Calibration of 3D reference standards using metrological large range AFM and calibrated confocal microscopy

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Objectives

A variety of three-dimensional (3D) microscopes are increasingly used in a number of industrial applications such as roughness measurements and edge contour measurements of diamond cutting tools. Traceability is a fundamental issue to ensure accurate and reliable measurements. Today, the calibration of 3D microscopes requires not only the calibration of the lateral- and height scales, but also the calibration of the flatness error of coordinate planes as well as the shearing of coordinate axes. To satisfy these demands, suitable standards and reference metrology for the accurate calibration of these standards are needed.

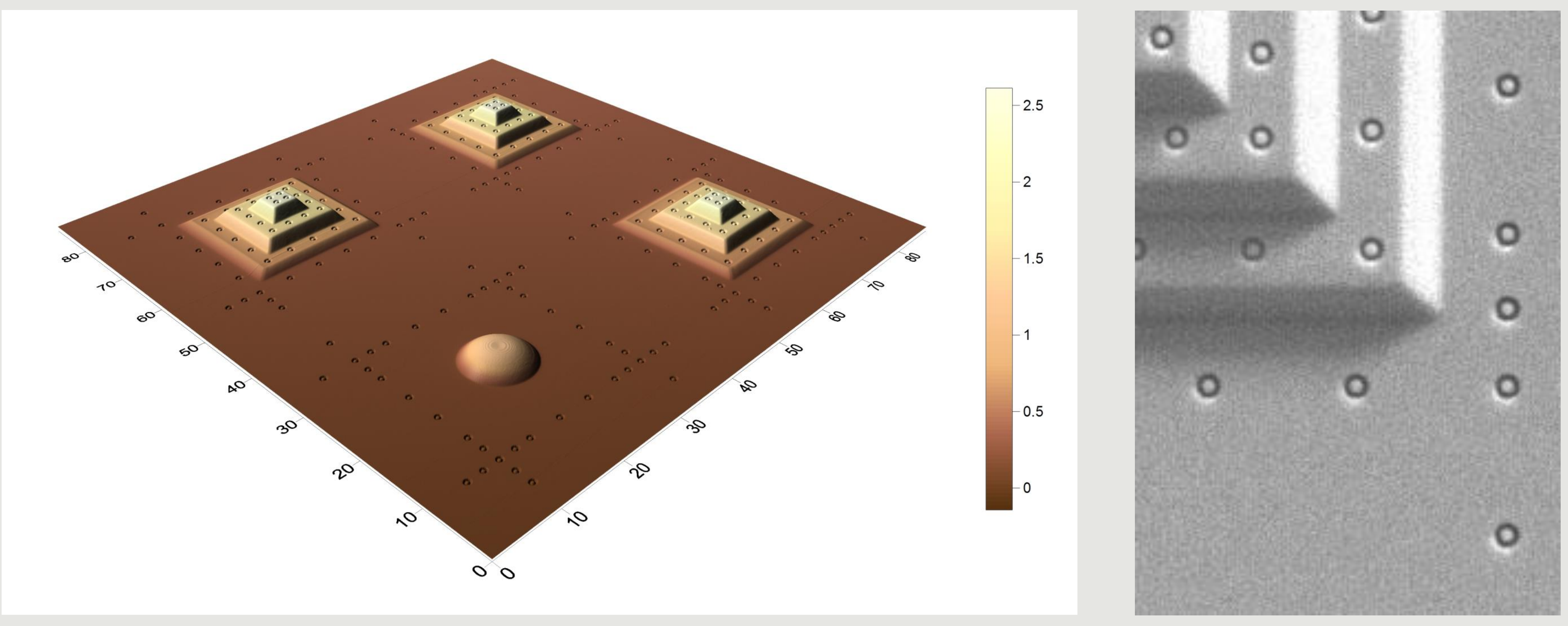

Figure 1: 3D calibration standard with reference marks, 3D view of AFM measurement data (left, units in µm), Detail (right, SEM image)

3D calibration – concept and standards

The calibration of geometric errors of 3D microscopes is usually performed by applying a set of height and lateral standards, respectively. To overcome the limitations of this approach, dedicated 3D calibration reference structures were established. For automated and statistical over-determined evaluation, the 3D calibration artefacts are equipped with a large number of laterally and vertically distributed reference marks (see figure 1). In combination with a dedicated software (figure 2), these calibration samples are applicable for the 3D calibration of various types of microscopes, e.g. atomic force microscopes (AFM), confocal laser scanning microscopes (CLSM) and 3D scanning electron microscopes (3D SEM) and thus enabling comparative or correlative measurements [1], [2].

