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A new method for measuring a large set of poses with a single telescoping ballbar

Albert Nubiola, Mohamed Slamani, Ilian A. Bonev*

École de technologie supérieure, Montreal, QC, Canada

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ABSTRACT

This paper presents a novel method of measuring a set of more than fifty poses under static conditions, using a single telescoping ballbar and two fixtures, each bearing three equally spaced magnetic cups. The position accuracy of the device is in the ±0.003 mm range, making it suitable for measuring the pose accuracy and repeatability of industrial robots and even calibrating them. The proposed method is an extension of a known approach using a hexapod (a Stewart-Gough platform) comprising telescoping ballbar legs and provides an original solution to the constraint imposed by the limited measurement range of current telescoping ballbars, namely an innovative hexapod geometry capable of assembly in 144 different configurations. An additional advantage of the method is that the pose of one fixture with respect to the other can be obtained for each of these configurations by solving a cascade of three quadratic equations using the six hexapod leg lengths as input. The application of the device and method to measuring numerous poses of an ABB IRB 120 industrial robot is presented.

1. Introduction

Precise and accurate measurement is required in order to evaluate the end-effector pose (position and orientation) repeatability and accuracy of six-degree-of-freedom (6-DOF) machines such as six-axis industrial robots, as it is for their calibration. Under static conditions, any 3D coordinate measurement system can be used to measure the pose of a rigid body by measuring the position of three non-collinear points on that body. Conventional coordinate measurement machines (CMMs) provide some of the most accurate measurements for this purpose, but are bulky and very expensive. Laser trackers are an excellent alternative for applications involving industrial robots (robots being much less precise than machine tools), but they too are expensive (over $100.000) and have the additional drawback of high sensitivity to ambient disturbances. Measurement arms are probably the least expensive 3D measurement systems, and the smaller units may provide volumetric measurement accuracies of 0.020 mm.

There are also 6D measurement systems such as so-called optical trackers (*e.g.* the C-Track from Creaform or the OPTOTRAK from NDI) or laser trackers combined with a 6D probe (*e.g.* Leica's T-Mac or API's Smart-TRACK). The cost of these systems is often prohibitive and the accuracy provided is not comparable to that of a CMM [1].

A much less expensive yet very accurate commercially available system for measuring 6D poses (under static conditions) is single-camera photogrammetry (*e.g.* the MaxSHOT 3D from Creaform or the DPA from AICON). The volumetric accuracy of these systems is comparable to that of measurement arms. Unfortunately, they are relatively difficult to operate. A single pose measurement requires a multitude of photos taken from relatively long distances and various viewpoints.

Measurement arms and almost all conventional CMMs are based on so-called serial mechanisms (all links are connected in series through revolute or prismatic joints instrumented with encoders). However, parallel mechanisms can potentially improve accuracy and lower cost. For example, Lapic (Russian Federation) has been manufacturing CMMs for at least two decades, based on 6-DOF parallel mechanisms called *hexapods* (Fig. 1). A hexapod (also called a *Stewart-Gough platform*) most often consists of an end-effector connected to a base through six telescoping legs.

Although the origin of hexapods with telescoping legs dates back at least to the late 1940s [2], the idea of using them as passive 6D pose measurement devices seems more recent. Schiele et al. [3] patented in 1986 a method for measuring the position or pose of a robot end-effector using respectively three (Fig. 2a) or six telescoping ballbars. Seven years later, Goswarni et al. [4] reported the development of a very similar hexapod pose measurement device (Fig. 2b, courtesy of Prof. Michael Peshkin) consisting of two fixtures with magnetic cups, the distances between each cup center of one fixture to at least two cup centers of the other fixture being measured using a single telescoping ballbar from API. An industrial robot was thus guided through the same path nine times, with dynamic measurement of one of the possible nine distances

* Corresponding author.
E-mail address: ilian.bonev@etsmtl.ca (I.A. Bonev).

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Fig. 1. A CMM of hexapod design.
Courtesy of Lapic, Russian Federation.

each time, and the resulting data were used to calibrate the robot. Renishaw co-founder David R. McMurtry was later granted a US patent for a very similar device (Fig. 3c) and Paul C. Sheldon was granted a US patent [6] in 1999 for a hexapod CMM such as the one shown in Fig. 1. More recently, Gilles Diolez [7] developed three 6D pose measurement devices, two of these being hexapods each using six custom-designed telescoping ballbars simultaneously and one being an octopod using eight custom-designed telescoping ballbars simultaneously.

Since the telescoping ballbar is a relatively low-cost off-the-shelf high-accuracy device, the previously proposed pose measurement methods [3–5] illustrated in Fig. 2 seem suitable for robotic applications. Unfortunately, these methods no longer work with today's commercially available telescoping ballbars.

