Automated Calibration of Robot Paths by Identifying Dimensional Variations and Adaptive Adjustment

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Abstract
Loss of positioning accuracy of the robot end effector can be a result of discrepancies in dimensions between the designed and the manufactured systems. These errors can originate from the geometrical tolerance of the robot arm manipulator itself, or the dimensional variations of the robot work cell. This paper aims at improving the robot positioning accuracy by modelling the effects of changes in robot workbench configurations on the end effector pose. A transformation matrix relating these changes is proposed and tested on a six-axis robot arm manipulator for (i) pick and place tasks and (ii) assembly tasks. Position sensors are used to obtain the workbench position.

Keywords – Robot, Calibration, Path Planning.

1. Introduction
Industrial robots have gained popularity because they can perform repeatable industrial tasks rapidly, precisely, and accurately. Current industrial robot applications usually involve Off-Line Programming (OLP) for robot path generation in a virtual environment. During manufacturing and assembly of robot arm manipulators, tolerances often lead to deviation of robot kinematic parameters from their nominal values. Other deviations in the robot system may result from discrepancies in the workbench coordinates, that lead to changes in poses of objects to be handled by the robot. These discrepancies result in end effector pose errors when initial values of kinematic parameters and workbench coordinates are used in estimating end effector pose. Usually these issues have been corrected by manual robot calibration, which is a method of improving robot positioning accuracy by iteratively modifying the original robot paths generated by OLP software instead of changing the robot design or its control system. There are currently lots of techniques of calibration, but they mainly focus on correcting kinematic parameters due to the dimensional variations of the robot manipulator.

This paper aims at developing a model that improves robot positioning accuracy by automatically correcting errors that arises from changes in robot workbench configurations. A homogeneous transformation matrix that relates changes in translation and rotation in yaw of the robot workbench to the desired pose of the end effector is proposed.

2. Problem Description
It is very unlikely to design any system and manufacture it to the exact measurements as intended. This issue also arises in robot systems; it can lead to discrepancies in robot workbench configurations. This will affect the pose of the end effector. In many industrial tasks, the end effector movements require multiple point-to-point trajectories. This may be due to the complexity of the task or the presence of obstacles in the robot workspace. In these cases, the trajectories of the end effector are obtained by not only defining the initial and final points but also intermediate points.

Deviations of the workbench configuration from the nominal configurations, will lead not only to loss in end effector accurate positioning while handling objects, but also to changes in the intermediate points of the robot end effector path. There is a need to automatically generate new intermediate points because of the changes in the robot workbench.

Figure 1. robot arm manipulator and its workbench
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Figure 2. Example of a robot path program.

Figure 1 shows a robot arm manipulator and its workbench and shows an example of a robot path program. Any variations in the workbench pose will lead to modification of the robot path program to match the end effector pose with the task.

Figure 3. Robot path with intermediate points (P1, P2, P3)

Figure 3 shows a robot path that involves intermediate points. The developed method assumes no change in the robot location. The workbench pose is described relative to the end effector pose, which is in turn described relative to the workshop base coordinate. To ensure repeatability of the robot task the length and direction of point P3 to the target should be kept constant while generating new intermediate points.

3. Adaptive Robot Path Adjustment

In robotics, displacement, position and orientation are defined by homogeneous transformation matrices [1]. Pose of objects can be described relative to other objects. The relative pose of object j with respect to object i can be described by the following matrix:

\[ T_{i,j} = \begin{bmatrix} R_{i,j} & d_{i,j} \\ 0 & 1 \end{bmatrix} \]

where \( T_{i,j} \) is the transformation from i to j, \( R_{i,j} \) is the rotation part of the homogeneous transformation, \( d_{i,j} \) is a vector that connects the origin of frame i to that of frame j. Figure 4 shows the relationship between the different entities that make up the robot system. The workshop base coordinate is taken as the reference frame for the system.

![Figure 4. Entities of the robot system](image)

Homogeneous transformation matrices can be compounded and composed [2]. The following equation relates the workbench coordinate to the workshop base coordinate:

\[ T_{b,w} = T_{b,r} \cdot T_{r,e} \cdot T_{e,w} \]

For industrial manipulators, the path is mainly defined by the geometry of the task, taking into account that the motion should be collision free from the initial point to the final one [3]. The experimental system consists of position sensors and a six-axis robot arm manipulator that performs pick and place tasks, and assembly tasks.

4. Conclusion and Future work

In this work, a method to model changes in the workbench configuration into the robot path program is proposed. The robot pose was assumed to remain unchanging. Only changes in translation and yaw rotation of the workbench were considered, and therefore, future works will also include changes in the pitch and roll rotation.

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Reference