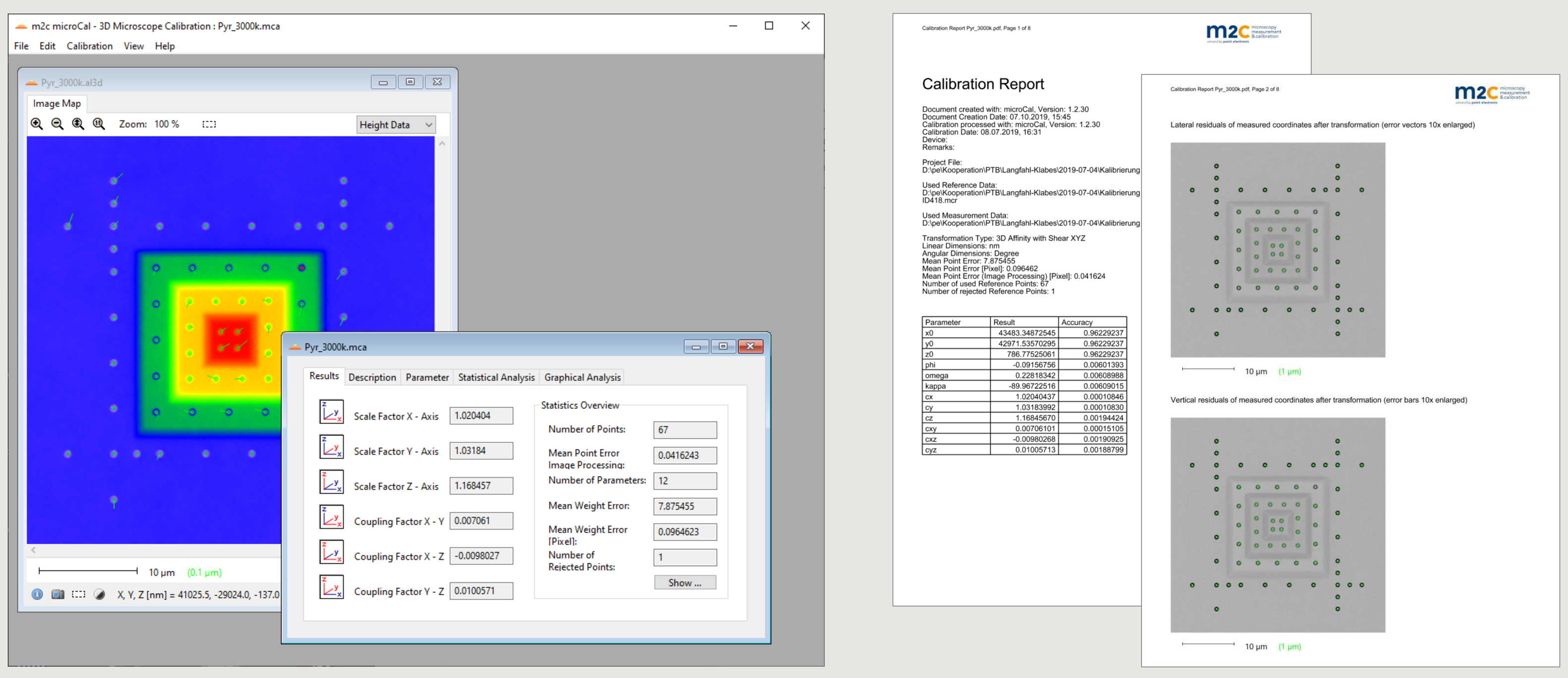

Figure 2: 3D calibration software "microCal" with 3D SEM data (left), first two pages of the automatically generated calibration report (right)

