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Analysis on Kinematic Model of Welding Robot Calibration for Automobile Fittings

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Abstract: According to the actual structure of the welding robot car fittings, D-H kinematics model is established, so as to analyze the robot kinematics and kinematics solution; whether it is suitable for actual robot calibration verification to find whether it is feasible to determine; through the experiment, to determine the follow-up theoretical model by using the theory model instead of error modeling.

Keywords: Kinematic calibration, D-H model, Kinematics positive solution

Introduction

Under the condition of industrial robots with smaller loads, the main reasons to cause the pose error lies in the small deviation between the actual physical model of robot kinematics model and the theory of the robot controller, the deviation is mainly produced in the period of manufacturing robots and the installation process. Thus selecting an appropriate kinematic model and measurement method is the basis of calibration.

Adopting calibration method based on kinematic model to calibrate the Motoman_UP20 robot in welding automobile fittings. Firstly, we need to establish D-H kinematics model according to the actual structure of the robot, discussing the forward kinematics solution of the robot.

Establishment of Robot Bar Coordinate System and Kinematic Positive Solution

Before the robot kinematics model is established, firstly number the members and joints of the robot. Assuming the base as rod 0. The direction from the base to the end operator is rod 1, rod 2 ......rod 6; the joint i is connected with rod i-1 and rod i, that is, the bar i has a joint i on the one end near the base(shored for near end), and there is a joint i+1 on the far end from the base(shored for far end). According to the principle described by D-H method, the rules of the coordinate system of each member of robots are established as follows:

In order to determine the relative motion relationship between the parts of the robots, a coordinate system is fixed on each member respectively. The coordinate system fixed with the base is recorded as {0}. The coordinate system fixed with the rod i is recorded as {i}. The connecting rod can be shown in Figure 1.

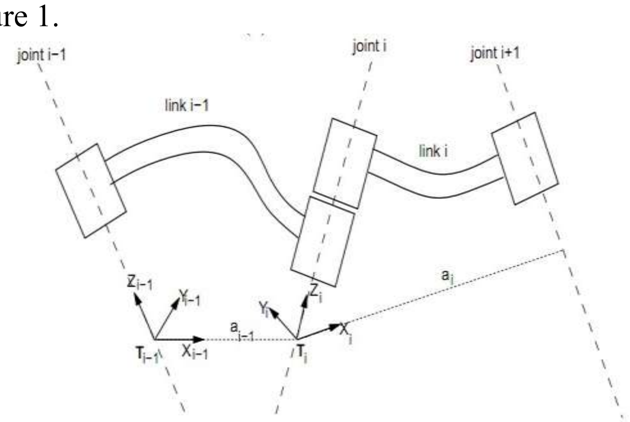

Fig.1 Coordinate System of Central Connecting Rod

(1) The Z axis of the coordinate system {i-1} z_{i-1} is aligned with the joint axis i-1, the direction is arbitrary.

(2) The X axis of the coordinate system {i-1} x_{i-1} is aligned with the connecting rod i-1, the direction is overlapped with any common perpendicular line, directing from joint i-1 to joint i, taking $x_{i-1}=\pm z_{i-1}\mathrm{X}$, when $a_{i-1}=0$.

(3) The Y axis of the coordinate system {i-1} y_{i-1} is defined by the right hand rule, that is, $y_{i-1}=z_{i-1}\mathrm{X}\,x_{i-1}$.

(4) The origin point o_{i-1} of the coordinate system {i-1} is taken at the intersection point between x_{i-1} and z_{i-1}; when z_i is intersected with z_{i-1}, the origin point is at the intersection point of two axes. When z_i is paralleled with z_{i-1}, the origin point is taken to make d_i=0. Fig.1 -- The setting position of the connecting rod i-1 and the connecting rod i in coordinate system {i-1} and {i} is drawn.

According to the set connecting rod coordinates, the corresponding connecting rod parameters can be defined as follows:

a_{i-1} = the measured distance along x_{i-1} from z_{i-1} to z_i;

α_{i-1} = the angle of rotation around x_{i-1} from z_{i-1} to z_i;

d_i = the measured distance along z_i from x_{i-1} to x_i;

θ_i = the angle of rotation around z_i from x_{i-1} to x_i.

a_{i-1} can represent the length of the rod i-1, so $a_{i-1} \geq 0$ is specified; while $\alpha_{i-1}, d_i, \theta_i$, the value of can be positive and negative.

From the above analysis we can know that D-H parameters are including: link length a_{i-1}, angle α_{i-1}, offset distance d_i, joint angle θ_i. Among them, the first two parameters, a_{i-1} and α_{i-1} are used to describe the shape of the connecting rod; the next two parameters, d_i and θ_i are used to describe the relative position of the adjacent connecting rods. The latter pair of parameters is directly related to the joints. For rotating joints, d_i is a constant parameter while θ_i is a variable parameter (i.e. joint variable). For sliding joints, θ_i is a constant parameter while d_i is a constant parameter.

