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Trajectory Tracking Control Algorithm of Six Degrees of Freedom Industrial Robot

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Abstract

Because the robot system has the characteristics of time-varying, strong coupling, and nonlinear system, the influence of many factors, such as load change, friction, interference and so on, is inevitable when the robot system is running in the industrial field. Therefore, the adaptive ability of the control system is required to be better. This paper discusses the pose description of robot and the transformation between coordinate systems. Under the condition of satisfying various constraints, the shortest running time is used as the optimization objective function to optimize the motion trajectory of six degrees of freedom Industrial Robot. The purpose is to minimize the running time of six degrees of freedom Industrial Robot under the conditions of point-to-point motion or along the given trajectory, and improve the working efficiency of the robot. The experimental results show that the trajectory tracking control method can meet the speed and acceleration constraints of the robot in Cartesian space and joint space at the same time, realize the overall motion smoothness of six degrees of freedom Industrial Robot, and maintain high motion efficiency.

Keywords: Six degrees of freedom; Six degrees of freedom Industrial Robot; Trajectory; Tracking control algorithm.

1. Introduction

Trajectory tracking control is a key technical module in the design of 6-DOF Industrial Robot, which focuses on the research of various trajectory tracking control algorithms to meet the diverse needs of users [1, 2]. At present, trajectory tracking control is mainly designed for three aspects: running time, energy optimization and stability. It is always the focus of research to find a reliable and stable algorithm to keep the motion of six degrees of freedom Industrial Robot smooth and stable, avoid the sudden change of speed and acceleration, and reduce the vibration and impact of the machine. It is also the basis and guarantee of other trajectory tracking control algorithms. Trajectory tracking control can be carried out in both joint space and Cartesian space [3]. The trajectory tracking control in joint space is easy to calculate, which can make the trajectory of robot joint smooth and continuous, and avoid the problem of robot singularity. Therefore, the trajectory tracking control in joint space can make the robot move smoothly and safely, but the disadvantage is that it is unable to control the robot end effector to move according to the expected trajectory. However, the trajectory tracking control based on Cartesian space can make the robot move according to the expected Cartesian coordinate system, which can clearly reflect the needs of users, and it is intuitive and clear. However, the disadvantage is that it needs to repeatedly carry out inverse kinematics to obtain the required joint information and then transmit it to the robot controller. Due to the nonlinear structure of six degrees of freedom Industrial Robot, it is difficult to judge the joint space variables when tracking the trajectory in Cartesian space. Therefore, it is possible that the joint motion exceeds the upper limit of velocity or acceleration when the end effector satisfies the Cartesian space motion constraint [4]. To solve the above problems, this paper optimized the structure of six degrees of freedom Industrial Robot and used the actuator with high load capacity and speed to reduce friction resistance. However, from the perspective of trajectory tracking control, the current common method used by Industrial Robots is to limit the speed and acceleration of the end effector according to the actual situation, so as not to cause vibration and other undesirable phenomena of the robot joint movement because of the excessive speed and acceleration of the end effector.

A joint space trajectory optimization algorithm which can avoid singularity in the process of robot motion is designed and studied by You et al. [5]. Using the redundancy of a joint's function during a six-degree of freedom robot's task, the joint limitation and singularity of the robot are taken as constraints, and the time weighted average (TWA) method is used to optimize the calculation. The time optimal trajectory tracking control algorithm was first proposed by using the position velocity phase diagram [6]. Its central idea is to use the joint angle position on the path as the abscissa parameter to describe the dynamic equation of the Industrial Robot.

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The dynamic programming algorithm is introduced by Campeau-Lecours et al. [7]. However, the trajectory tracking control algorithm introduced before ignores the change of driving torque when establishing the dynamic mathematical model. Therefore, the produced trajectory will have discontinuous joint torque and acceleration, which will lead to bad effect. Therefore, this paper proposes the research on motion trajectory tracking control algorithm of six degree of freedom Industrial Robot. Firstly, the position and pose of the robot and the transformation between the coordinate systems are described. Under the constraint conditions, taking the shortest running time as the optimization objective function, the motion trajectory of the 6-DOF Industrial Robot was optimized, so as to improve the working efficiency of the robot. The results show that the trajectory tracking control method can achieve the overall motion smoothness of six degrees of freedom Industrial Robot, and can maintain high motion efficiency.

