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Linking of multi-sensor measurement data for micropart measurements

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Abstract

Multi-sensor coordinate metrology is one of the most important development trends in industrial dimensional metrology and has great potential to fulfil the requirements to measure complex microparts. When measuring with different sensors, the data needs to be linked, so a common coordinate system is established. In this work we will address the case when the sensors are part of the same measuring machine. In particular, the linking of the two sensors, 3D-tactile and optical-vision, of the Zeiss F25 µCMM has been investigated. Measurements have been performed on different linking standards, such as a sphere and a half-sphere. The uncertainty of the linking has been investigated. Besides the repeatability of performing the linking, there are systematic effects. E.g., systematic differences arise due to the fact that different points or amount of the points are measured on e.g. a sphere by the different sensors resulting in a different calculated origin of the sphere. Also the strategy of the origin calculation differs for the different sensors which is also a contributing factor to the observed measurement errors. Furthermore, temperature drift effects originating from the lighting have been observed. The results on the different linking standards and the derived uncertainty of linking will be discussed including approaches to minimize the systematic differences.

Keywords: CMM, linking, multi-sensor, metrology, tactile, optical, microparts

1. Introduction

A Coordinate Measurement Machine (CMM) is a universal tool for high-precision measurements of the geometrical characteristics of an object. The common parts of a CMM are a computer, controlled moving stage and a sensor. A mechanical tactile probe plays the role of a 'classical' sensor. Specially developed µCMM are nowadays capable of measurement uncertainties on the sub-micrometer level [1]. Even though a tactile probe is the most common sensor in CMM applications, slow measurement speed and accessibility limitations of this probe result in the necessity of multi-sensor CMMs to measure complex microparts.

For example, the optical ViScan camera sensor of the VSL's Zeiss F25 µCMM (Figure 1) allows to perform high-resolution, high-speed dimensional measurements. This sensor can be used for standard calibration routine with repeatability below 0.12 µm and measurement uncertainty below 0.13 µm for unidirectional and 0.5 µm for bidirectional measurements [2, 3].

Figure 1. The photo of the tactile and optical sensors of the Zeiss F25 µCMM.

In order to link the sensors, Zeiss offers a dedicated calibration standard, F25-R02 that is shown in figure 2. This standard contains two elements, that can be used for linking the sensors: a 1 mm sphere intended for rough/initial linking and a reversed half-sphere. The reverse half-sphere has the advantage to better define the Z-coordinate and as disadvantage that not the full sphere can be measured due to accessibility constraints. The linking of both sensors results in synchronizing both sensors during repeated measurements and is evaluated, to our knowledge, for the first time in µCMMs. We evaluate the linking of the tactile and optical sensors between these two elements below.

2. Experimental setup and measurement scheme

The Zeiss F25 µCMM, has two types of sensors: tactile and optical. The tactile sensor has a 300 µm diameter ruby sphere that is glued on a metallic shaft that is mounted on a chip that has piezo-resistive displacement sensors. The optical sensor, VIScan, consists of a 10X magnification lens with a working distance of 45 mm that forms an image on a digital 1/3'' ExView CCD camera produced by Sony.

In order to link the two sensors, firstly we measured the half-sphere of the F25-R02 calibration standard (Figure 2 (bottom panel)) by using a tactile probe. For this purpose, the spherical surface of the half-sphere (12 points) and plane of the sphere cut (8 points) were measured. It allows constructing a circle as an intersection of the sphere and plane surfaces. Then the optical sensor was focused on the edge of the half-sphere and 4 half-sphere segments by 250 points per segment were obtained. The circle was reconstructed as the least-squares circle fit to the data.

We compared the geometrical parameters, centre coordinates of the circle for both sensors measurements. The optical measurements were repeated 200-1000 times. Overall the measurement runs took between 2 and 10 hours.

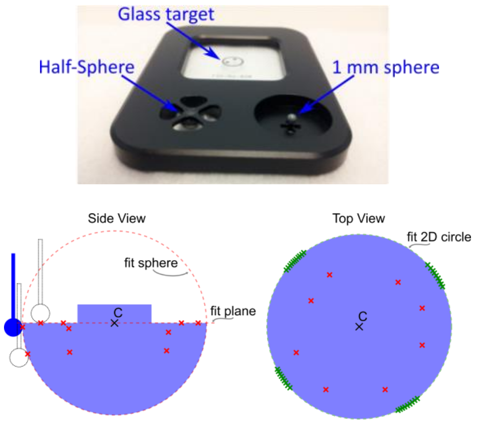

Figure 2. The calibration artefact Zeiss F25-R02 and the measurement scheme. *Top:* The 1mm sphere and the half-sphere used in the linking are indicated. *Bottom:* The measurement scheme for the half-sphere shows tactile (red crosses) and optical (green crosses) probing points.

