Experimental Investigation on 3D-SEM Reconstructions of a Wire Gauge Using Stereo-pair Technique

L. Carli[1], G. Genta[2], A. Cantatore[1], G. Barbato[2], L. De Chiffre[1], R. Levi[2]
[1] Department of Mechanical Engineering, Technical University of Denmark (DTU), Kgs. Lyngby, Denmark
[2] Department of Production Systems and Business Economics, Politecnico di Torino, Italy

loca@mek.dtu.dk

Abstract

In this work an experimental investigation is addressed concerning 3D-SEM reconstructions obtained from the so-called stereo-pair technique. Three-dimensional topography of an object can be derived from two SEM images acquired from two different angles, through item rotation by means of the SEM stage. A wire gauge with a 250 µm reference diameter was adopted as calibrated artefact to perform an uncertainty evaluation of the diameter estimate, in terms of input parameters required by commercial software performing stereophotogrammetry. Systematic exploration of sample space was performed resorting to factorial experimentation and statistical analysis of results.

1 Introduction and case study

3D-SEM procedure exploits two SEM images, called the stereo-pair, to obtain three-dimensional topographic reconstructions of the object concerned using stereo-photogrammetric technique. The specimen is imaged in the SEM acquiring the two images by scanning the same area under two different perspectives, achieved by eucentric tilt of the sample. Surface features of different heights on the specimen surface differ in their lateral displacement in the two images. The disparities between the projections of the surface features in the two images are measured to derive quantitative surface topography [1]. Several software packages are available for practical implementation, mainly based on the model function introduced by Piazzesi [2] adapted for eucentrically tilted stereo-pairs [1]. Among these packages, *MeX* by *Alicona Imaging GmbH* was selected in the present work. As a case study, 3D-SEM reconstructions of a wire gauge with a 250 µm reference diameter were considered.

The wire gauge was initially clamped vertically on the SEM stage, and then tilted by 90°. Multiple views were obtained by rotating the wire gauge along its horizontal axis by specified angles.

2   Theoretical principles of the stereo-pair technique

Surface features of different heights on the specimen surface differ in their lateral displacement in the two images composing the stereo-pair. Projections of surface features in the two images are measured to derive quantitative surface topography, by analyzing differences due to parallax. For a proper measurement of the parallax, it is of paramount importance to be able to calculate the correct matching of single surface features in the two images (Figure 1). The image-matching problem is centred on automatic identification of homologous points in the stereo-pair, a procedure currently performed with commercial software. The stereo-matching exploits area-based or feature-based methods [3] as follows. Starting from two SEM images, forming the stereo-pair, three input parameters must typically be specified as input parameters in the software, namely working distance d, rotational angle $\Delta\Phi$ and pixel size p, being the parallax shift proportional to the latest.
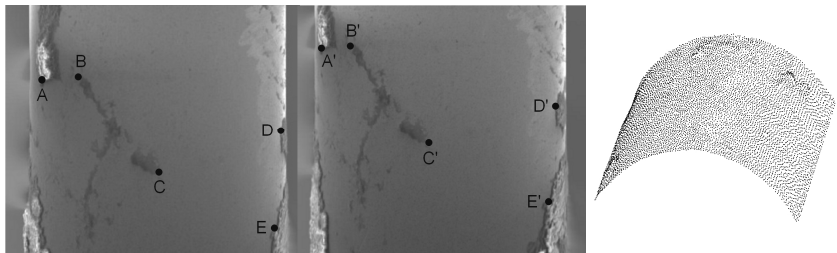

Figure 1: Example of two SEM images of the wire gauge, rotated by 7° one with respect to the other (left and centre). Five corresponding spots on the surface topography are marked being moved as a result of the parallax shift. The resulting 3D-SEM reconstruction is also shown (right).

3   Designed experiment approach and regression analysis

Three SEM images of the wire gauge were exploited to form two different stereo-pairs *SP*, denoted by set angles of rotation, that is -7&0 and 0&+7. For each stereo-

pair, the effect of working distance d, rotational angle $\Delta\Phi$ and pixel size p (i.e. main *MeX* input parameters) was examined. A $2*3^3$ full factorial experiment was performed entailing 54 treatment combinations [4], with factor *SP* at two levels (-7&0 and 0&+7), while factors d, $\Delta\Phi$, and p took three levels each, respectively 6 – 9 – 12 mm, 6.5° – 7.0° - 7.5°, and 0.2850 - 0.2994 - 0.3140 µm/pixel. Three replications were performed, yielding a total of 162 point clouds, obtained from *MeX* reconstructions. Point clouds were post-processed using dedicated software, yielding estimates of wire gauge diameter D (i.e. response variable).

Analysis of variance highlighted single effects of both pixel size p and rotational angle $\Delta\Phi$, minor interactions being also significant. Pixel size accounts for over 60% of overall sum of squares, followed by rotational angle, covering most of the remainder. Selection of model terms for wire gauge diameter D was further clarified resorting to regression analysis, leading to the following equation [4]:

$$D= -2.79+395.4\ p+0.026\ d^2-0.0382\ \Delta\Phi\cdot d+68.6\ \Delta\Phi\cdot p-1.55d\cdot p$$

where D is given in micrometers and independent variables are in the measurement units referred to above. An uncertainty evaluation according to GUM [5] was further carried out, leading to assessment of expanded uncertainty related to diameter estimation, based upon theoretical uncertainty values associated to the *MeX* input parameters [6], see Figure 2.
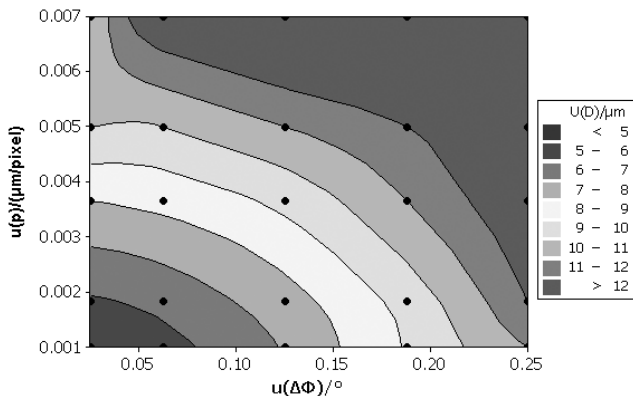

Figure 2: Contour plot of the expanded uncertainty of the diameter $U(D)$ as a function of uncertainty values of pixel size $u(p)$ and rotational angle $u(\Delta\Phi)$. The dots correspond to values of $U(D)$ calculated in terms of the regression equation [4].

An uncertainty increment of about 1 nm/pixel for the pixel size results in about 1 µm increment in the expanded uncertainty of the diameter. Assuming theoretical uncertainty values given in [6], an expanded uncertainty of the diameter equal to about 9 µm is arrived at.

4   Conclusions

An experimental investigation was performed on 3D-SEM reconstructions, obtained from the stereo-pair technique. A wire gauge with a 250 µm reference diameter was adopted as calibrated artefact, and the expanded uncertainty pertaining to the diameter estimation was assessed, in the light of a comprehensive factorial experiment covering input parameters required by commercial software. Major effects were observed to be due to pixel size and rotational angle, although with minor significant interactions. An expanded uncertainty of the diameter equal to about 9 µm was estimated.

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