2. Kinematics and Dynamics Analysis of Six Degrees of Freedom Industrial Robot

The kinematics of six degrees of freedom Industrial Robot mainly studies the way and nature of the robot's motion process, neglecting the external forces. In the kinematics of six degrees of freedom Industrial Robot, the calculations involved are the mathematical factors associated with the mode of motion [8]. So the kinematics research of the six degrees of freedom Industrial Robot includes all the time and geometric parameters related to the motion [9]. In the field of robot dynamics, the effect and influence of environmental dynamic factors and human dynamic factors on robot motion are studied.

2.1. Pose description

The position and attitude of the end-effector in the base coordinate system are described to represent the working attitude of the 6-DOF Industrial Robot. Therefore, it is necessary to customize the uniform standard to describe the posture and posture in the robot space, including work actuator and machining parts.

(1) Location description

By measuring the three-dimensional coordinate component of a location point in the base coordinate system, a position vector in the form of 3×1 describing the point can be obtained [10]. The motion space of six degrees of freedom industrial robots is very complex, so multiple coordinate systems are established to analyze and discuss the motion between the robot and the parts. In order to clearly represent the coordinate system of a part or a position point, the reference coordinate system is marked in the left front of the position vector to be represented. For example, P_A, which indicates that the value of P_A is represented by the distance along the axis $\{A\}$.

$$P_A = \begin{Bmatrix} P_x \\ P_y \\ P_z \end{Bmatrix} \tag{1}$$

where the elements of the vector are indicated by subscripts x, y, z, and a position vector is used to describe the position of the midpoint in space.

(2) Attitude description

In practical engineering applications, it is often necessary not only to represent the points in space, but also to describe the attitude of objects in space. As shown in Figure 1, vector X_A directly determines a certain point between the operating actuators. Only when the attitude of the actuator is known can the position of the actuator be fully determined [11]. In order to describe the pose of an object, a coordinate system can be fixed on the object and its representation relative to the reference system is given.

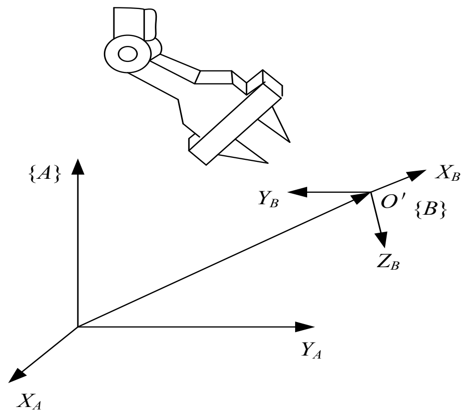

Figure 1. Pose of terminal actuator of Industrial Robot with six degrees of freedom

In Figure 1, the known coordinate system a $\{B\}$ is fixed to the end effector of six degrees of freedom Industrial Robot in some way. $\{B\}$ relative to the description in $\{A\}$ is enough to represent the attitude of the end of six degrees of freedom Industrial Robot. $\hat{X}_B$, $\hat{Y}_B$ and $\{B\}$ are used to represent the unit vector of the axis direction of coordinate system $\{B\}$ in coordinate system $\{A\}$. The three unit vectors are arranged in order into a 3×3 matrix, which is called rotation matrix. Since this special rotation matrix is the expression of $\{B\}$ relative to $\{A\}$, it is represented by the symbol R_B^A.

$$R_B^A = [X_B, Y_B, Z_B] = \begin{bmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{bmatrix} \tag{2}$$

(3) Combination of position and attitude

After getting the position and attitude of the terminal actuator of six degrees of freedom Industrial Robot. They can be combined in what is called a pose. In the kinematics of six degrees of freedom Industrial Robot mechanism, the position and attitude usually change together, so the position and attitude can be combined into a mathematical variable, which is recorded as the pose. R_B^A and P_{BORG}^A are used to describe the pose of coordinate system $\{B\}$ in coordinate system $\{A\}$.

$$\{B\} = \{R_B^A, P_{BORG}^A\} \tag{3}$$

where P_{BORG}^A is the position vector determining the origin of the coordinate system $\{B\}$.

2.2. Transformation of coordinates

In the application of six degrees of freedom Industrial Robots, it is often necessary to describe the same part in different operating space. So the same quantity can be described in different space by the transformation between coordinate systems.