3. Measurement results & Discussion

The experimental data for the X-coordinate (500 measurements) is presented in Figure 3 (top panel) (the measurement results for the other axes reveal similar behaviour). The measurements lasted approximately 4 hours. There was a clearly visible drift of approximately 0.7 µm and saturation for the X-axis that was associated with a thermal stabilization due to the camera/lighting “switch on”. This thermal effect was further confirmed by using tactile measurements only with switching on and off lighting state. The error distribution of short term measurement error, based on 20 measurement points and removing the drift by a high-pass filter, is presented in figure 3 (bottom panel). The distribution least-squares fit gives a standard deviation for the short-term optical measurements of σX=0.017 µm. The standard deviation for other axis is σY=0.015 µm and σZ=1.085 µm for Y- and Z-axis respectively. The standard deviations for the 1 mm sphere are σX=0.023 µm, σY=0.051 µm, and σZ=1.297 µm that is slightly larger than for the half-sphere case. This can be explained by a poorly defined edge that is crucial for low-uncertainty optical sensor measurements.

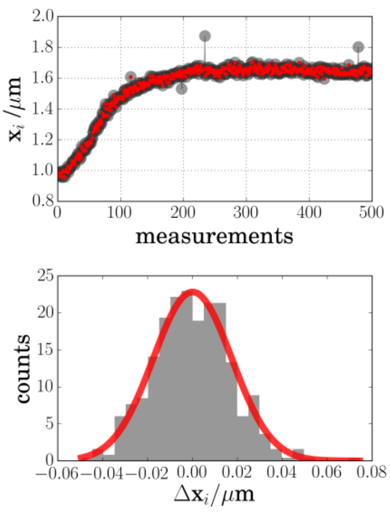

Figure 3. The linking results for X-axis of the half-sphere. *Top:* The linking X-axis coordinate difference between optical and tactile sensors. The outlier data points are indicated by grey circle only (>5σ). *Bottom:* The high-pass filtered distribution that results in standard deviation σX=0.017 µm.

4. Modelling of uncertainty using a Virtual-CMM

The uncertainty of determining the diameter of a complete sphere with the F25 was evaluated to be ~50 nm [1] which also includes an uncertainty of ~30 nm due to the probing sphere which does not play a role in linking. Here we evaluate the uncertainty of the tactile measurement of the half-sphere R02, together with its upper plane. The uncertainty of the tactile probing was assessed using an in house developed Virtual CMM (VCMM) software tool [4]. This approach has as particular merit that an uncertainty contribution for unknown systematic error of the probing system is taken into account, which may not appear in the variation of experimental measurement data. It can help to understand the experimental results and to optimize the linking procedure. The calculated uncertainty of the fitted tactile linking point amounted to $U(X_{tact})$ = 20 nm, $U(Y_{tact})$ = 20 nm and $U(Z_{tact})$ = 46 nm (k = 2). The higher uncertainty in Z_{tact} results from a systematic probing uncertainty when probing the half-sphere upper-plane. This uncertainty is somewhat averaged out when probing the spherical part of the standard, as this involves various probing directions with different probing errors. Note that in most measurement tasks the absolute systematic error in the coordinates is irrelevant, whereas in this case it directly impacts the uncertainty of the sensor linking.

Another relevant source of uncertainty for the linking is the physical off-set of (44, -8, -26) mm between the tactile and optical sensors, as geometrical errors of the F25 are different at different locations in the machine volume. The magnitude of this effect on the uncertainty of the measured linking vector is still under study.

5. Conclusions

In summary, we demonstrated the linking between the optical and tactile sensors and the associated uncertainties on the Zeiss F25 µCMM using a Zeiss F25-R02 calibration standard. It has been shown experimentally that short term measurement standard deviations for the half-sphere are slightly better than for the 1 mm sphere. This result is probably due to better defined edge.

The uncertainty evaluation by means of the VCMM of the initial tactile measurement of the half-sphere does not show an additional uncertainty as compared to that of the 1 mm sphere.

The long term uncertainty is related to the thermal influence due to the lighting heating. When designing a measurement strategy this thermal effect needs to be considered and e.g. the order in which features are measured needs to be optimized to minimize the influence.

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