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Discontinuity check of scanning in coordinate metrology

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ABSTRACT

The paper presents a new algorithm for detecting the presence of measurement discontinuities in scanning measurements carried out on coordinate measuring machines (CMMs). The proposed algorithm marks the regions that are inaccessible to the stylus tip. This allows the machine user to decide whether to change the tip for a smaller one. The method is for use in a high-definition coordinate metrology (HDCM) context, where the density of points per scanned distance ensures that the successive probe ball positions overlap partially with each other and can be applied directly to the data collected during a measuring process. The paper describes the operating principle of the new algorithm and experimental verification on a Zeiss ACCURA CMM with an active VAST Gold scanning probe.

1. Introduction

One of the most difficult measurement tasks is to scan an unknown surface with a geometrically complex shape. New generation measurement scanning probes are gaining in popularity as a standard equipment of coordinate measuring machines (CMM) because they offer new and effective possibilities for taking measurements not only of dimensions, but also positioning and shape. These probes can gather dense sequences of measured points without leaving the tested surface. By not having to hop along the surface, the continuous contact mode significantly increases speed and precision of measurements.

Discontinuity of scanning measurement occurs when a local radius of curvature of the measured surface is smaller than the radius of the spherical probe tip, as shown in Fig. 1. Its occurrence may be limited by using styli of smaller tip radius. But those styli my cause larger measurement errors, resulting from their low stiffness and of oscillations induced by their movement on the measured surface. The smallest tip employed in coordinate technology, which may be used with scanning probes, are of 0.3 mm radius. But even using such a small tip does not solve the problem of the measured surface discontinuity in relation to the scanning process. The problem is that the CMM users are often unaware of the existence of discontinued areas since the CMM software does not provide for their detection.

Therefore, a distorted measurement result smoothing the measured profile is given, instead of information that the areas are impossible to measure with a tip of the given radius. The CMM user is not aware that the measuring tip is not able to penetrate certain areas of the measured profile.

Such tool for detecting the presence of measurement discontinuities in scanning measurements carried out on coordinate measuring machines is unknown to date. Existing methods of the adaptive sampling for model-unknown sculptured surface coordinate metrology [1–5]. Also, some attempts to estimate uncertainty using the so-called virtual CMM [6–10] does not solve the discontinuity detection problem.

In previous papers [11,12] authors described an algorithm for stylus tip radius correction which enables not only to calculate corrected measured points but also to provide a discontinuity check of the measured profile. It

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also provides CMM user with a tool to evaluate the correctness of measurements and optimize the measuring process by selecting an appropriate stylus tip.

2. Stylus tip radius correction

Corrected measured points (estimators of the actual point of tangency between the stylus tip and the surface of the measured object) are estimated by adding a vector, of length equal to the effective stylus tip radius, to the indicated points. The direction of this vector should be the direction normal to the surface of the measured object at the point of tangency with the stylus tip.

Many solutions are known that can be used to determine the direction of the stylus tip radius correction vector. If the nominal geometry of the measured section is known, it is relatively easy to calculate a normal vector based on the CAD model of the measured surface [13–15]. If the shape of the measured object is unknown the correction vector can be estimated using the information retrieved from the force transducers of active scanning probes [16,17] or making use of the information on the reciprocal position of neighboring indicated measured points [18–24]. Till now the most accurate algorithms employ NURBS curves [18,24] which are used to approximate the path of the stylus tip center. Then the direction of the correction vector is determined as perpendicular to the curve. This leads to the smoothing of the actual shape of the surface, and therefore points may be generated even in places inaccessible to the stylus tip due to the constraints of its diameter. Such an effect can be noted when measuring concave surfaces.

3. Outline of new correction algorithm

A new algorithm for corrected point calculation was proposed [11,12] that do not require a correction vector to be calculated. The algorithm is intended for high-density sampling, i.e. those in which the distance between indicated measured points is considerably smaller than the diameter of the stylus tip.

The general idea of the new algorithm is presented in Fig. 2. The ball-shaped stylus tip moves across the surface. At the same time, the position of the stylus tip center, the indicated measured points O_i, are recorded at a defined spatial frequency. Let us leave a circle trace of the stylus tip at each measured point and consider the overall envelope of these circles. The envelope is composed of the arcs, each with a radius equal to that of the stylus tip, caused by

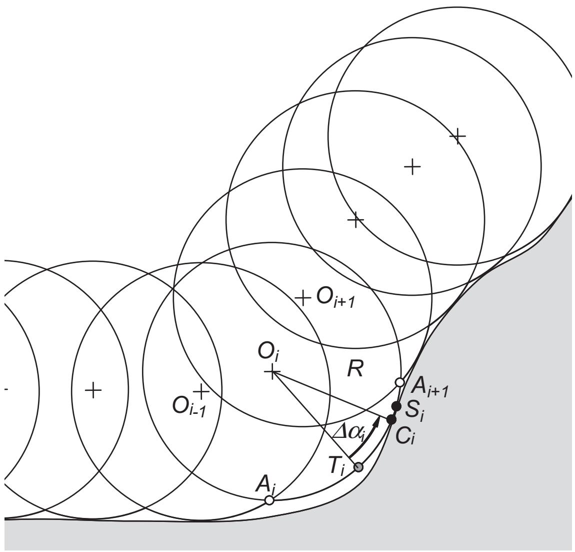

Fig. 2. Analysis of the subsequent positions of the stylus tip in scanning measurements to determine corrected measured points using the new stylus tip radius correction algorithm.

subsequent circles crossing at points A_i. The A_i points designating the arc boundaries are given by known geometry principles as

$$A_i = \begin{bmatrix} -|O_iO_{i-1}|/2 \\ \sqrt{R^2 - (|O_iO_{i-1}|/2)^2} \end{bmatrix}. \tag{1}$$

The sought corrected measured points, which are estimates of the actual points of tangency between the stylus tip and the surface of the measured object are located only and exclusively on the resultant arcs. The first approximation of a corrected measured point may be point T_i, which is the center of the corresponding arc. The coordinates of point T_i can be obtained with the following equation:

$$T_i = \begin{bmatrix} \cos\alpha_i & -\sin\alpha_i \\ \sin\alpha_i & \cos\alpha_i \end{bmatrix} \begin{bmatrix} -|O_iO_{i-1}|/2 \\ \sqrt{R^2 - (|O_iO_{i-1}|/2)^2} \end{bmatrix}, \tag{2}$$

where

$$\alpha_i = \frac{1}{2} ar\cos\left(\frac{\overrightarrow{O_iA_i} \cdot \overrightarrow{O_iA_{i+1}}}{|\overrightarrow{O_iA_i}||\overrightarrow{O_iA_{i+1}}|}\right). \tag{3}$$

To determine a more likely position of the tangency point S_i on the arc, correction angle $\Delta\alpha_i$, and consequently the coordinates of point C_i that are closer to the actual point of tangency, has to be calculated as follows:

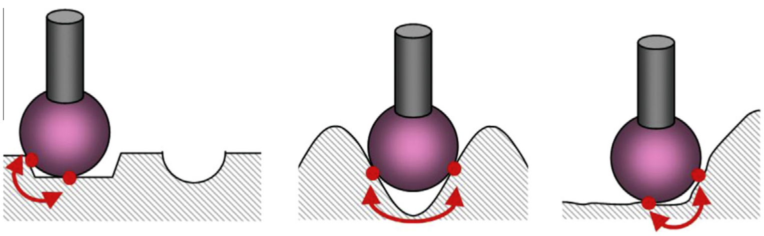

Fig. 1. Examples of the measured surface discontinuity during the scanning process.