(1) Translation transformation of coordinate system

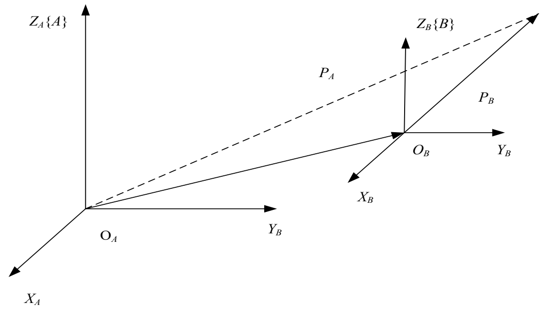

Figure 2. Translation transformation

As shown in Figure 2, it is a translation of the coordinate system. The 3D vector P_B refers to the position of P point in coordinate system $\{B\}$. If the coordinate system $\{A\}$ and $\{B\}$ have the same attitude, in this case, $\{B\}$ can obtain $\{A\}$ by translation. If $\{A\}$ coordinate system is needed to describe the space point, the position of the origin of coordinate system $\{B\}$ in $\{A\}$ can be expressed by vector P^A_{BORG} .Since the two vectors have the same attitude in the same space, we can use the offset plus the,position of P in the coordinate system $\{B\}$ to obtain P_A :

$$P_A' = P_B + P^A_{BORG} \tag{4}$$

(2) Rotary transformation of coordinates

As shown in Figure 3, the rotation transformation of the coordinate system is realized by a 3×3 rotation matrix formed by three unit vectors arranged together. If this matrix refers to the description of $\{B\}$ relative to $\{A\}$, represented by the symbol R^A_B , then there is:

$$P_A'' = R^A_B \times P_B \tag{5}$$

By Equation (5), the description F of P_B point in space relative to $\{B\}$ is transformed into the description P_A of the point relative to $\{A\}$.

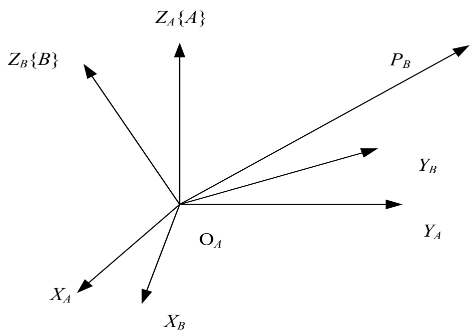

Figure 3. Rotation transformation

(3) Complex transformation of coordinates

As can be seen from Figure 4, the composite transformation graph is usually a transformation from one coordinate system to another, which requires translation and rotation. The origin of coordinate system $\{B\}$ and coordinate system $\{A\}$ do not coincide, there is a vector offset. The vector determining the origin of $\{B\}$ is represented by P^A_{BORG} , and the rotation of $\{B\}$ relative to $\{A\}$ is described by R^A_B . Given P_B , in order to find $\hat{P}_A$, first transform P_B into an intermediate coordinate system, which has the same attitude as $\{A\}$, and the origin coincides with the origin of $\{B\}$. Then the origin is translated by vector addition.

$$\hat{P}_A = R^A_B \times P_B + P^A_{BORG} \tag{6}$$

where $\hat{P}_A$ represents the composite transformation of a vector description from one coordinate system to another. A new concept is derived from Equation (6):

$$\tilde{P}_A = T^A_B \times P_B \tag{7}$$

In Equation (7), P_B is a homogeneous representation of four-dimensional vector, and T^A_B is a 4×4 -form homogeneous transformation matrix:

