Robust, dense and accurate 3D surface reconstruction in SEM through automatic calibration data calculation from multiple images

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The scanning electron microscope (SEM) is an excellent tool for the characterisation of surfaces. It offers a large depth-of-focus and high contrast images with a lateral resolution up to 1nm or even below. The scanning process of a surface leads to a two-dimensional image of a three-dimensional surface. Nevertheless SEM images reveal also 3D information. In order to access this information conventional approaches analyze stereoscopic images. The major drawback of this approach is found in the sensibility to the accurate determination of the calibration data, namely the tilt angle. The user is faced with the almost unsolvable task of determine the accurate tilt angle, as most stages do not offer the desired angle resolution of 0.1 degree [1], [2].

In this paper we present a new approach that solves this problem. The operator is capturing three images at different tilt angles. The only restriction the operator is faced is a nearly eucentric tilting and a rough estimate of the tilt angle with the given order. The presented method automatically determines the true tilt angle up to 0.1 degrees accuracy based on image processing algorithms. After calculation of the accurate calibration data a dense 3D reconstruction can be calculated.

Experiments were performed with images of the size 1024 times 768 pixel resolution, captured at a pixel size of 0.3µm at a working distance of 5mm. In order to evaluate the accuracy of the system a known depth standard (Fig.1a)for tactile depth measurement devices was observed. The estimated tilt angles were 5 and -10 degrees. The automatically determined tilt angles lead to 4.49 and -9.53 degrees. The known depth of the height step is 92 µm. The reconstruction based on the classical stereo approach leads to a height measurement of 79.1µm (Fig.2). The difference to the true height is found in the wrong tilt angles. The automatically determined angles lead to a height measurement of 93.2µm (Fig. 2).

The resulting digital elevation model (DEM, Fig.1b) can then be used for consecutive height analysis as profile, roughness, area and even volume measurements [3]. The great benefit of the (E)SEM technique is that the topography of almost any specimen can be imaged, reconstructed and analysed provided that the surface is visible the images without touching the surface or destroy sensitive samples or surface details by contact with the stylus.
It doesn't matter if the surface is conductive or not, biological, made of plastic or rubber or even a transparent paint. The presented approach does allow to directly measure depth in the digital image (*topomicroscopy*) at highest accuracy.

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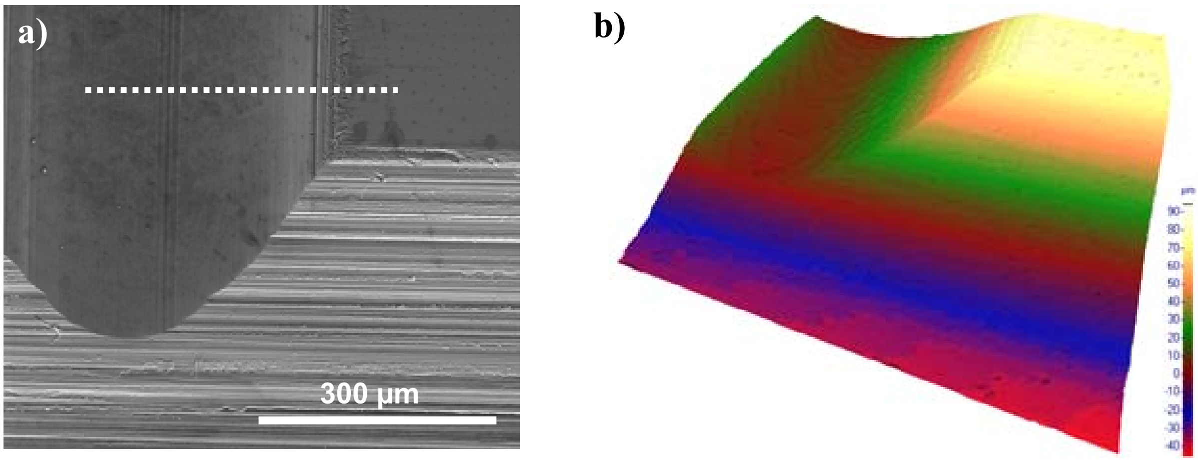

Figure 1. a) Secondary electron (SE) image of the depth standard with marked line (dashed) for profile measurement, b) calculated digital elevation model (DEM)

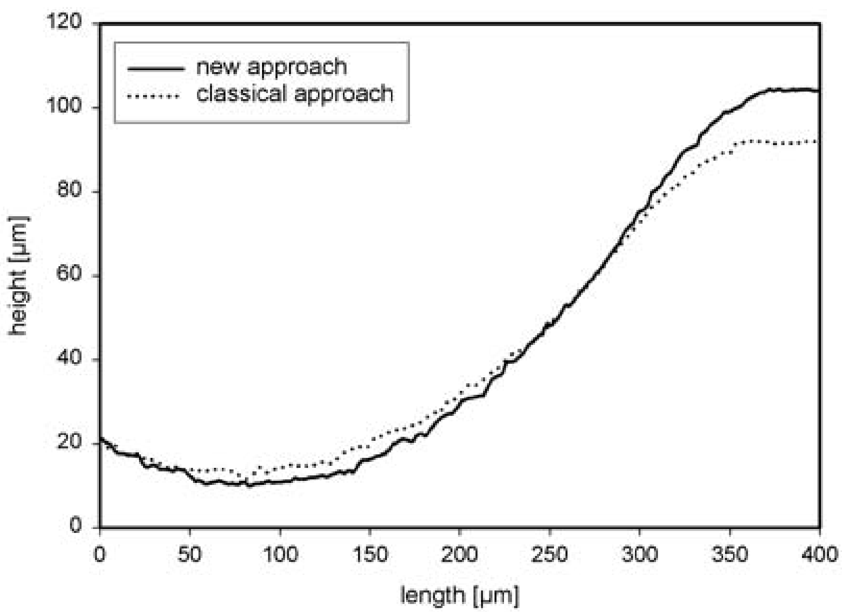

Figure 2. Comparison of the two depth profiles obtained with and without automatically determined angles (classical approach gives 79.1µm, new approach gives 93.2µm)