euspen's 18th International Conference & Exhibition, Venice, IT, June 2018
www.euspen.eu

Fixed point calibration of an industrial robot

M. Bottin, G. Rosati, G. Boschetti

University of Padua

giulio.rosati@unipd.it

Abstract
Industrial robots have high repeatability, but lack in terms of accuracy. For this reason, dedicated calibration procedures are often necessary to fulfil functional requirements of the application. A new method is proposed, which addresses the problem of calibrating an industrial robot around a given point of the workspace. This method requires a low cost equipment, including a length gauge, one calibration sphere and a simple reconfigurable support for the gauge (tool). The tool allows two different positionings of the gauge with respect to robot tool axis, with the measuring direction either alighed or perpendicular to the axis. Several measures are performed while moving the robot along the surface of the calibration sphere, with the gauge in both configurations. At the end of the measuring procedure, a set of x-y-z corrections (in tool reference frame) are calculated, that allow to correct robot positioning along the surface of the sphere in a way that the tool axis is perfectly aligned to the centre of the sphere. Validation has been performed using a 6-axis Epson C4-A601s robot (665mm reach, 4kg payload). The standard deviation of the positioning error has been reduced of more one order of magnitude, close to robot repeatability (0.02mm).

Accuracy, Calibration, Robot

1. Introduction

The widespread demand for a high variety of product models and small batch production makes flexible robotic systems an emerging need in manufacturing industry [1,2,3], which in turn requires reconfigurable feeding systems, machine vision sensing and proper design of the gripper [4,5,6]. Robotics is also rapidly emerging as a valuable tool in new sectors like surgery and rehabilitation [7,8], where task complexity and variability is extremely high. In this context, robot calibration becomes a key point, and in order to calibrate an industrial robot, usually expensive equipment is used [9], often with multiple devices [10,11]. Because of the wide variety of calibration techniques, a hierarchy has been proposed, based on the complexity of the mathematical model [12]. In this article we propose a low cost 1st level method to calibrate an industrial robot around a given point of the workspace.

2. Hardware equipment

The equipment consists only in a length gauge, one calibration sphere and a simple reconfigurable support for the gauge (robot tool). All the data from the gauge is stored and processed by a workstation outside the workcell.

2.1. The length gauge

The length gauge is a device that measures a distance by evaluating the travel of a cylinder along a specific direction. This is possible thanks to an encoder and a pulse meter placed inside the device. The length gauge used in our setup is the HEIDENHAIN ST 1278 (in figure 1b the gauge is mounted on the support), with a measuring range of 12 mm and an accuracy of ±1 µm. The connection with the workstation is established by a serial port at a fixed frequency.

2.2. The calibration sphere

The surface measured by the length gauge has to be known in order to perform a good calibration, so a calibration sphere is used (figure 1a). The calibration sphere is a 20mm Metroutil SPHM-20C. The grade of the sphere [13] is 10, so the shape tolerance limits are lower than the accuracy of the length gauge. The calibration sphere can then be assumed as a perfect sphere with a known diameter.

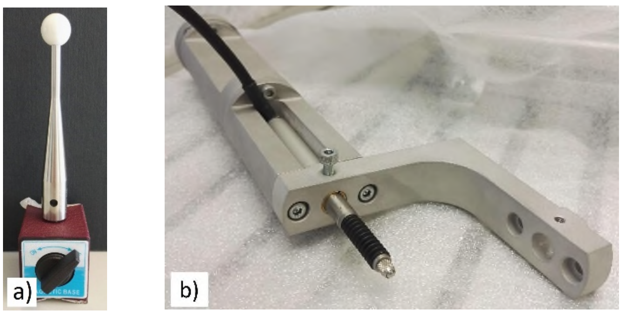

Figure 1. *a*) the calibration sphere with its support. *b*) the reconfigurable support with the length gauge parallel to joint-6 axis.

