Calibration method for articulated industrial robots

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Abstract

Robot calibration is a technique used to increase system positioning accuracy. In our research, we have reviewed self-calibration techniques of articulated industrial robots and proposed an original method to reduce production and maintenance down times. The proposed technique is using an inertial measurement unit (IMU) to measure robot poses, plus ultrasonic triangulation sensors to increase processing speed and reduce computational power. Thanks to all of that, robot is more responsive, i.e. we have an improved speed, reliability and accuracy in determining the orientation of the manipulators. The advantages of this method in comprising with the vision based calibration, is that it does not need the complex steps, such as camera calibration, image capture, memory and corner detection. This makes the robot calibration procedure more autonomous in a dynamic manufacturing environment. The proposed technique was applied at Six Degrees of Freedom (6-DOF) robot and compared to existing calibration methods.

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1. Introduction

Industrial robots have been used for about 50 years with their usage becoming increasingly popular in applications such as material handling, welding assembly and dispensing, in which they have demonstrated high efficiency and speed performances. In the applications that require high accuracy, such as prototyping, pre-machining end milling, poor precision limited their use. Positioning errors are associated with the manufacturing and assembly tolerances. Errors could be significantly eliminated by implementing calibration process. Nowadays, calibration tasks use a substantial amount of measurement techniques; nonetheless, the most common approach is to utilize a laser track interferometer that measures the position and orientation of the end effector\(^1\). Gong et al\(^3\) used a
hybrid non-contact optical sensor (a combination of vision sensor and structured light) attached to the end-effector to implement self-calibration of a 6-DOF robot manufactured by Staubli Company based on the distance measurement rather than absolute position measurement. Guanglong et al. proposed online calibration that required a position marker, inertial measurement unit (IMU) and hybrid sensors. However, his method required the robot to stop working during the pose measurement.

Robot calibration is more efficient with the dynamic pose measurements. Meanwhile, Zhuang in proposed self-calibration method for the parallel mechanism with a case study on the Stewart platform in which he used the forward and inverse kinematics with six rotary encoders for the three objectives functions of parameter identification. On the other hand, Khalil and Besnard installed two orthogonally allocated inclinometers as tool to calibrate Stewart platform. There are still some limitations of these methods. One of them is that some kinematic parameters orthogonally are not independent of the error model, hence, the position and/or orientation of the tool on the platform cannot be calibrated.

In the other approach, motion constraint approach, the mobility of the resultant system is lowered, than its inherent degrees-of-sensing position, by fixing one or more passive joints or constraining partial DOF of the manipulators so that the calibration algorithm can be performed. In their research, Park et al. lowered the mobility of the tool of a serial manipulator and performed self-calibration by using only the inherent joint sensors in the manipulator. Consequently, this idea was used and extended to calibrate a robot system with a hand mounted instrumented stereo camera. However, the position and/or orientation of the tool on the platform cannot be calibrated, and some parameter errors related to the locked passive joints may become unobservable in the calibration algorithm due to their ability constraints.

Laser pointer could also be used for self-calibration of a robot through line-based approach. With the restriction of cost, absolute accuracy of a robot can be achieved to a large extent through the calibration of its geometric parameters using these techniques. However, these systems are not only expensive but also not user-friendly. In order to perform calibration, production has to be halted until the set-up, calibration and programming are completed. This interruption causes undesirable delays in the process cycle and inflicts losses due to the downtime. Therefore, some studies as in references have proposed autonomous calibration methods which do not require an external sensor, thus, eliminate the need for elaborate time consuming setup. Since all the industrial robots are equipped with joint sensors, these were used, along with orientation sensor and camera fixed on the robot, to measure the tool position and orientation.

The use of self-calibration reduces production downtime. However, the downtime needed for solving kinematic equations for calibration and programming the kinematic parameters is still present. Hence, some studies as in references managed to eliminate the occurrence of any production downtime through implementing online calibration using different algorithms and processing techniques. These techniques have been proven to be efficient and accurate, yet the use of visual camera for position tracking and running image processing algorithms in real time requires a huge amount of CPU processing power and is relatively slow.

Following all of that, we introduced the utilization of ultrasonic triangulation in position tracking and Inertial Measurement Unit (IMU) for orientation measurement in Six Degrees of Freedom (6-DOF) robot calibration. The use of ultrasonic triangulation for position tracking increases processing speed and reduces demand for computational power, therefore allowing the robot to be more responsive.

Shraga and Johann presented a method for measuring the relative position and orientation between two mobile robots using a dual binaural ultrasonic sensor system. DO Kim et al. introduced a GPS system using ultrasonic sensor for a mobile robot to perceive its’ location. Ultrasonic sensors (sonars) are commonly used for range measurements, including robotics applications as in and . This paper is organized as follows; Section 2 provides the kinematic modeling for the ABB IRB120 robot, Section 3 discusses the methods of the pose measurements and parameters identification in details, finally discussion and conclusion of the paper are presented in Section 4 and 5 respectively.

2. Case study - kinematic model

Many researchers have found suitable robot kinematic models since 1980s, such as: Hayati et al. models, Veitschegger and Wu’s model, Stone and Sanderson’s S-model and Zhuang et al., model. Standard Denavit-Hartenberg (D-H) convention is the most widely used to describe robot kinematics. The error models of D-H are not continuous for the robots that possess parallel joint axes. In order to avoid the singularity of D-H convention, D-H modelling, or Hayat modelling convention were used, respectively. Singularity-free calibration model prevents the
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