polynomial trajectory

Path point	Joint one (rad)	Joint two (rad)	Joint three (rad)	Joint four (rad)	Joint five (rad)	Joint six (rad)
A	1.1791	0	2.2589	-2.2639	2.2791	1.7831
B	1.0848	0	1.9975	-2.3313	2.2671	1.5841
C	0.6521	0	0.2471	-2.8413	2.3198	0.7831
D	0.3881	0	-0.8574	-pi	2.6413	0.1873

2.2.3 Comparison of three and five polynomial trajectory planning

The first two sections take the trajectory planning of three and five polynomials for the manipulator, and it can be concluded that the less computation is an advantage of the trajectory planning of the three -polynomial function. The four coefficients of the function are obtained by solving the quaternary equations. Moreover, the curve of angle and angular velocity of each joint angle is smooth. But the boundary condition of the three- polynomial function does not take into account the angular acceleration, so it may cause problems in the smoothness of the angular acceleration of the joint. This will cause the motor of the drive joint to be unstable during operation. The five- order polynomial function takes into account the angular acceleration of the joint in the constraint condition, and the calculation amount will increase. It guarantees that the angle and angular velocity of each joint is smooth, and that the angular acceleration of the joint angle is also smooth. At the same time, it can also reduce the mechanical wear of the motor, and ensure the smooth operation of the motor.

2.3 Trajectory planning of cartesian coordinate space

In the previous section, the end of the mechanical arm is controlled from the space position A to the position B in the joint space. In fact, the kinematics of the manipulator is calculated by using the equations of the six joint angles at the position A, and then the six joint angles at the position B are calculated. The drive motor of the manipulator controls six joint angles into positions corresponding to B degrees. This allows the robotic arm to reach the B at the end. This description in the joint space only ensures that the robot arm moves to the B, but the motion between the A and the B is uncertain [10]. Therefore, this is a disadvantage in describing the trajectory of the joint coordinate space.

In order to control and determine the motion path at the end of the robot arm, the motion path at the end of the robot arm can be described in cartesian coordinates. On this basis, the joint is transformed into a description of the joint space, so that the path points at any time at the end are known. This trajectory planning method is called trajectory planning in cartesian coordinate space.

2.3.1 Introduction of spatial linear interpolation algorithm

The condition of spatial linear interpolation is to determine the initial and termination points of the spatial line. Then, the position information of the interpolation points in the middle of the trajectory is determined by solving the inverse kinematics of the manipulator. In general, since the mechanical arm moves in a straight line, the attitude of the robot arm remains the same. Therefore, there is no need to interpolate the attitude, and the attitude of the initial point remains unchanged. As shown in figure 3, the end of the robot arm moves from point $A(x_1, y_1, z_1)$ to point $B(x_2, y_2, z_2)$ in a linear manner.

Here, point A and point B are represented by three components of the axis relative to the reference coordinate system, and the linear speed at the end of the mechanical arm is set to v.

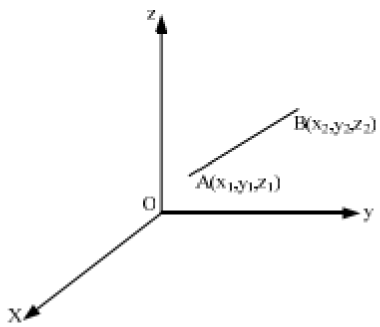

Fig. 3. Sketch of spatial linear interpolation

The distance between A and B is obtained by the space geometric formula:

$$L = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2}$$

The point A is represented as $A = x_1 i + y_1 i + z_1 k$, and the point B is represented as $B = x_2 i + y_2 i + z_2 k$. This path can be expressed in P_{BA}:

$$P_{BA} = B - A = (x_2 - x_1)\ i + (y_2 - y_1)\ j + (z_2 - z_1)\ k \qquad (2)$$

Therefore, P_{AB} is used to represent the unit direction vector:

$$P_{AB} = \frac{P_{BA}}{L}$$

After the rule, the position vector of the end of the robot arm can be represented at any time t., that is $P_t = A + P_{AB} vt$. It is assumed that t_s is the interpolation interval, and the total interpolation time is $T = L / v$. Therefore, the number of interpolation needed is N , and the calculation equation is $N = Ent(T / t_s) + 1$. In the expression, Ent represents the integer part of the result of the selection. Thus, the coordinate values of each interpolation point can be calculated, that is $i = 0, 1, 2, \ldots N$

$$\begin{cases} x_{i+1} = x_1 + i\Delta x \\ y_{i+1} = y_1 + i\Delta y \\ z_{i+1} = z_1 + i\Delta z \end{cases}$$

The coordinates of each interpolation point in the base coordinate system are obtained. By using the inverse kinematics of manipulator, 6 joint angles corresponding to each interpolation point can be obtained. In this way, the robot's arm controls the end of the robot arm in accordance with the planned path of motion by controlling the 6 joint angles. In this process, the inverse kinematics equations must be solved repeatedly to calculate joint angles.