$$T^A_B = \begin{bmatrix} R^A_B & P^A_{BORG} \\ 000 & 1 \end{bmatrix} \tag{8}$$

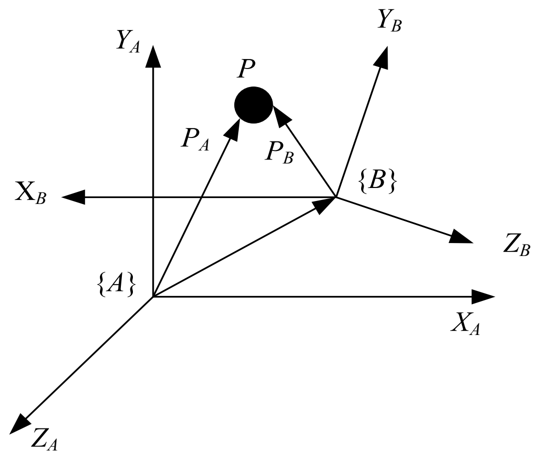

Figure 4. Composite transformation

3. General Trajectory Tracking Control Algorithm for Industrial Robots with Six Degrees of Freedom

In Cartesian space, it can also be done in joint space, but the trajectory curve functions must be continuous and smooth so that the end effector can move smoothly without large fluctuations [12, 13]. Trajectory tracking control in right angle space refers to the function that the position, attitude, velocity and acceleration of the terminal actuator are expressed as time, while that in joint space refers to the function that the angle of the joint is expressed as time, and it constrains its angular velocity, angular acceleration, force and torque.

Rectangular coordinate space trajectory tracking control in the workspace coordinate system, tracking control results are very intuitive, can clearly observe the end of the movement of the trajectory. However, the cartesian space trajectory requires a large amount of calculation, so it is necessary to ensure the accuracy of the trajectory by fast calculation speed. In addition, it is not guaranteed that there is no singular point, and the singular point can not be tracked. Under certain circumstances, the linear path in joint space is easy to realize, but the linear path in Cartesian space is impossible to realize. In addition, the motion between two points may cause a mutation in the joint value of six degrees of freedom Industrial Robot [14]. In order to solve the above problems, six degrees of freedom Industrial Robot can be specified to pass through the intermediate points to avoid these singular points. Due to the problems mentioned above, most current six degrees of freedom trajectory tracking controllers can generate trajectory in both joint space and right angle space. Users usually apply the joint space tracking control method, and only apply the cartesian coordinate space tracking control when necessary.

3.1. Joint space trajectory tracking control

For trajectory tracking control in joint space, it is necessary to determine the arm pose of the Industrial Robot at the starting point and the ending point. When interpolating joints, a series of constraints should be satisfied. Under all constraints, different types of joint interpolation functions can be selected to generate different trajectories.

Now we consider the general problem that the terminal actuator of six degrees of freedom Industrial Robot moves from initial position to target position in a certain time. First of all, we need to use the inverse kinematics calculation to solve the joint position of a group of initial and final positions [15, 16]. Therefore, a smooth function $q(t)$ of joint angle can be used to describe the trajectory of the end effector. The value of $q(t)$ at time $t=0$ is the initial joint angle q_0, and the value of t_f at the terminal time is the terminal joint angle q_f. Obviously, there are many smooth functions satisfying this condition, and the cubic spline interpolation diagram is shown in Figure 5.

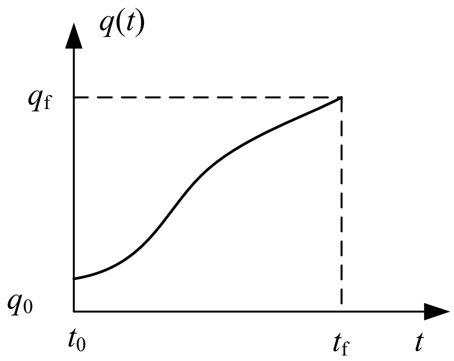

Figure 5. Cubic spline interpolation diagram

In order to ensure the smooth operation of the joint, the trajectory function $q(t)$ of each joint should meet at least four constraints: two end point position constraint and two end point velocity constraint.

The end position constraint contains the joint angles given by the start pose value and the end pose value respectively. The value of $q(t)$ at time $t_0=0$ is equal to the angle q_0 of the starting joint, and the value of t_f at the terminal time is equal to the angle q_f of the terminal joint, i.e.:

$$\begin{cases} q(0)=q_0 \\ q(t_f)=q_f \end{cases} \tag{9}$$

In order to meet the requirement of continuous joint velocity, the joint angular velocity at the starting and ending points can be simply set to zero:

$$\begin{cases} \dot{q}(0)=q_0 \\ \dot{q}(t_f)=q_f \end{cases} \tag{10}$$

A cubic polynomial can be uniquely determined by the above four constraints:

