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Effect of void pixels on the quantification of surface topography parameters

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Abstract
In the last decades the measurement of surface topographies was further developed using the capabilities of 3D optical profilers based on different measuring principles. These instruments have significant advantages over contact stylus measuring instruments but also some limitations. One limitation is depending from the interaction of the surface with the numerical aperture of the objective. Because of the surface slope, some parts of the surface are not correctly detected by the instrument, resulting on void pixels i.e. missing information on the measured topography. Data generated using fitting algorithms can be used to reconstruct the surface and replace the missing data, and the way this operation is performed affects the evaluation of surface parameters. As an alternative, the calculation of parameters may be performed on non-reconstructed datasets. In this work, the effect of void pixels on the determination of 3D parameters on different manufactured surfaces has been investigated using computer simulation starting from actual measurement data. Both randomly distributed and slope-dependent void pixels are considered. A sensitivity analysis with different distributions of void pixels as well as the effect of increasing slope are also presented.

Keywords: Surface metrology, uncertainty, void pixels.

1. Introduction

In optical measurements of surface topographies, when insufficient light is reflected back into the optical probe, some areas of the measured surface are not measured. The measuring instrument classifies pixels related to these areas as non-measured (void) pixels. Typically this happens because of high-sloped areas or high-roughness regions of the measurand surface. The maximum detectable slope depends on the numerical aperture of the objective, on the optical properties of the sample and on the roughness of the specimen. Measuring instrument are generally able to identify the void pixels, the problem and the challenge is how to handle them, to avoid incurring in evaluation errors: replacing the void pixel with a known value, e.g. by interpolation of valid neighbours, or maintaining the topography as it is. Padding of the void pixels introduces a source of error. This error is usually small when the analysis is carried out over entire image, because the number of voids is small compared to the image size [1]. Some potential solutions to reduce the number of measured points were studied and described [2]. Moreover, particular techniques to increase the maximum detectable slope were developed [3]. However, generally a small number of void pixels is still present and not reducible because of the nature of the surface. In these cases the presence of void pixels in the scale limited surface influences the evaluation of surface parameters, which can be evaluated either on the reconstructed surface (in which the void pixels are replaced using interpolation algorithms) or, on non-reconstructed datasets (in which the void pixels are not considered for evaluating the parameters).

2. Methodology

In this work, the effect of void pixels on the determination of 3D surface parameters on different manufactured surfaces has been investigated using computer simulation starting from actual measurement data. The analysis was focused, in this preliminary work, on the effect of the void pixels on the evaluation of the arithmetical mean height of the scale limited surface (Sa) in the case of turned samples (periodic surfaces).
Starting from real parts, these were measured with a Sensofar PLU NEOX 3D optical profiler, using 20× confocal objective with a numerical aperture NA=0.45 and a field of view of 877×660 µm. All the post process procedures and evaluations were developed in *Matlab r2014b*.

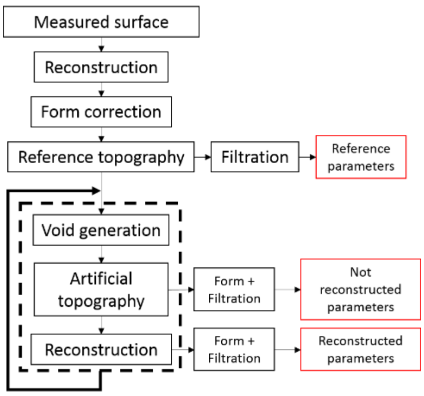

Figure 1. Scheme of the applied procedure.

In figure 1 the scheme of the adopted procedure is presented.
The topography was firstly reconstructed by padding the void pixels with a reference value obtained by interpolation of valid neighbours. After the reconstruction, a form correction procedure (based on least square polynomial fitting) was applied. The obtained reference topography was then filtered for the evaluation of reference parameters. All the subsequent comparisons were based on these reference parameters.
The reference topography was then used as input for the sensitivity analysis loop considering it as a matrix of height values. For each cycle of the loop a different distribution of void pixels was created and applied to the reference topography: the parameters evaluated on the not-reconstructed topography and the ones evaluated on the reconstructed topography are stored.