According to the above provisions, combined with the problems to be solved in this paper, a workpiece coordinate system is added correspondingly. It has only translation relationship with the sixth coordinate system, and the measured point is located in the center of the workpiece coordinate system. The coordinate system of Motoman_UP20 robot can be shown in Fig. 2.

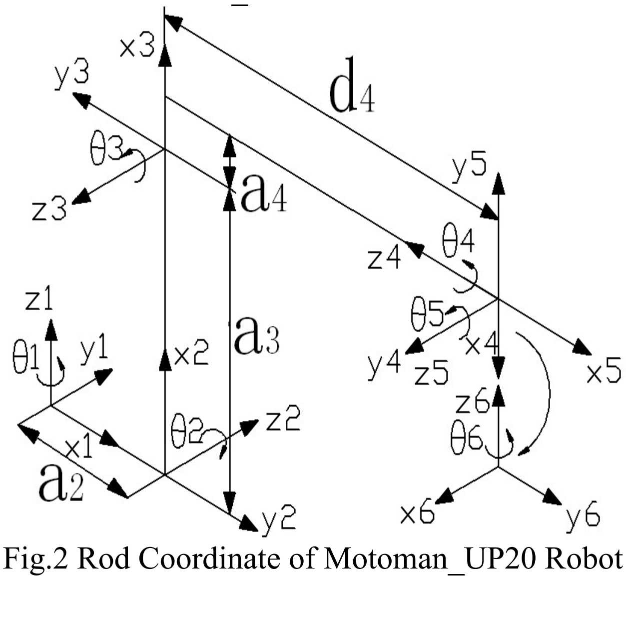

Fig.2 Rod Coordinate of Motoman_UP20 Robot

The nominal value of the obtained D-H parameter of robot, can be shown in Table 1.

The nominal value of the D-H parameter of Table 1

Joint n	Transform An a (mm)	a(mm)	α(°)	d(mm)	θn(°) (initial value)
1	A1	0	0	0	θ1(0)
2	A2	150	-90	0	θ2(-90)
3	A3	730	180	0	θ3(0)
4	A4	140	-90	-765	θ4(180)
5	A5	0	-90	0	θ5(90)
6	A6	0	-90	0	θ6(-90)

Kinematics Positive Solution of Robot Bar Coordinate System

The transformation ${}^{i-1}_{i}T$ of the connecting rod coordinate system {i} relative to the {i-1} is called the connecting rod link transformation. Obviously, ${}^{i-1}_{i}T$ is related to the four parameters of a_{i-1}, α_{i-1}, d_i, and θ_i. So. The connecting rod transformation ${}^{i-1}_{i}T$ can be decomposed into four basic sub-transformation problems, in which each sub-transformation is dependent on only one connecting rod parameter to be written directly.

The connecting rod transformation ${}^{i-1}_{i}T$ can be considered as the following four sub transformations of the coordinate system {i}.

(1) Around $A_i = \begin{bmatrix} \cos(x_i) & -\sin(x_i) & 0 & \mathrm{b}_i \\ \cos(\mathrm{a}_i)\sin(x_i) & \cos(\mathrm{a}_i)\cos(x_i) & -\sin(\mathrm{a}_i) & -\mathrm{f}_i\sin(\mathrm{a}_i) \\ \sin(\mathrm{a}_i)\sin(x_i) & \sin(\mathrm{a}_i)\cos(x_i) & \cos(\mathrm{a}_i) & \mathrm{f}_i\cos(\mathrm{a}_i) \\ 0 & 0 & 0 & 1 \end{bmatrix}$ axis and turn α_{i-1} angle.

(2) Move a_{i-1} along x_{i-1} axis;

(3) Around the z_i and turn θ_i angle;

(4) Move d_i along z_i axis.

Because these sub-transformations are all described relative to the dynamic coordinate system, according to the principle of "from left to right" , thus we can get

$${}^{i-1}_{i}T = \mathrm{Rot}(x,\ \alpha_{i-1})\ \mathrm{Trans}(x,\ a_{i-1})\ \mathrm{Rot}(z,\ \theta_i)\ \mathrm{Trans}(z,\ d_i) \qquad \text{(Formula 1)}$$

The general formula of the connecting rod transformation A can be obtained by the four sub transformations on the right of according to Formula (3.1).

$${}^{i-1}_{i}T = \begin{bmatrix} \mathrm{c}\theta_i & -\mathrm{s}\theta_i & 0 & a_{i-1} \\ \mathrm{s}\theta_i\mathrm{c}\alpha_{i-1} & \mathrm{c}\theta_i\mathrm{c}\alpha_{i-1} & -\mathrm{s}\alpha_{i-1} & -d_i\mathrm{s}\alpha_{i-1} \\ \mathrm{s}\theta_i s\alpha_{i-1} & \mathrm{c}\theta_i s\alpha_{i-1} & \mathrm{c}\alpha_{i-1} & d_i c\alpha_{i-1} \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

After determining the structural parameters of the robot and giving the angles of each joint, the position and posture of the robot's terminal manipulator in the base coordinate system can be calculated. This is the so-called robot positive kinematics solution.

