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Kinematics Control and Analysis of Industrial Robot

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Abstract. The robot's development present situation, basic principle and control system are introduced briefly. Research is mainly focused on the study of the robot's kinematics and motion control. The structural analysis of a planar articulated robot (SCARA) robot is presented,the coordinate system is established to obtain the position and orientation matrix of the end effector,a method of robot kinematics analysis based on homogeneous transformation method is proposed, and the kinematics solution of the robot is obtained.Establishment of industrial robot's kinematics equation and formula for positive kinematics by example. Finally,the kinematic analysis of this robot was verified by examples.It provides a basis for structural design and motion control.It has active significance to promote the motion control of industrial robot.

1. Introduction

The robot is the most typical electromechanical integrated digital equipment with high added value and wide range of applications. As an emerging industry of information society and supporting technology, advanced manufacturing will play a more and more important role in the future production and social development [1].In recent years, the robot industry has maintained a rapid growth trend. Robot's manufacturing demand market potential, and usher in an excellent opportunity for development of Chinese robot automation industry. Chinese industrial robot market developed rapidly, accounting for about 1/3 of the global market share, is the world's largest industrial robot application market.

It pays a great attention to the research of robot technology in the national high technology research and development plan, the National Natural Science Foundation and the national science and technology special program in china. It has a great expectations for the future development of robot technology in the industry at home and abroad. Thus, the technology of robot is one of the foundations for the development of high-tech and emerging industries in the future. It is of great significance to the national economy and national defense construction[2].

2. The basic working principle of industrial robot

Industrial robot is a kind of production equipment, whose basic function is to provide the movement and power required by homework. The basic working principle is that the movement function and technical requirements of the hand operation can be realized automatically through the movement of each moving component on the operating machine. Therefore, in the basic function and working principle, the industrial robot and the machine tool have the same place:the end effector of the two has the position change requirement, and the position change requirement of the end effector is realized by coordinate motion. Of course, the robot also has its unique requirements, mainly in the form of joint movement. At the same time, the flexibility of the robot is required to be high, and its stiffness and precision is required to be low.

3. Motion control system of industrial robot

Motion control system is one of the key components to determine the performance of industrial robots. The core technology of improving the characteristics of motion control system and enterprise competitiveness. Therefore, it is of great significance to study a motion control system which is stable, efficient and suitable for industrial robot operation. [3]

The motion control system of industrial robot , which includes program interpreter, motion interpolator, servo driver and some other auxiliary modules, is composed. The motion interpolator is equivalent to the part of the human brain intelligence, motion control command which receives the user program instruction interpreter output, and according to the requirements of the directive with technology, careful planning position or trajectory parameters, to drive the server. For limited space, it studys kinematics and motion control of industrial robot in the following Words.[4]

4. kinematics and motion control of industrial robot

4.1 The kinematics

It studys the time history of the position, velocity and acceleration for the kinematics of industrial robot. At present, the industrial robot which has the six degree of freedom(SDOF) is widely used in the equipment manufacturing industry, and the modeling of the kinematics of the six degree of freedom robot has been more mature.But the robot's running, trajectory planning, and the dynamics of the robot is determined by the robot kinematics modeling[5]. Therefore, it is very important to establish kinematic model which is a simple solution method for robot system. Therefore, it is very important to establish and solve a simple kinematic model for robot system. The solution method is simple kinematic model.[6,7]

4.1.1 Robot's kinematics equation. The coordinate system is established according to the robot connecting rod, and the relative relation between the coordinate systems is described by the homogeneous transformation equation. This homogeneous transformation matrix is usually called the A matrix.[8]