$$q(t)=a_0+a_1t+a_2t^2+a_3t^3 \tag{11}$$

3.2. Cartesian space trajectory tracking control

3.2.1. Linear trajectory tracking control

The trajectory tracking control of a straight line is to calculate the position and attitude of the middle point (interpolation point) on the trajectory of a straight line by knowing the position and attitude of the first and last points of the line, and to use the linear function of parabolic transition, which means to add a parabolic buffer curve segment within the neighborhood of two points when linear interpolation is used between the positions and attitudes of two points [17]. Because the second derivative of the parabola is a constant, that is, the acceleration is constant in the corresponding curve segment, the trajectory can be smoothly transferred, and the displacement and velocity can be continuous on the whole trajectory curve. A function consisting of two parabolic curves and a linear function connected smoothly is defined as a linear function transitioning to a parabolic curve. In order to design the trajectory curve, the same constant acceleration value is used in the transition line of the two parabolas, but the positive and negative values are opposite. The normalized factor can be solved in the following way.

Let the velocity of the straight line segment on the linear function of the parabola transition be v and the acceleration of the parabolic segment be a. Then the motion time and displacement of the parabolic line segment are:

$$T_b=\frac{v}{a} \tag{12}$$

$$L_b=\frac{1}{2}aT_b^2 \tag{13}$$

The total displacement and time of the linear motion are as follows:

$$L=\sqrt{(x_2-x_1)^2+(y_2-y_1)^2+(z_2-z_1)^2} \tag{14}$$

$$T=2T_b+\frac{L-2L_b}{v} \tag{15}$$

It is assumed that the linear segment velocity of the linear function of parabolic transition is v, and the acceleration of parabolic segment is a, rather than the total time of a given motion. The main consideration is that all six degrees of freedom Industrial robots have motion speed and acceleration constraints, and different six degrees of freedom Industrial robots have different constraint conditions, so velocity and acceleration are taken as input variables.

3.2.2. Trajectory tracking control of spatial arcs

In order to control the trajectory of circular arc in Cartesian space, it is necessary to use the coordinate system transformation, that is, to establish a new rectangular coordinate system on the plane where the circular arc is located, and obtain the values of the circular interpolation points in the new coordinate system, then to map these values back to the old coordinate system and find out the values of the interpolation points in the old coordinate system, and the displacement curve of circular interpolation also adopts linear function of parabola transition.

Three points can uniquely determine an arc. Suppose that the end effector of six degrees of freedom Industrial Robot passes through the intermediate point P_1 from the starting position P_2 to the terminal point P_2, if these three points are not collinear, there must be an arc from the starting point P_1 through the middle point P_2 to the end point P_3. This paper introduces the solving steps of arc trajectory tracking control.

The center $P_0(x_0, y_0, z_0)$ of the circle and the three points r, $P_1(x_1, y_1, z_1)$, $P_2(x_2, y_2, z_2)$ and $P_3(x_3, y_3, z_3)$ are calculated to determine the unique plane M, whose equation can be expressed as:

$$M = \begin{vmatrix} x - x_3 & y - y_3 & z - z_3 \\ x_1 - x_3 & y_1 - y_3 & z_1 - z_3 \\ x_2 - x_3 & y_2 - y_3 & z_2 - z_3 \end{vmatrix} \tag{16}$$

The equation of plane T passing through the midpoint of P_1 and P_2 and perpendicular to P_1 and P_2 is as follows:

$$T = \left[x - \frac{1}{2}(x_1 + x_2)\right](x_2 - x_1) + \left[y - \frac{1}{2}(y_1 + y_2)\right](y_2 - y_1) + \left[z - \frac{1}{2}(z_1 + z_2)\right](z_2 - z_1) \tag{17}$$

The equation of plane S passing through the midpoint of P_2 and P_3 and perpendicular to P_2 and P_3 is as follows:

$$S = \left[x - \frac{1}{2}(x_3 + x_2)\right](x_3 - x_1) + \left[y - \frac{1}{2}(y_3 + y_2)\right](y_3 - y_2) + \left[z - \frac{1}{2}(z_3 + z_2)\right](z_3 - z_2) \tag{18}$$

Combined with the three plane equations M, T and S, the elimination method can be used to solve the center $P_0(x_0, y_0, z_0)$ of the circle. However, attention should be paid to the situation when the denominator is zero in the process of elimination. Then the radius can be obtained as follows:

$$r = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2} \tag{19}$$

Based on the above results, the interpolation points on the arc can be obtained. The three attitude angles of each interpolation point can be calculated respectively according to the linear function of the parabolic transition of displacement curves. The joint angle of each interpolation point can be obtained by inverse kinematics solution of the position and pose of each interpolation point.

