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Devising kinematics model for parallel link mechanism type machine tool

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Abstract

In recent years, a parallel mechanism with multiple links is expected to be applied to machining because of its higher rigidity, accuracy, and output rather than a series mechanism as industrial robots. However, unlike conventional machine tool which consists of linear and rotary axes, the parallel mechanism has many error factors. In this paper, we devise and evaluate kinematics model of a robot-type machine tool which has parallel mechanism using the shape creation theory. The kinematics model was derived by formulating the constraint conditions of the parallel mechanism of the target device. To evaluate the accuracy of the forward kinematics model, we used the internal functions of the controller to measure the operating state of each axis of the robot machine tool. As a result of comparing the devised forward kinematics model with the target value using the measurement results, we report that the tool tip coordinates can be calculated with high accuracy and its evaluation results.

Keywords: parallel mechanism, shape creation theory, homogeneous transformation matrix, kinematics

1. Introduction

In recent years, industrial robots are expected to be used not only for transportation but also for machining. The robot type machine tool as shown in Fig.1 have a parallel mechanism and a serial mechanism. The parallel mechanism has a smaller working area, higher rigidity and higher accuracy than the conventional serial mechanism. However, the positioning accuracy may be reduced due to the complexity of the machine structure and errors in assembling and motion of each part, considering the application to machine tools, it is necessary to improve the accuracy. Therefore, by creating an original kinematics model, it is possible to simulate the tool path. In addition, by inputting encoder information during machining, it is possible to compare the machining results with the behavior of each axis and clarify the factors that affect the machined surface. In addition, to cope with the digital-twin concept, the kinematics model of this machine must be built in case of the model unrevealed. Therefore, a three-dimensional geometric model was derived for target robot-type machine tool, and the mechanism of the machine tool was modeled. Based on the model, we derive a kinematics model and report the result of its evaluation results.

2. The target machine tool

Figure 1 shows the schematic diagram of the robot type machine tool (XMINI made by EXECHON Enterprises L.L.C). There are three coordinate systems to represent this machine tool with kinematics model. The first is the Internal Coordinate System (ICS), which is a coordinate system that uses the intersection of the Base platform and the 1st-axis as the origin and serves as a reference for representing the internal structure. The second is the Moving Platform Coordinate System (MPS), which is a coordinate system that takes into account the posture of the Moving platform. The third is the basic coordinate system (BCS), which is a coordinate system that is parallel to the three axes of the spatial coordinate system and represents the direction and coordinates of the tool center axis.

The geometric model of the machine tool is represented as shown in Fig.2 to visualize the parameters with the direction and the offset value considered in the motion controller program. Table 1 shows the parameters of robot type machine tool. In the

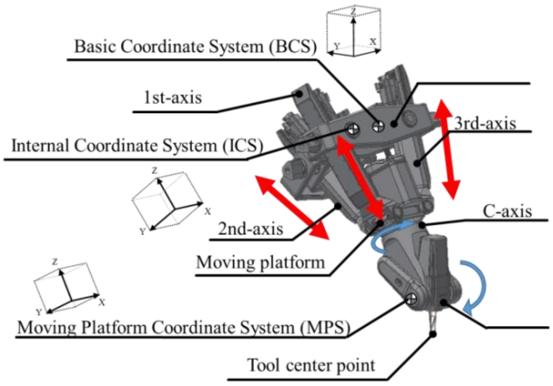

Figure 1. Schematic diagram of robot type machine tool.

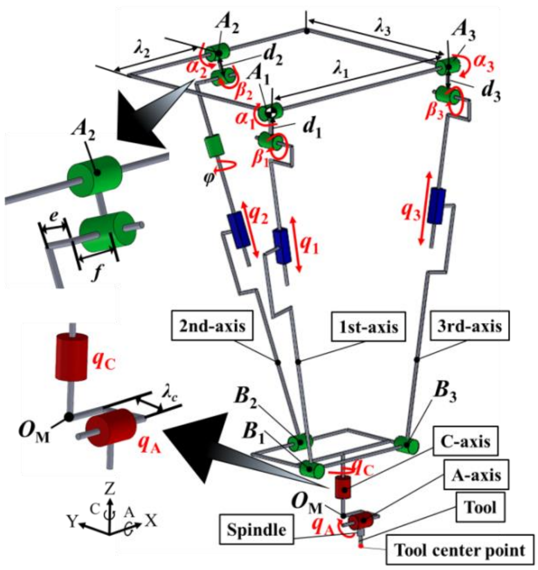

Figure 2. Geometric model of a machine tool.

following the index i runs from 1 to 3. The FARO® Gage which is three dimensional measurement device for the offsets and coordinate acquisition was used based on a software called xCAL provided by Exechon Enterprises L.L.C.

3. Forward kinematics model

The forward kinematics model is derived based on the shape generation theory using a homogeneous coordinate transformation matrix [1]. Modeling is performed in the order of ICS origin A_1, 1^{st}-axis, 2^{nd}-axis, 3^{rd}-axis, moving platform, C-axis, A-axis, tool. The input parameters are the stroke q_1 (1^{st}-axis), the stroke q_2 (2^{nd}-axis), the stroke q_3 (3^{rd}-axis), the angle q_C (C-axis), and the angle q_A (A-axis) respectively, which are the drive axes.