Advantages of 3D calibration

In contrast to the separate calibration of height and lateral scale, marker-based 3D calibration has the following advantages:

- Simultaneous calibration of lateral and height scale
- Calibration of shearing between all coordinate axes
- Analysis of non-linear errors (e.g. spatial distortions and drift)
- Fast and automated calibration based on feature recognition and sub-pixel marker measurement, independent of sample orientation
- Statistical evaluation of results based on Least-Squares-Method (LSM): Accuracy and reliability of calibration parameter, outlier detection

Reference measurement with confocal microscopy

For the reference measurement of the 3D calibration artefacts, a calibrated Confocal Laser Scanning Microscope (CLSM) Olympus Lext OLS4000 is applied. A number of special topics has to be considered for this application:

- 3D calibration of CLSM before and after each series of 3D artefact measurements is mandatory to ensure traceability (see figure 4)
- Repetitive measurements to determine and correct 3D drift effects (see figure 3)
- Measurements with different sample rotations and estimation of mean values of the coordinates to minimize non-systematic errors
- Integration of filtering techniques into feature recognition to avoid errors from erroneous reflections on the sample surface

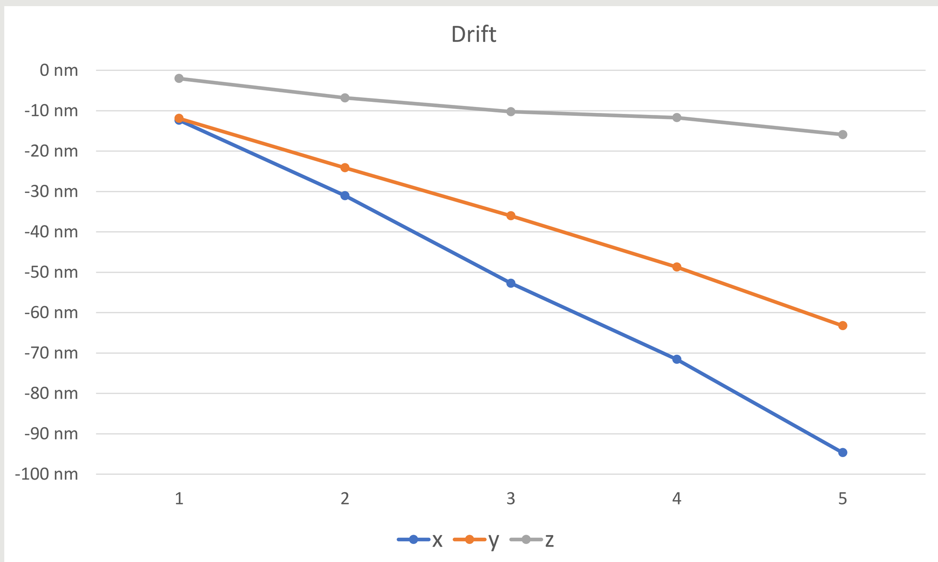

Figure 3: Typical drift of the applied CLSM (08/2019). X-axis shows the number of the measurement, which is not exactly the time axis.

Traceability to metrological AFM

To ensure the traceability of the CLSM reference measurement of the 3D calibration artefacts, the Metrological Large-Range AFM (Met. LR-AFM) of the PTB is applied [3]. This metrology tool is equipped with laser interferometers for measuring the motion along all three axes. The optical frequency of interferometers is calibrated to the frequency standards of the PTB, thus providing measurement results directly traceable to the definition of the "meter".

