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Study on D-H parameter errors of a six-axis serial robot using a circular path

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Abstract

In the field where manipulator robots are applied, offline programming for generating motion profiles of the robot rather than simple teaching is increasing. In order to implement the robot's motion, two robot kinematic models, forward kinematics that obtain the pose from the robot's joint values and inverse kinematics that obtain the joint values from the pose, must be built first. The kinematic models are built using the nominal DH parameters in the design stage, and the robot's motion data is generated using them. However, actual robots cannot behave like the ideal kinematic models due to errors in the machining process of parts and the assembly process of the robot. Therefore, the effect of errors on the pose accuracy must be analysed first, and robot calibration must be performed to reduce the errors. In this study, the effect of errors on the pose accuracy is analysed using the robot's kinematic model and the circular path. First, an ideal kinematic model of a six-axis serial robot is built using the nominal D-H parameters, and the pose for the circular path and the corresponding nominal joint values are calculated. Then, the circular path is generated by applying the nominal joint values to the kinematic model built using the D-H parameters including errors, and the pose accuracy for the change of each parameter is analysed.

a six-axis serial robot, D-H parameter errors, pose accuracy, circular path, kinematic model

1. Introduction

Kinematic error in a robot is the deviation between a physical system and a kinematic model. This error is one the major sources affecting the pose and path accuracy in the robot [1]. Therefore, various methods for evaluation and calibration have been tried [2-4].

A circular test with a circular path is a simple and rapid way to evaluate the robot's performance by measuring radial deviation [5]. In this work, a kinematic model is established using D-H parameters first, and the errors on the end-effector of a six-axis serial robot are evaluated by calculating the radial deviation for the D-H parameter errors using a circular path.

2. Kinematic Model using D-H parameters

A kinematic model to plan the motion of the six-axis serial robot (KR6 R700-2, KUKA) was established by substituting the D-H parameters into HTM(Homogeneous Transformation Matrix) ${}^{0}_{6}\boldsymbol{T}$. Using the HTM, a forward/inverse kinematics can be calculated [6].

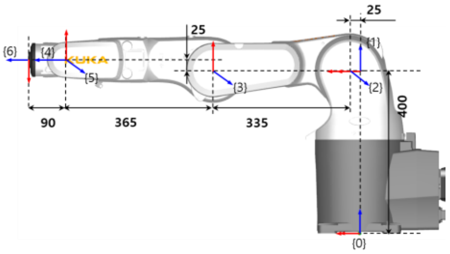

Figure 1. Kinematic details of a six-axis serial robot (KR6 R700-2, KUKA)

Table 1 D-H parameters (unit: distance/mm, angle/raidan)

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	400	θ_1
2	$-\pi/2$	25	0	θ_2
3	0	335	0	θ_3
4	$-\pi/2$	25	365	θ_4
5	$\pi/2$	0	0	θ_5
6	$-\pi/2$	0	90	θ_6

$${}^{0}_{6}\boldsymbol{T} = {}^{0}_{1}\boldsymbol{T}\,{}^{1}_{2}\boldsymbol{T}\,{}^{2}_{3}\boldsymbol{T}\,{}^{3}_{4}\boldsymbol{T}\,{}^{4}_{5}\boldsymbol{T}\,{}^{5}_{6}\boldsymbol{T} = \begin{bmatrix} \boldsymbol{R} & \boldsymbol{p} \\ \boldsymbol{0} & 1 \end{bmatrix}$$

Herer, $\boldsymbol{p} = [p_x, p_y, p_z]^T$ represents the position of the robot's end-effector without any error. When errors are introduced, the position is expressed as $\boldsymbol{p} + \Delta\boldsymbol{p} = [p_x + \Delta p_x, p_y + \Delta p_y, p_z + \Delta p_z]^T$, where $\Delta p_x, \Delta p_y$, and Δp_z correspond to the deviations.

3. Circular path plan and error evaluation

In order to evaluate the errors, the circular path was planned taking into account the experimental conditions. The center point of the circle was set at (510, 0, 220), and the radius of the circle was set to 150 mm considering the circular test using a ball-bar measurement system as shown in Figure 2.

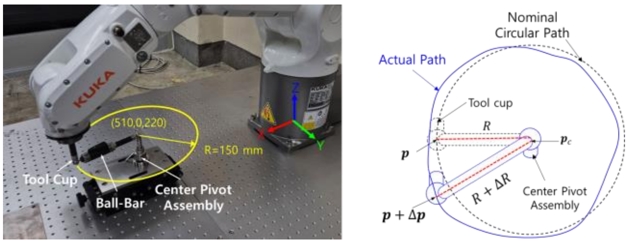

Figure 2. Experimental setup for circular test and radial deviation

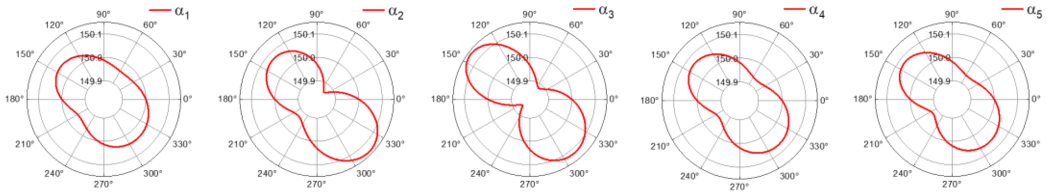

Figure 3. Radial deviation by error of D-H parameter α in circular path ($\alpha_1$to α_5)