First, the intersection of each axis and the moving platform is derived. By deriving B_1, B_2, and B_3, the posture of the moving platform and the coordinates of the origin O_M of MPS can be calculated.

$$B_1 = R(\alpha_1)D_1R(\beta_1)Q_1 \quad (1)$$

$$B_2 = A_2R(\alpha_2)D_2R(\beta_2)EFR(\varphi)Q_2 \quad (2)$$

$$B_3 = A_3R(\alpha_3)D_3R(\beta_3)Q_3 \quad (3)$$

Tooltip coordinates are derived using the calculated O_M coordinates. θ_0 is the tilt of the entire target device, O_M is the O_M coordinates, θ_{CYZ}, θ_{CXZ} are MPS C-axis corrections, and T is the distances from the A-axis to the tip end of the spindle, S is tool tip coodinates. Tooltip coordinates can be obtained by the next eq.(4).

$$S = R(\theta_0)O_\mathrm{M}R(\theta_\mathrm{CYZ})R(\theta_\mathrm{CXZ})R(q_c)L_cR(q_\mathrm{A})T \quad (4)$$

In order to evaluate the results calculated using the forward kinematics model, the behavior is verified using the command values actually given to the machine tool. In the simulation, a linear motion of ± 180 mm was performed at 20 mm intervals in the X axis direction. Figure 3 shows the simulation results with mechanical error and without mechanical error. Considering that the calculation of the command unit provided in the controller can be regarded as is accurate, we compared the controller calculated value with the calculation result by our forward kinematics model. From this results, we found that the devised forward kinematics model without mechanical errors can acquire the tool tip coordinates with an error of about 1 µm or less. In the forward kinematics model with mechanical error, the maximum error was about 25 µm. This result leads us to improve the model considering the error model.

4. Inverse kinematics model

In the inverse kinematics model, Tooltip coordinates and the orientation of the tool are used as input parameters, 1^{st}-axis stroke q1, 2^{nd}-axis stroke q2, 3^{rd}-axis stroke q3, C-axis angle q_C , and A-axis angle q_A are used as output parameters. Inverse kinematics models are also calculated using the homogeneous coordinate transformation matrix. θ_{MPX} is the rotation of the moving platform around the X axis, θ_{MPY} is the rotation of the moving platform around the Y axis, l_{MPZ} is a translational motion in the Z-axis direction. The above three parameters are used as the 3-degrees-of-freedom of the parallel mechanism. The inverse kinematics model derives the position and orientation of the Moving Platform, the C-axis angle, and the A-axis angle from the eq.(5). The linear motion axis is derived from the positions of the Base platform and Moving platform.

$$R(\theta_0)R(\theta_\mathrm{MPX})R(\theta_\mathrm{MPY})L_\mathrm{MPZ}R(\theta_\mathrm{CYZ})R(\theta_\mathrm{CXZ}) R(q_c)L_cR(q_\mathrm{A})T = S \quad (5)$$

Table 1 Parameters of robot type machine tool

O_{ICS}	Origin of internal coordinate system (A_1)
O_M	Origin of moving platform coordinate system
A_i	Point of intersection of base platform and the each axis
B_i	Point of intersection of Moving platform and each axis
q_i	Length of the perpendicular between A_i and B_i
q_C	Angle of the C rotary axis
q_A	Angle of the A rotary axis
α_i β_i	Angle of the outer, inner universal joint at the base platform
λ_i	Distance between O and A_2, A_3 along the X, Y direction
λ_c	distance between O_M and A axis
d_i	Distance between both rotaries of a universal joint
e,f	Possible offsets perpendicular to 2-axis at the base point A_2
φ	Angle between 2-axis about its longitudinal direction

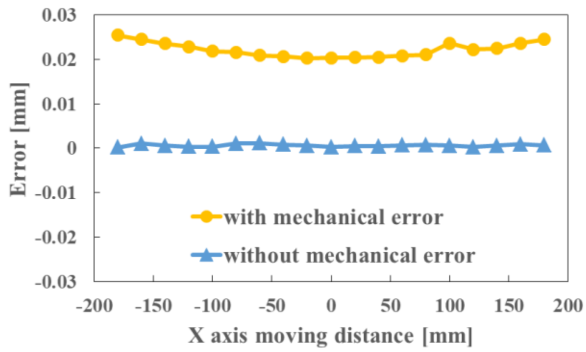

Figure 3. Error of simulated results of forward kinematics model

Table 2 Error of simulated results of inverse kinematics model

	Target value	Calculated value
1st-axis[mm]	734.7025	734.8162
2nd-axis[mm]	689.1889	689.9319
3rd-axis[mm]	666.7449	666.8872
C-axis[deg.]	17.4918	17.3631
A-axis[deg.]	25.3417	25.5136

Table 2 shows the results of comparing the calculation results of the command unit provided in the controller with the calculation results of the inverse kinematics model with mechanical error. From this results, the error on 2^{nd}-axis is as large as about 0.8 mm. The inverse kinematics model with mechanical errors is to be improved especially by considering the parameter models contributing to the main calculation error.

5. Conclusions

The following results were obtained for the devised kinematics model.

1) We found that the devised forward kinematics model with mechanical errors can acquire the tool tip coordinates with an accuracy of about 1 µm or less.
2) The inverse kinematic model including mechanical error still remain a large calculation error and needs improvement.

References

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