Trajectory tracking control in joint space and Cartesian space are discussed. Linear Trajectory tracking control and arc Trajectory tracking control are discussed in Cartesian space. The trajectory tracking control algorithm of space line and arc is the most basic and mature algorithm, which has been widely used in the six degrees of freedom Industrial Robots. But it is necessary to determine the velocity function according to the specific requirements, that is, to determine the normalized factor in the algorithm, and the normalized factor is a linear function with a parabolic transition.

4. Experimental Analysis

4.1. Parameter setting

In view of the fact that there is no specific dynamic parameters of the actuator, and the amount of dynamic calculation is huge, the error influence is more, and it is inconvenient to observe and analyze, so the moment constraint is not considered here, and the constraint conditions are simplified. The former three joints are taken as examples. In order to compare the data and prove the optimization of the algorithm, the set parameters can be selected according to the simulation results of trapezoidal acceleration and deceleration trajectory tracking control. According to the results of Cartesian trajectory tracking control by trapezoidal acceleration and deceleration of robot, it can be seen that the maximum velocity of the first to the third joint is about 0.4 rad/s, 0.1 rad/s, 0.25 rad/s, and the maximum acceleration is about 0.3 rad/s^2, 0.1 rad/s^2 and 0.2 rad/s^2 respectively. The six values are used as the constraints of the first three joints of the multi constraint trajectory tracking control algorithm. Given that the maximum acceleration and maximum velocity of the end effector in Cartesian coordinate system are V_{max}=0.25 m/s, A_{max}=0.25 m/s^2, and the error factor is g_p=0.0025 m, g_v=0.01 m/s. The starting and ending conditions of trajectory are P_0 = (0.5963, -0.1500, -0.0144) and P_1 = (0.3963, 0.3500, -0.0144), and the velocities of both start and end points are zero, and the interpolation period of trajectory tracking control is 0.1 s. The complete parameters are shown in Table 1.

Table 1 Simulation parameters table

Parameter name	Parameter value
Initial position	(0.5963, -0.1500, -0.0144)
Terminal position	(0.3963, 0.3500, -0.0144)
Initial joint velocity	$\dot{q}_t(t_0) = 0, i = 1, 2, ..., 6$
End joint velocity	$\dot{q}_t(t_f) = 0, i = 1, 2, ..., 6$
End effector speed and acceleration constraints	$V_{max} = 0.25$ m/s, $A_{max} = 0.25$ m/s
Joint velocity and acceleration constraints	$\dot{q}_{max} = (0.4$ rad/s, 0.1 rad/s, 0.25 rad/s$)$ $\dot{q}_{max} = (0.3$ rad/s, 0.1 rad/s, 0.2 rad/s$)$

