学 位 論 文 概 要

題　目　　Novel kinematic model for six-axis industrial robots.
（　産業用６軸ロボットの新しい幾何学モデルの提案　　）

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The demand for industrial robots in machining is expanding at an exponential rate, requiring, particularly for large-sized parts such as aircraft parts, taking an advantage of their portability, compared to a traditional large-sized machine tool. Unlike conventional robots that are typically programmed by the teach method, a machining robot must be programmed based on a virtual model ("offline programming"), which critically requires a robot to have higher absolute positioning accuracy, just like machine tools.

The numerical compensation for a robot’s static positioning error has been extensively studied, based on its kinematic model to predict the positioning error. Researchers have studied the robot kinematic model comprising position and orientation errors of rotational axes average lines, also known as Denavit–Hartenberg (D-H) parameters, extensively to increase a robot's absolute positioning accuracy. However, in many previous research works, even when numerical compensation is applied based on the conventional D-H model, a robot’s positioning accuracy is typically 10 to 100 times worse than typically machine tools. This research proposes a novel kinematic model and its identification approach to increase the absolute positioning accuracy of industrial robots over the entire workspace.

The kinematic modeling theory for a six-axis industrial robot is first reviewed. The definition of each local coordinate system based on the measured position and orientation of the rotating axis average lines is demonstrated in this thesis, as well as the derivation of the kinematic model using the coordinate transformation theory is presented. While the present model is equivalent to the classical D-H model, the study shows how an alternative kinematic model can be derived from a different specification of local coordinate systems.

The proposed kinematic model for a typical serial-linked 6DOF (degrees of freedom) industrial robot contains the bidirectional angular positioning deviations "error map" of each rotary axis in addition to its D-H parameters. The angular positioning deviations of the rotary axes are modeled as a function of angular command positions as well as the directions of rotation to model the impact of backlash. This study also proposes a novel approach to identify the angular positioning deviations of all the rotary axes by using a laser tracker with indexing each rotary axis at specified angular positions. Moreover, the model-based compensation technique is being experimentally investigated to validate the prediction accuracy of the proposed kinematic model.

The weight of the links and the end effector can cause the elastic deformation of rotary axes. Such a gravity influence on the end-effector position varies depending on the robot pose. As an additional contribution, this thesis presents the extension of the proposed model to include such an influence. The influence of one rotary axis on the angular positioning deviation of the other axis is measured and then modeled as the "the axis-to-axis crosstalk". Furthermore, the impact of angular velocity and acceleration is also observed on the positioning accuracy of the robot.

The results of the experiment reveal that the proposed kinematic model considerably improves the robot's absolute positioning accuracy over the entire workspace.