2.3.2 Introduction of spatial arc interpolation algorithm

For the trajectory of the end of the robot arm, it is not enough to consider the trajectory of the straight line. Therefore, the arc interpolation algorithm can be used to plan the trajectory of the end. A space arc can be determined by three points that are not collinear in three-dimensional space. Usually, in the three-dimensional space, the plane arc is used to replace the spatial arc, so that the three-dimensional space problem can be transformed into the two-dimensional plane space. Then, the arc interpolation algorithm is converted into a plane, and finally the coordinate of the planned interpolation points is converted back to the coordinates in the three-dimensional space. Then the interpolation algorithm of the spatial arc is completed.

As shown in figure 4, the three points, such as A, B and C in the coordinate system, determine a space arc. There is a spatial arc in coordinates $O_0X_0Y_0Z_0$, and then the coordinate system $O_1X_1Y_1Z_1$ is established and connected to the arc ABC. Coordinate $O_1X_1Y_1Z_1$ is constructed according to the right-hand rule. In the coordinate $O_1X_1Y_1Z_1$, the axis coordinates of the Z correspond to 0 in the three coordinates of A, B and C in arc. At this point, the plane arc trajectory is interpolated in coordinate $O_1X_1Y_1Z_1$, and the trajectory planning can be carried out.

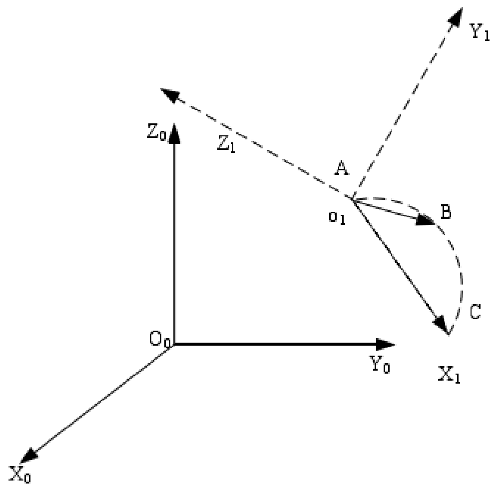

Fig. 4. The transformation of space arc and plane arc

3 RESULT AND DISCUSSION

3.1 Simulation of spatial linear interpolation

Trajectory simulation at the end of the robot arm is carried out. The position of the reference point of the initial point at the end of the arm is set to $A(0,1,1)$. The coordinates of the stop point position are $B(5,4,3)$, and N is 25. 24 middle points are inserted in this path. According to the spatial interpolation algorithm, the simulation results are shown in figure 5.

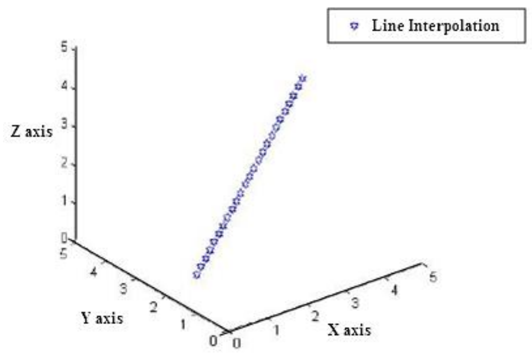

Fig. 5. Spatial linear interpolation graph

3.2 Simulation of spatial arc interpolation

The interpolation diagram of the space arc algorithm is shown in figure 6.

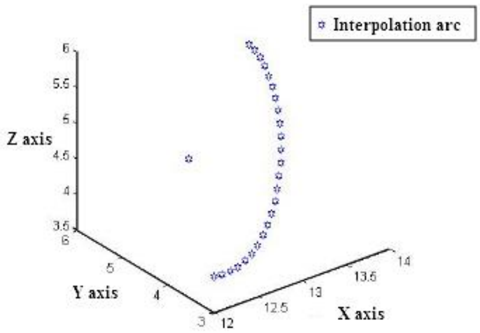

Fig. 6. Spatial arc interpolation diagram

As shown in figure 6, the position of the reference point of the initial point at the end of the arm is set to $A(12,3,4)$. The midpoint position coordinates are $B(13,5,6)$, and the termination point coordinates is $C(11,3,5)$. N takes 25, that is, 24 middle points are inserted in this path.

4 CONCLUSIONS

The motion planning of the manipulator is carried out by analyzing the trajectory planning problem of the manipulator and taking the cubic and quintic polynomials in the joint space. It is concluded that the relatively small amount of computation is an advantage of the cubic polynomial function trajectory planning. The advantage of the fifth-order polynomial function trajectory planning is to ensure that the angle, angular velocity and angular acceleration of each joint angle are smooth, thus effectively reducing the motor wear. Then, in the space system of cartesian coordinate system, the spatial straight line and the space circular interpolation algorithm are analyzed concretely. This makes up for the drawbacks of the intermediate path of the joint space trajectory planning. The control robot performs the task according to the path set in advance.

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