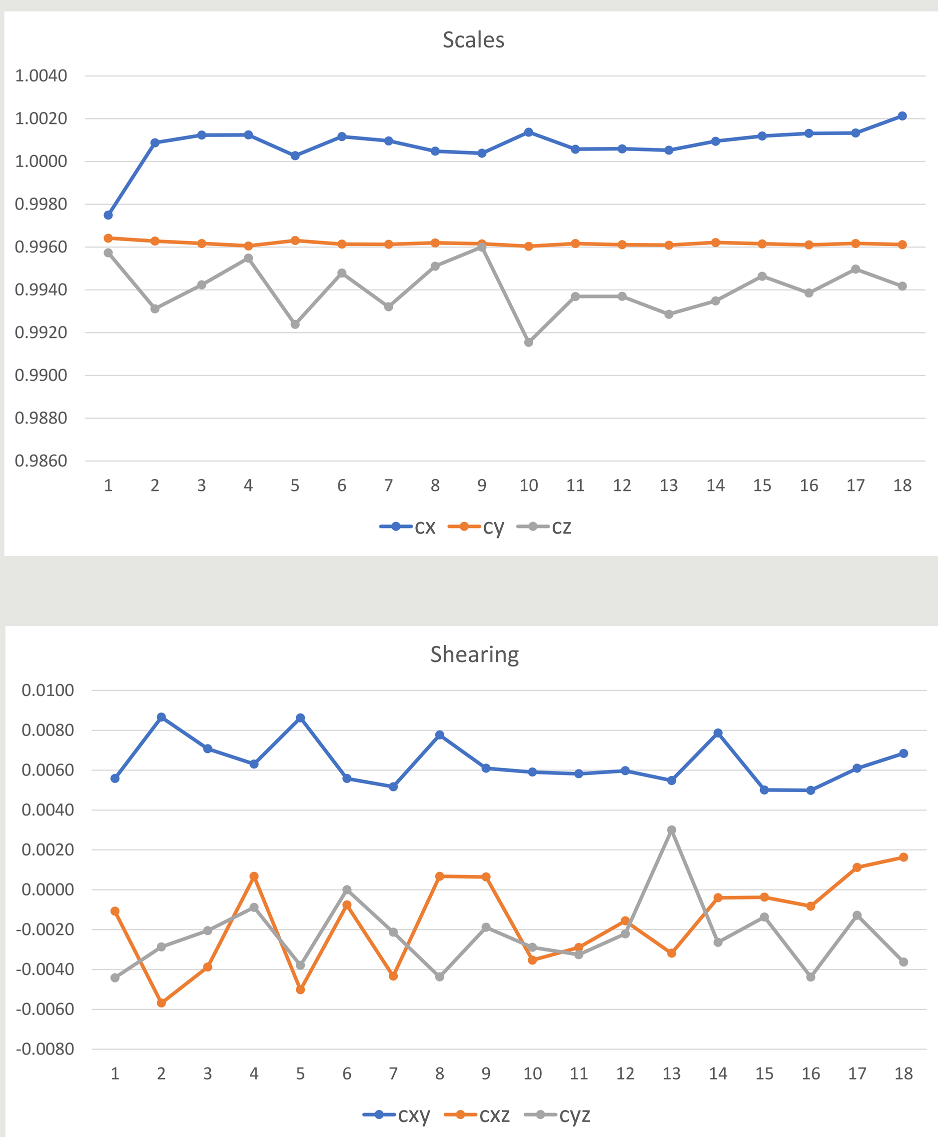

Figure 4: 3D calibration of the applied CLSM with a 3D calibration standard traceable to Met. LR-AFM during a period over 1.5 years (02/2018-08/2019). X-axis represents the series of measurements in the mentioned period, which is not equivalent to the time axis. Top: Scale correction factors in x, y and z. Bottom: Shearing correction between coordinate axes.

Summary and outlook

We introduced two solutions for the calibration of 3D reference standards. Each of these is best suited for specific needs: Calibration directly with the Met. LR-AFM for high-end applications where highest calibration accuracy is demanded and the much faster and thereby less expensive measurement with CLSM, which is calibrated with a 3D reference standard traceable to the Met. LR-AFM. Our final goal is to set up an uncertainty budget for 3D calibration standards, thus offering a complete traceable calibration solution for various 3D microscopes applied in industry.

References

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More information and detailed technical specifications can be found at www.pointelectronic.de / www.m2c-calibration.com