2.3. The reconfigurable support

The support is composed by several pieces: a flange that connects the support with the robot, an interchangeable part that may vary to change the total length of the calibration tool, a gauge holder and a 'L' shaped piece. In figure 1b all the pieces are assembled together, and the total length of the calibration tool is such that the center of the sphere is positioned at 250 mm from the robot flange[1]. The 'L' part of the support allows the positioning of the length gauge in two different configurations: length gauge parallel to the joint-6 axis, or perpendicular.

[1] This dimension must be adjusted, by substituting the interchangeable part, to fit the length of the tool that will be used in the application. This condition is necessary to guarantee the usability of calibration results in the application.

3. Calibration method

The calibration method is composed by several steps:

1. Alignement the length gauge with the joint-6 axis; by aiming it through an approximate position of the sphere's centre, several contact measurements are performed over a grid of points defined on the surface of the sphere, estimating the distance of sphere centre from robot tool (the diameter of the sphere is known).
2. The length gauge is placed perpendicular to the joint-6 axis, so it can touch the side of the sphere, aligned with the sphere centre. Several joint-6 rotations are performed acquiring the data from the gauge to estimate the real position of the sphere centre in a plane that is orthogonal to joint-6 axis. Such measures are repeated on the same grid of points used for distance measures, with the joint-6 axis of the robot always aiming at the sphere center.
3. A set of x-y-z corrections (in tool reference frame) are calculated, so the robot positioning is corrected, making it possible to align the joint-6 axis with the sphere centre.
4. This correction data is interpolated for each coordinate, in order to obtain a correction function outside the measurement grid.
5. Validation is performed by moving again the gauge on the surface of the sphere and measuring gauge reading.

Steps 1 and 2 are both necessary, since the first one is used to calculate z correction, whereas x-y corrections computation is based on data collected during step 2.

4. Results

Experimental tests have been performed with a 6-axis Epson C4 robot. The support is made by aluminium and craved at the milling machine. Figure 2 shows the positioning error of the robot before the calibration. The fitting purple lines are defined by a polynomial function, and can be applied as a modification of the robot target position in the area.

Figure 3 shows the positioning error in the x-y-z coordinates for each joint position. While the blue dots define the pre-calibration scenario, the black crosses show the positioning error after the implementation of the polynomial function shown in figure 2. The standard deviation of the positioning error is reduced of one order of magnitude in all directions, reaching values close to robot repeatability which is 0.02mm (table 1). The greatest reduction is obtained along the tool axis (z).

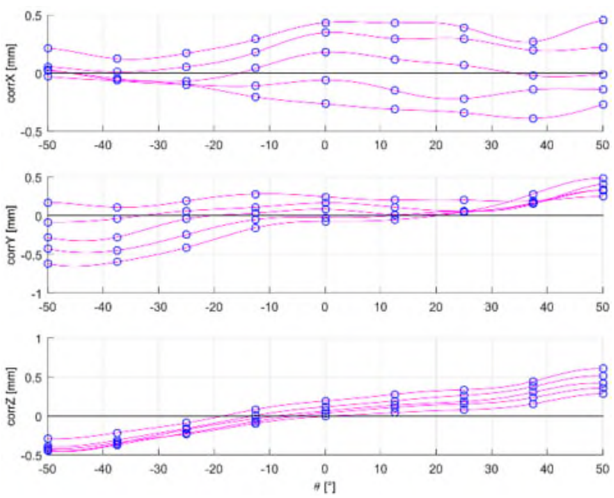

Figure 2. X-y-z positioning errors (circles) in the tool reference frame during the rotation around the joint-6 axis. The θ angle defines the azimuth. The different fitting lines define different tilting angles (elevation).