If the matrix A_1 is used to represent the homogeneous transformation of the first link coordinate system with respect to the fixed coordinate system, the pose is T_1

$$T_1 = A_1 \cdot T_0 \tag{1}$$

Formula: T_0 is the homogeneous matrix expression of the fixed coordinate system,

$$T_0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

If the matrix A_2 represents the homogeneous transformation of the second link coordinate systems with respect to the first link coordinate system, then the pose T_2 can be represented by the product of A_1 and A_2, and the A_2 should be multiplied by right

$$T_2 = A_1 \cdot A_2 \tag{3}$$

Similarly, if the matrix A_3 represents the homogeneous transformation of the third link coordinate systems with respect to the second link coordinate systems, there is:

$$T_3 = A_1 \cdot A_2 \cdot A_3 \tag{4}$$

In this way, the following T_6 matrices:

$$T_6 = A_1 \cdot A_2 \cdot A_3 \cdot A_4 \cdot A_5 \cdot A_6 \tag{5}$$

This formula represents a multiplicative transform matrix between the right hand coordinate system from the fixed reference frame of the connecting rod coordinate system, T_6 said the hand coordinate system with respect to a fixed reference position, we call type (5) for the kinematics equation of the robot. Formula (5) the result of calculation T_6 is a following (4 * 4) matrix:

$$T_6 = \begin{Bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{Bmatrix} \quad (6)$$

In the formula, the first three columns represent the gesture of the hand, and the fourth column indicates the position of the hand.

4.1.2 positive kinematics. The positive kinematics mainly solves the problem of the establishment of robot kinematics equation and the solution of the hand position and pose.[9] The following are the methods of establishing the robot kinematics equation and two examples.

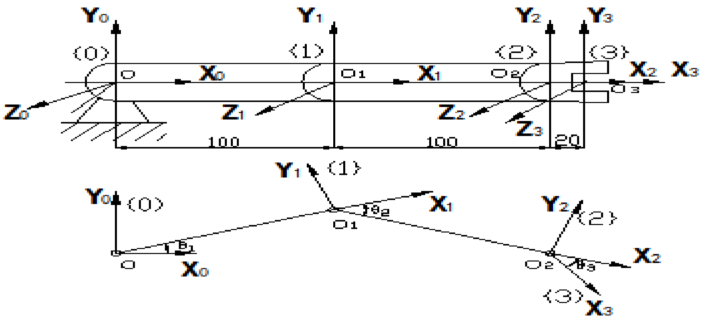

Figure 1. Planar articulated robot (SCARA)

As shown, a planar joint robot (SCARA), {0},{1},{2} and {3}respectively represents a shoulder joint, an elbow joint, and a wrist joint[10]. The center of the circle is O, O_1, $O_2$and O_3. The corresponding coordinate system is XYZ, $X_1Y_1Z_1$, $X_2Y_2Z_2$ and $X_3Y_3Z_3$.The mechanical structure of such robots is that the axes of the three joints are parallel to each other.The coordinate system (o) and the connecting rod 1, the connecting rod 2 and the connecting rod 3 are respectively located at the joint 1, the joint 2, the joint 3 and the hand center.The D in the linkage parameter is the variable, and the other parameter J is the root. All constants. Considering that the axis of the joint is parallel and that the connecting rods are all in one plane, the parameters of the planar joint robot (SCARA) robot link are shown in Table 1.

Table 1. Connecting rod parameters of planar articulated robot (SCARA).

connecting rod	angle （variables）θ	Distance between two connecting rods d	connecting rod length a	Torsion angle of connecting rod α
connecting rod 1	θ_1	d_1=0	a_1=l_1=100	α_1=0
connecting rod 2	θ2	d_2=0	a_2=l_2=100	α2=0
connecting rod 3	θ3	d_3=0	a_3=l_3=20	α3=0