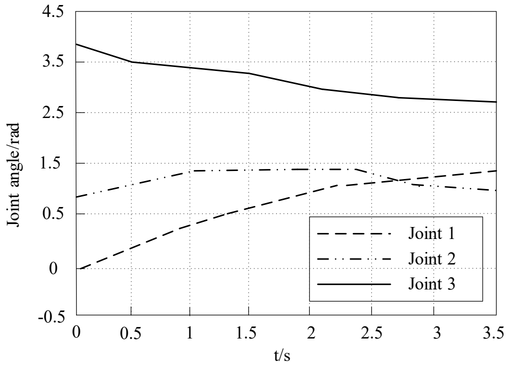

Figure 6. Joint angle

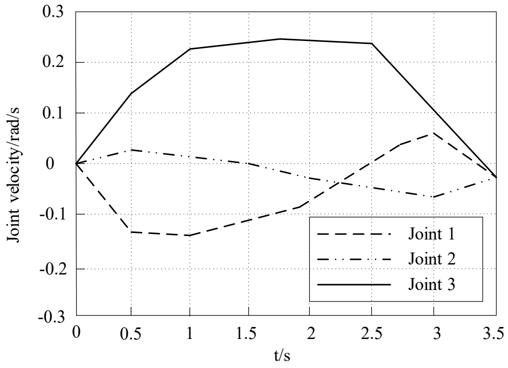

Figure 7. Joint velocity

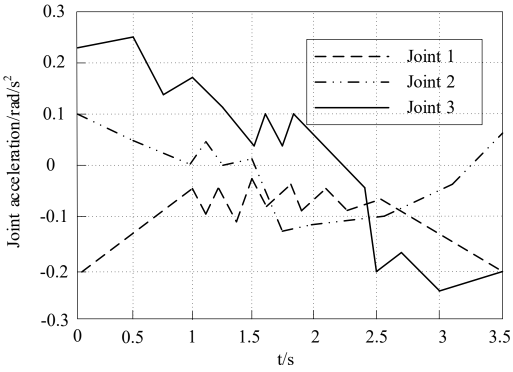

Figure 8. Joint acceleration

Figure 6 to Figure 8 are the curves of the first three joint angles of six degrees of freedom Industrial Robot. It can be seen from Figure 6 that the changes of the angles of the three joints are smooth and continuous during the whole movement period, and there is no sudden change. This is because the upper limit of joint velocity and acceleration is restricted in the trajectory tracking control algorithm. As shown in Figure 7 and Figure 8 are the curves of joint velocity and acceleration in the process of trajectory tracking control. It can be seen from the curve that the velocity and acceleration of the three joints are within the upper limit of the constraint from beginning to end, and the velocities and accelerations of these three joints are very close to their upper limits in some different periods of time, which is due to the nonlinear structure of six degrees of freedom Industrial Robot. The reason is that the time of acceleration or deceleration of each joint is different. Compared with the trapezoidal acceleration and deceleration algorithm with the same joint velocity and acceleration constraints, the Simulation results show that the 6-DOF Industrial Robot has shorter movement time.

In order to further verify the effectiveness of the trajectory tracking control algorithm for six degrees of freedom Industrial Robot, a simulation example is added to analyze and verify the algorithm. The initial position was taken as P_0 = (0.5963, -0.1500, -0.0144), and the end position was taken as P_2 = (4.7556, 0.6000, -2.5728). Except for the joint constraints, other parameters are consistent with the above simulation examples. Firstly, the trapezoidal acceleration and deceleration algorithm is used to track the trajectory of six degrees of freedom Industrial Robot in Cartesian space from P_0 to P_2, and the whole motion process is still maintained for 60 seconds. Figure 9, Figure 10 and Figure 11 show the angles, angular velocities and angular acceleration curves of joint 1, joint 2 and joint 3 respectively.