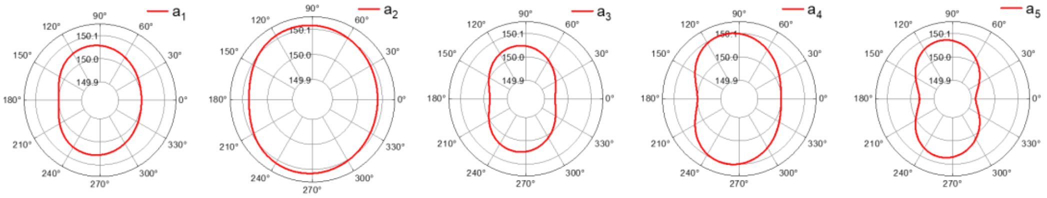

Figure 4. Radial deviation by error of D-H parameter a in circular path ($a_1$to a_5)

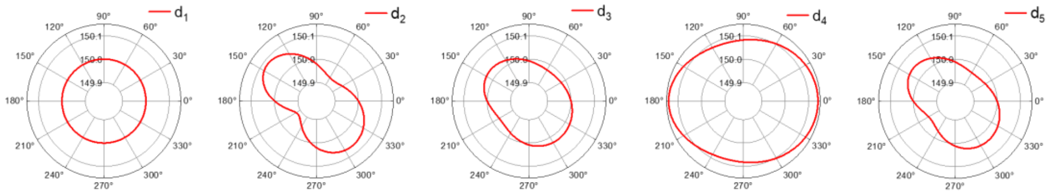

Figure 5. Radial deviation by error of D-H parameter d in circular path ($d_1$to d_5)

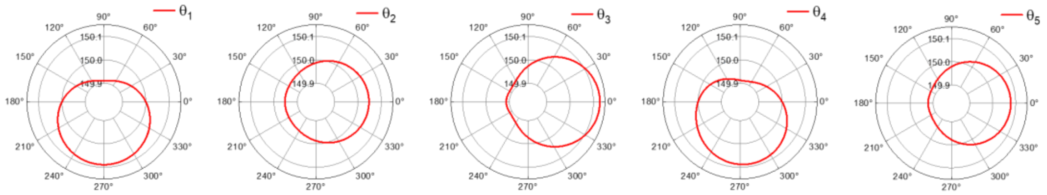

Figure 6. Radial deviation by error of D-H parameter θ in circular path ($\theta_1$to θ_5)

The nominal joint values of the robot for the circular path are calculated applying error-free D-H parameters to the kinematic model. Using the nominal joint values and kinematic model, the radial deviation was calculated by giving positive/negative error values to the D-H parameters (α, a, d, θ) for link frames 1 to 5, respectively.

Figure 3 through 6 show the radial deviation for positive error values for the given robot configuration. The error of d_1 in Figure 5 does not affect the radial deviation because d_1 is a value in the z-axis direction. Therefore, the error does not appear in the X-Y plane, but the error may appear in the Y-Z or X-Z plane.

With the combination of the above radial deviation results, the data obtained from circular test experiment using a ball-bar measurement system can be fitted, and each D-H parameter can be estimated.

Figure 7 shows the results of the circular test using a ball-bar before and after calibration. The measurement data before calibration were compared with the error-included profiles shown in Figures 3 to 6, and the D-H parameters were modified accordingly. A new circular path was then generated using the calibrated parameters, and re-measurement was performed.

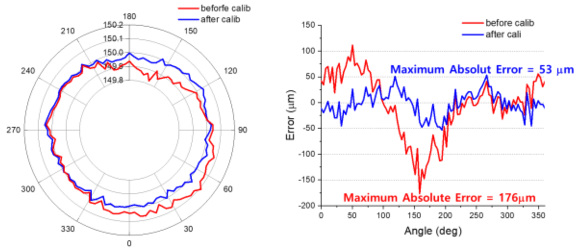

Figure 7. Result of circular test (before/after calibration)

After calibration, the radial deviation was reduced to a maximum of 53 μm, indicating a decrease compared to the pre-calibration maximum of 173 μm.

4. Conclusion

The kinematic model of the robot and the circular path are used to show the influence of the D-H parameter error in this work. The radial deviation in the circular path by error in each parameter can be used to predict the behaviour of the robot's end-effector. And the actual D-H parameters, including errors, can be estimated by a combination of radial deviations.

Acknowledgements

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