The kinematics equations of the planar joint robot are:

$$T_3 = A_1 \cdot A_2 \cdot A_3 \quad (7)$$

Formula A1 represents the homogeneous transformation matrix of the connecting rod 1 coordinate system {1} with respect to the fixed coordinate system {0};A2 represents the homogeneous transformation matrix of the connecting rod 2 coordinate system {2} with respect to the fixed coordinate system {1};A3 represents the homogeneous transformation matrix of the connecting rod 3 coordinate system {3} with respect to the fixed coordinate system {2}; Hence:

$$A_1 = Rot(z_0, \theta_1) Trans(l_1, 0, 0) \tag{8}$$

$$A_2 = Rot(z_1, \theta_2) Trans(l_2, 0, 0) \tag{9}$$

$$A_3 = Rot(z_2, \theta_3) Trans(l_3, 0, 0) \tag{10}$$

$$A_3 = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 0 \\ s\theta_3 & c\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & l_3 c\theta_3 \\ s\theta_3 & c\theta_3 & 0 & l_3 s\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11}$$

$$A_3 = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 0 \\ s\theta_3 & c\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & l_3 c\theta_3 \\ s\theta_3 & c\theta_3 & 0 & l_3 s\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{12}$$

$$A_3 = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & 0 \\ s\theta_3 & c\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & l_3 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} = \begin{bmatrix} c\theta_3 & -s\theta_3 & 0 & l_3 c\theta_3 \\ s\theta_3 & c\theta_3 & 0 & l_3 s\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{13}$$

Therefore, it can be written out

$$T_3 = \begin{bmatrix} c_{123} & -s_{123} & 0 & l_3 c_{123} + l_2 c_{12} + l_1 c_1 \\ s_{123} & c_{123} & 0 & l_3 s_{123} + l_2 s_{12} + l_1 s_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{14}$$

Formula:

$c_{123} = \cos(\theta_1 + \theta_2 + \theta_3); s_{123} = \sin(\theta_1 + \theta_2 + \theta_3); c_{12} = \cos(\theta_1 + \theta_2); s_{12} = \sin(\theta_1 + \theta_2); c_1 = \cos\theta_1;$

$s_1 = \sin\theta_1$

T3 is the result of multiply by A_1、A_2、A_3, represents the position and attitude of the hand coordinate system {3}.

$$T_3 = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{15}$$

Thus, the hand position (4 * 1) of the hand can be positioned as an array

$$P = \begin{bmatrix} p_x \\ p_y \\ p_z \\ 1 \end{bmatrix} = \begin{bmatrix} l_3 c_{123} + l_2 c_{12} + l_1 c_1 \\ l_3 s_{123} + l_2 s_{12} + l_1 s_1 \\ 0 \\ 1 \end{bmatrix} \tag{16}$$

The direction vectors n, o and a that represent the gesture of the hand are

$$n = \begin{bmatrix} n_x \\ n_y \\ n_z \\ 0 \end{bmatrix} = \begin{bmatrix} c_{123} \\ s_{123} \\ 0 \\ 0 \end{bmatrix} \tag{17}$$

$$o = \begin{bmatrix} o_x \\ o_y \\ o_z \\ 0 \end{bmatrix} = \begin{bmatrix} -s_{123} \\ c_{123} \\ 0 \\ 0 \end{bmatrix} \quad (18)$$

$$a = \begin{bmatrix} a_x \\ a_y \\ a_z \\ 0 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 1 \\ 0 \end{bmatrix} \quad (19)$$

When the corner variable $\theta_1, \theta_2, \theta_3$ is timed, the specific value can be calculated[11]. As shown in the figure above. hypothesis, $\theta_1 = 30°, \theta_2 = -60°, \theta_3 = -30°$. Then the kinematics positive solution can be obtained according to the kinematics equation of the planar joint robot, that is, the position matrix of the hand is expressed as:

$$T_3 = \begin{bmatrix} 0.5 & 0.866 & 0 & 183.2 \\ -0.866 & 0.5 & 0 & -17.32 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (20)$$

5. Summarize

Industrialization and industrial application of industrial robots is an important symbol to measure a country's scientific and technological innovation and high-end manufacturing development level.

To develop the robot industry is of great significance for creating new advantages in China's manufacturing, promoting industrial transformation and upgrading, speeding up the construction of manufacturing power and improving the living standards of the people.Establishment of industrial robot's kinematics equation and formula for positive kinematics by example. It has active significance to promote the motion control of industrial robot.

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