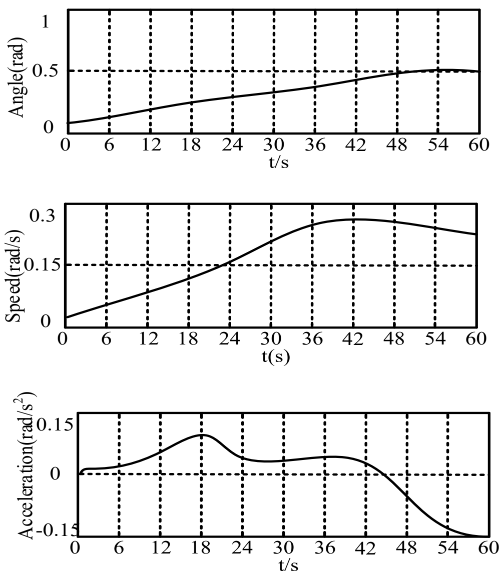

Figure 9. Joint 1 locus

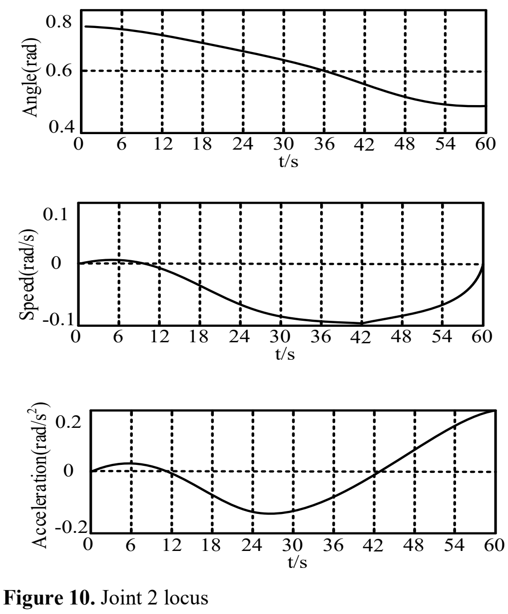

Figure 10. Joint 2 locus

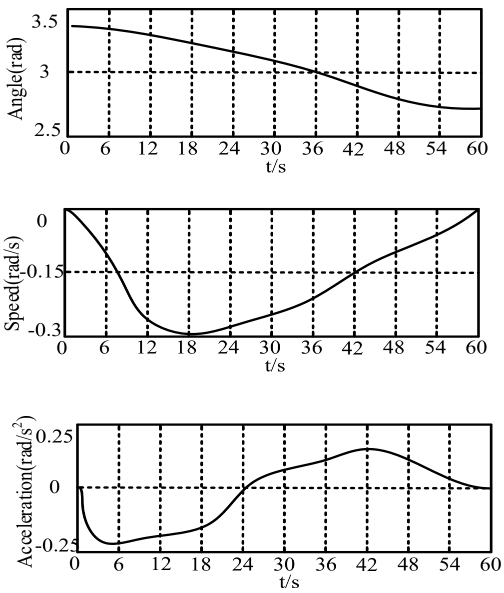

Figure 11. Joint 3 locus

As can be seen from Figures 9-11, the maximum angular velocity and acceleration of joint 1 are about 0.27 rad/s and 0.19 rad/s^2, respectively. The angular velocity increases with time and then tends to be stable, and the acceleration reaches the maximum value at 18 s. Joint 2 was about 0.18 rad/s and 0.2 rad/s^2, both of which decreased first and then increased. The joint angular velocity reached the maximum value of 0.28 rad/s at 18 s, and the acceleration dropped to the maximum value of 0.24 rad/s^2 at 42 s.

Compared with Cartesian space trajectory tracking control algorithm without joint velocity and acceleration constraints, this trajectory tracking control algorithm has the advantage of smooth and safe motion. Because the motor load capacity is limited, its speed, driving torque has an upper limit value, too high load may make the motor vibration or even damage the motor. The joint of six degrees of freedom Industrial Robot is driven directly or indirectly by motor, so the motion of joint is limited by motor. At the same time, this algorithm can make the six degrees of freedom Industrial Robots optimize the motion time as much as possible within the range of satisfying constraints, instead of sacrificing efficiency. Its multi-constraint characteristics are also limited, and the motion of six degrees of freedom Industrial Robots is always limited within these constraints. This trajectory tracking control method can be used in the situation that the six degrees of freedom Industrial Robot is required to work smoothly and at the same time has certain requirements for the motion speed of the robot.

5. Conclusion and Prospect

5.1. Conclusion

Point-to-point control only needs to control the accuracy and time of the starting point and the ending point, so most Industrial Robots can realize point-to-point control, such as spot welding, handling and assembling robots. Continuous trajectory control requires not only the accuracy and time of the start and end points, but also the time and position of each trajectory point, such as spraying and arc welding robot. However, most six degrees of freedom Industrial Robots are limited by their structure and control program, and can only follow a simple continuous trajectory. Their flexibility and intelligence are still deficient, and their trajectories are not smooth enough.

In the actual production of six degrees of freedom Industrial Robot, people pay more attention to its efficiency and precision. This paper studies the kinematics and dynamics of Industrial Robots. The description of robot pose, the transformation between coordinate systems and the linkage mechanism are discussed. Several trajectory tracking control methods are analyzed and discussed in view of the different working environment and smoothness of six degrees of freedom Industrial Robots. The experimental results show that the trajectory tracking control method can satisfy the requirements of velocity and acceleration constraints in Cartesian space and joint space, and achieve the smoothness of the whole robot, and maintain a high efficiency.

5.2. Prospects

In this paper, the kinematics and dynamics analysis and trajectory tracking control of six degrees of freedom Industrial Robot are carried out in an ideal environment, without considering the influence of the external environment and the friction, stiffness and other dynamic factors of six degrees of freedom Industrial Robot. And only in theory and program analysis and Simulation of robot trajectory tracking control, not in the actual robot verification, so the experimental verification can be used as a further research content.

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