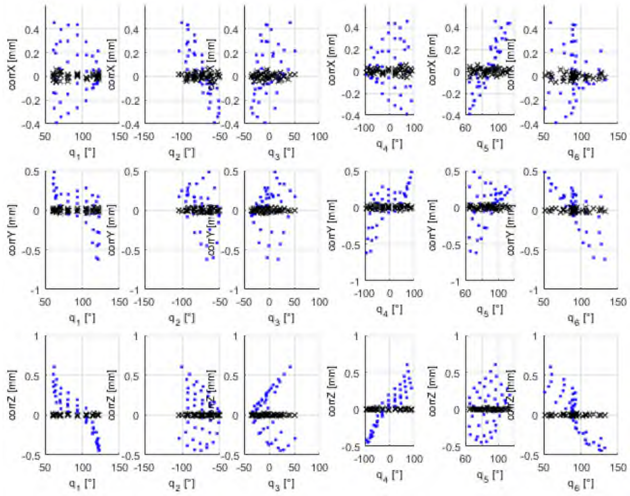

Figure 3. Positioning error. For each joint position the initial error (dots) is reduced after the calibration (crosses).

Table 1 x-y-z mean positioning error before and after the calibration.

	Before calibration	**After calibration**
$X_{error} \pm 2\sigma_x$ [mm]	0.040 ± 0.437	0 ± 0.047
$Y_{error} \pm 2\sigma_y$ [mm]	0.025 ± 0.502	0 ± 0.038
$Z_{error} \pm 2\sigma_z$ [mm]	0.030 ± 0.560	0 ± 0.014

5. Conclusion

A basic equipment together with a simple procedure can be enough to improve the accuracy of robots in a small volume. This can be satisfactory for a wide range of applications.

References

[1] Barbazza L, Faccio M, Oscari F, and Rosati G 2017 Agility in assembly systems: a comparison model *Assembly Automation* **37(4)** 411-421

[2] Rosati G, Faccio M, Barbazza L and Rossi A 2015 Hybrid flexible assembly systems (H-FAS): bridging the gap between traditional and fully flexible assembly systems *International Journal of Advanced Manufacturing Technology* **81(5-8)** 1289-1301

[3] Rosati G, Faccio M, Carli A and Rossi A 2013 Fully Flexible Assembly System (F-FAS): a new concept in flexible automation *Assembly Automation* **33(1)** 8-21

[4] Rosati G, Boschetti G, Biondi A and Rossi A. 2009 On-line dimensional measurement of small components on the eyeglasses assembly line *Optics and Lasers in Engineering* **47(3-4)** 320-328

[5] Rosati G, Minto S and Oscari F 2017 Design and construction of a variable-aperture gripper for flexible automated assembly *Robotics and Computer-Integrated Manufacturing* **48** 157-166

[6] Boschetti G 2016 A picking strategy for circular conveyor tracking *Journal of Intelligent & Robotic Systems* **81(2)** 241 255

[7] Masiero S, Poli P, Rosati G, Zanotto D, Iosa M, Paolucci S and Morone G 2014 The value of robotic systems in stroke rehabilitation *Expert Review of Medical Devices* **11(2)** 187-198

[8] Boschetti G, Rosati G and Rossi A 2005 A haptic system for robotic assisted spine surgery. In Proceedings of the IEEE Conference on Control Applications CCA05, pp. 19-24, Toronto, ON, Canada, August 29-31

[9] Bergström G 2011. Method for calibrating of off-line generated robot program (Master of Science Thesis). Retrieved from http://publications.lib.chalmers.se/records/fulltext/153281.pdf

[10] Joubair A and Bonev I A 2015 Kinematic calibration of a six-axis serial robot using distance and sphere constraints *The International Journal of Advanced Manufacturing Technology* **77(1-4)** 515–523

[11] Joubair A and Bonev I A 2015 Non-kinematic calibration of a six-axis serial robot using planar constraints *Precision Engineering* **40** 325–333

[12] Roth Z, Mooring B and Ravani B 1987 An overview of robot calibration *IEEE Journal on Robotics and Automation* **5(3)** 377–385

[13] AFBMA standard, American National Standards, 1989, Metal Balls.