Using D-H parameter of the last section, the following six transformation matrices can be obtained by Formula 1:

$$A_i = \begin{bmatrix} \cos(x_i) & -\sin(x_i) & 0 & b_i \\ \cos(a_i)\sin(x_i) & \cos(a_i)\cos(x_i) & -\sin(a_i) & -f_i\sin(a_i) \\ \sin(a_i)\sin(x_i) & \sin(a_i)\cos(x_i) & \cos(a_i) & f_i\cos(a_i) \\ 0 & 0 & 0 & 1 \end{bmatrix} \text{(i= 1, 2, 3, 4, 5, 6)}$$

$$A_7 = \begin{bmatrix} 1 & 0 & 0 & x \\ 0 & 1 & 0 & y \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$ Among them, a represents α, b represents a, c represents β, x represents θ, and f represents d.

Among them, x, y, z is the position of the measured point in the sixth coordinate system, which can be obtained by the five position points method.

So D-H transformation from the basic coordinate system to the tool coordinate system can be obtained as: $A_{17} = A_1A_2A_3A_4A_5A_6A_7$

It is calculated that:

$$A_{17} = \begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

In the formula, it is obvious that it is easy to find out the position and pose matrix of the end operator when the angle of each joint is known, thus matrix A_{17} is the solution of the robot's positive kinematics.

Calibration of Robot Kinematics Model

Due to the processing errors and assembly errors of robot occurred in the manufacturing process, plus the joint angle is obtained indirectly by the pulse number of each axis, and the relationship between the pulse and angle is just picked by a finite number of points fitting, so the pulse to angle conversion is a questionable link, whether these two factors will lead to the kinematics model is suitable for calibration of the robot, it can be verified by collecting a certain number of points.

The most theoretical model: it is kinematics model based on rod geometry parameters and joint angles. Its bar parameters are all pure integers, all conditions are in ideal state.

Theoretical model: a kinematic model of a robot when it comes out of the factory, its rod parameter has a tolerance band, and its angle is replaced by a pulse.

The actual model: when the robot works, the kinematic model has great location error. If all the factors that cause the error are equivalent to the rod error, the purpose of compensation reduction can be achieved.

The task of this paper is to calibrate the actual model to the theoretical model by calibrating, and the most theoretical model is simple and easy to get. It can replace the theoretical model, so we need to verify whether the error between them is within the allowable range. Because each joint angle of robot can not be read directly, it can only be transformed by reading pulse, so we need to establish the relationship between each joint angle and pulse number. The method adopted in this paper is to return to the second origin firstly, only rotate one joint, and read the transformation of the terminal posture (the angle around one shaft) to replace the rotation angle of this joint. Obviously, the number and rotation angle of each joint should be proportional. The experimental results show that the linear fitting of data is reasonable, and the pulse is positively proportional to the angle change.

The number of pulses and the terminal position of the corresponding joints can be recorded. According to the previous kinematic model of robots, the measured point can be located at the origin of the flange coordinate system, and the prediction point can be calculated by the following matrix.

$$A_{16}=A_1A_2A_3A_4A_5A_6=\begin{bmatrix} n_x & o_x & a_x & p_x \\ n_y & o_y & a_y & p_y \\ n_z & o_z & a_z & p_z \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Among them, the angle variables of each joint are converted by the number of joints corresponding to the number of pulses.

The verification results of several selected points show that the coordinate deviation is mostly within 0.02, which can not affect the process of subsequent calibration. Therefore, the most theoretical model can replace the theoretical model for subsequent error modeling.

Conclusion

According to the actual structure of the welding robot car fittings, D-H kinematics model is established, which analyzed the robot kinematics and kinematics solution; whether it is suitable for actual robot calibration verification, so as to find that it is feasible; through the experiment, determining the follow-up theoretical model by using the theory model instead of error modeling.

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References

[1] Xia Tian. Kinematic Calibration and Error Analysis of Industrial Robots [Master's Thesis]. Shanghai: Shanghai Jiao Tong University. 2009.

[2] Hu Zhonghua, Chen Huanming, Xiong Zhenyu, Jiang Shuyuan. Mechanical Analysis and Solving the Kinematics of Motoman - UP20 Robot Research & Application, 2006,19 (5): 24-26.

[3] Cai Hegao, Zhang Chaoqun, Wu Weiguo. Real Geometric Parameter Identification and Simulation of Robot. China Mechanical Engineering, 1998, 9 (10): 11-14.

[4] Song Yue er. Research on Coordinated Motion Accuracy and Off-Line Programming Calibration of Arc Welding Robot System [Doctoral Thesis]. Harbin: Harbin Institute of Technology,2002.