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Robot measuring form errors

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Abstract

This work presents an automated system for the measurement of form errors of mechanical components using an industrial robot. A three-probe error separation technique was employed to allow decoupling between the measured form error and errors introduced by the robotic system. A mathematical model of the measuring system was developed to provide inspection results by means of the solution of a system of linear equations. A new self-calibration procedure, which employs redundant data from several runs, minimizes the influence of probes zero-adjustment on the final result. Experimental tests applied to the measurement of straightness errors of mechanical components were accomplished and demonstrated the effectiveness of the employed methodology.
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Keywords: Industrial robot; Measurement automation; Straightness error; Multi-probe method

1. Introduction

Performing fast and accurate measurements are perhaps the most sought-after goal of the mechanical industry nowadays. Despite the extensive growth of the CNC machines market for the past 25 years, almost all shop-floor measuring processes rely even today on manual instruments and conventional techniques. One way to enhance existing automated manufacturing processes is to integrate an automated measuring system to the production line. Automatic measuring instruments are especially helpful for total inspection aiming selective assembly. If compared to conventional techniques, automatic measurement can be quickly accomplished and is free from human operator influence. A rather straightforward manner to develop an automated instrument is to use an industrial robot as a base.

Industrial robots can easily perform repetitive low-accuracy tasks, such as welding, painting and loading/unloading. Relatively low acquisition and maintenance costs, easy programming and fast execution of the programmed tasks make robots an attractive investment. Regarding accuracy requirements, however, the application of industrial robots as measuring instruments is not recommended. Currently available accuracy levels of industrial robot technology, in general, are not enough to allow reliable measurements when taking the robot coordinate system as a reference. Factors such as tolerances of parts that compose the robot structure, elasticity at joints, resolvers resolution, control system limitations, among others, produce a unique behaviour in each robot, which even limits the application of error compensation techniques.

Concerning the possibility of adapting a piece of measuring equipment to the wrist of a robot to make measurements [1], observes that, conceptually, a measurement device mounted to the end-effector of a robot will only be as accurate as the robot positioning. Therefore, robot coordinate system cannot be considered a reasonable reference for measurements. In order to make measurements independent from the robot coordinate system, it is necessary to employ some error separation technique allowing decoupling between errors of the artefact and those originated from the robotic measuring system. Error separation techniques are especially desired when errors from the measuring system are not negligible if compared to measured magnitude.

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The reversal technique, which is possibly the most renowned error separation technique, was developed to evaluate machine tools slideways [2]. The work by Ref. [3] presents a very comprehensive review of various reversal techniques, which are applicable to a wide range of common situations in the mechanical industry.

Multi-probe error separation techniques, compared to reversal, present the advantage of avoiding artefact manipulation. On the other hand, multi-probe methods require the acquisition of redundant data and besides, depending upon the type of the measured error, a specific probe arrangement is needed. A description of the theory behind both multi-orientation and multi-probe methods can be found in Ref. [4].

Three-probe methods applied to straightness error measurement are allegedly able to separate part error from both translational and angular errors of the scanning stage [5,6]. However, the three-probe method is extremely sensitive to the presence of zero-adjustment errors of the probes. The difference between the zero-readings of the probes introduces a parabolic bias term in the measured profile, which entirely deteriorates the result [7].

In this work, an automated and dedicated multi-probe measuring system for straightness error evaluation is presented. The system is basically composed of an industrial robot, specifically arranged displacement sensors and a multi-probe error separation mathematical model. A self-calibration procedure was developed to minimize the influence of zero-adjustment errors between probes. Experimental tests were performed and proved the efficiency of the proposed technique.

2. Robot-based inspection device

During the selection of a measuring system, several factors must be considered, for instance, the verified geometry, the required levels of tolerance, the number of parts to be tested, the degree of complexity of parts and the ability of reconfiguration to meet possible modifications in the production line. Fig. 1 indicates that a measuring system can be determined taking into account the lot size and the variety of parts to be verified [8].

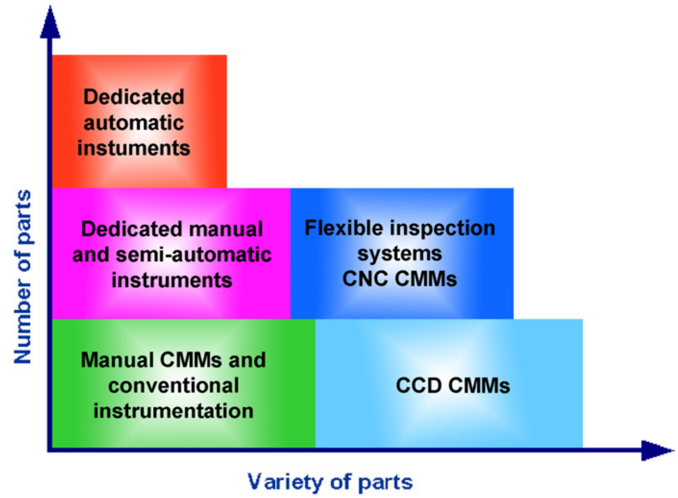

Fig. 1. Measuring system selection considering part number [8].

Coordinate measuring machines (CMM) are perhaps the most flexible measuring instruments of today, presenting the ability of measuring Cartesian coordinates of spatial points by means of scales and, frequently, a touch-trigger type probe, which can be replaced by laser scanning probes or CCD cameras. Some current models present resolution of about 0.1 μm. Complex geometry workpieces can be evaluated rather straightforwardly with CMMs. Considering the case of large lots of relatively simple geometry parts, dedicated and automated measuring instruments are potentially more efficient. Total inspection is sometimes considered undesirable, since it would indicate that the process is prone to errors [9]. However, some authors state that the aim of total inspection is not to compensate for poor process, but rather to identify very defective parts [10]. Moreover, total inspection can be used to classify and separate parts for selective assembly. In this case, a CMM is not so effective as an automated and dedicated measuring system.

Additional aspects can yet be considered in the implementation of a robotic measuring system: firstly, industries aim the increase of product quality by enhancing manufacturing process control. One manner to tackle this issue consists in using automatic systems due to the absence of human effects. Another factor to be considered is the velocity at the execution of a task. As long as the robot can provide velocity, larger productivity can be attained.

About the utilization of articulated arms [11], consider that repeatability and accuracy of this configuration are not good enough to allow the realization of precision tasks. As a matter of fact, robot accuracy, which is rarely quoted on manufacturers booklets, can sometimes be several orders of magnitude worse than positioning repeatability [12].

A measuring system that consisted of a robot and one displacement sensor for evaluation of roundness errors on cross sections of cylindrical parts was presented by Ref. [13]. The robot was employed just to place the transducer at three measuring locations around the workpiece and error value was calculated by means of the three points method [14].

In the field of non-contact measurement, several industries have been employing laser scanning devices on the wrist of robots in order to accomplish so said "more precise" measurements. However, measurement accuracy is limited by the accuracy of the robot itself, which is around 100 μm. Some examples of this type of application, which are considered low precision tasks, are the inspection of free-form shape workpieces using laser scanning [15], the application of an industrial robot with a laser scanning device to verify weldments on truck frames [10]. In order to cope with the poor positioning accuracy of industrial

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