The telescoping ballbar was invented in the USA in the early 1980s by James B. Bryan at the Lawrence Livermore National Laboratory [8,9] and licensed in 1986 to Renishaw, who introduced their first commercial version in 1992. In 1987, Drs Naren Vira and Kam Lau, then of the US National Bureau of Standards and unsatisfied with the limited measurement range of Bryan's ballbar (making it

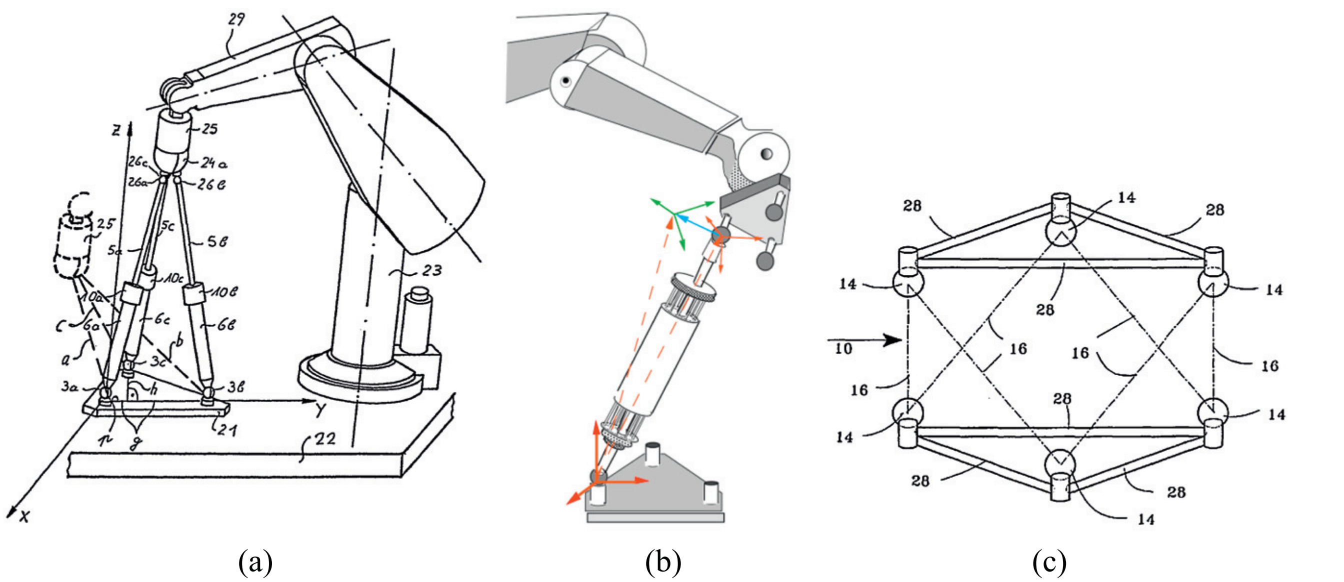

Fig. 2. Early designs using telescoping ballbars in a hexapod arrangement for pose measurements.

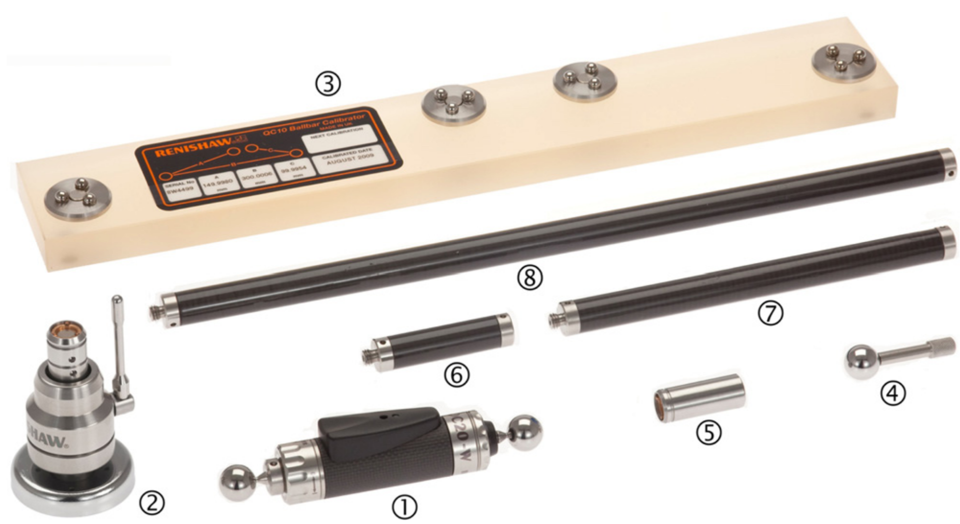

Fig. 3. The main components of the standard QC20-W kit from Renishaw: (1) QC20-W ballbar; (2) center pivot assembly; (3) Zerodur calibrator; (4) setting ball; (5) magnetic cup; (6–8) 50 mm, 150 mm and 300 mm extension bars.