Distribution of void pixels is based on two different methods:

- Random-based: simulating the presence of artefacts and noise on the topography, where void pixels are randomly distributed
- Slope-based: simulating the limitations of the optical instruments, with void pixels that are distributed only on the areas of the surface with higher slopes.

2.1. Random-based

The distribution of the void pixels is based on a random matrix with same dimension of the reference topography matrix. A Gaussian distribution of values between 0 and 1 are used: all the values of the matrix that exceed the fixed cutting level are substituted with a *"not-a-number"* value. All the other values, smaller than the cutting level, are fixed on zero. In this way after the sum of the reference topography and the mask, it is possible to obtain a random distribution of void pixels. The obtained topography is used for evaluation of surface parameters before and after substitution of void pixels. Changing the value of the cutting level means changing the percentage of void pixels. A hundred different distributions for each "cutting level" were analysed for a total amount of 15000 void distributions. An example of the results obtained after a simulation using the random-based method is shown in figure 2.

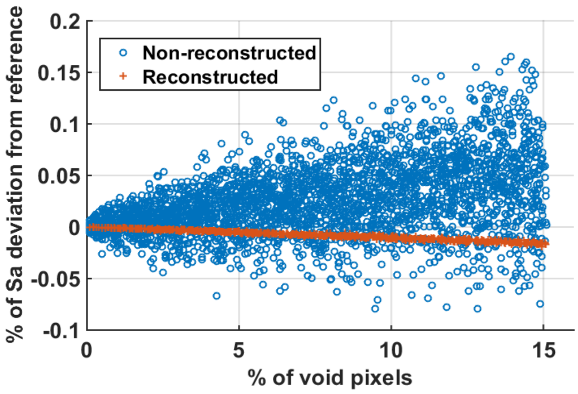

Figure 2. Distribution of Sa parameter with Random-based algorithm on turned surface with a reference Sa of 1.354 µm.

2.2. Slope-based

Using the *slope-based* procedure, the distribution of the void pixels is linked to the physical limits of the optical measuring instrument. The gradient of the reference matrix was computed and then a condition on the maximum measurable slope was applied. All the areas of the matrix that exceed these limit value are substituted with a *not-a-number* value. Changing the value of the limit causes a different position of the void pixels. To obtain several distributions of void pixels, the topography is rotated around the two axes of the topography plane, changing the position of the rotation axis. Different rotations (±1 deg around the aligned position with 0.1 deg steps) around the six different rotation axes are applied to the topography to simulate misalignments between the part and the optical axes. A total amount of 10000 different void pixels distributions was simulated. An example of the results obtained after a simulation using the slope-based method is shown in figure 3.

3. Results

Figures 2 and 3 present the results obtained for a turned surface with a Sa reference value of 1.354 µm. The variability of the Sa parameter evaluated on the reconstructed topographies is smaller than the variability of the value obtained from non-reconstructed ones. The Sa parameter computed on the non-reconstructed surfaces is generally an overestimation of the reference value and this trend increases with the percentage of void pixels. On the contrary, the evaluation based on the reconstructed surface tends to underestimate the Sa parameter. This tendency is confirmed in both *random-based* void distribution and *slope-based* void distribution.

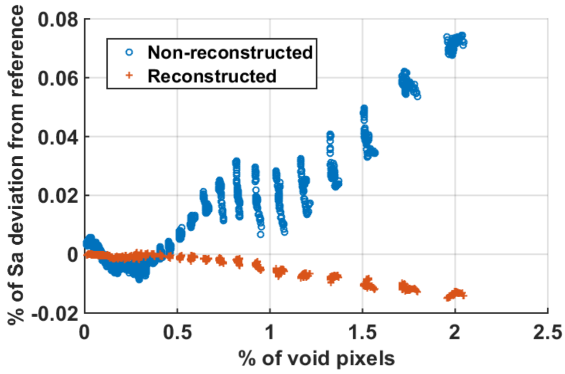

Figure 3. Distribution of Sa parameter with slope-based algorithm on a turned surface with a reference Sa of 1.354 µm.

Table 1 summarizes all the results obtained in this work for turned surfaces with different Sa reference values. It also reports deviations from the reference value and standard deviations, both expressed as percentage of the reference parameter. Results are referred to a class with percentage of void pixels equal to 1±0.3%.

Table 1 Results for the different surfaces: all values are expressed as percentage of the reference Sa value

Random-based							
Sa ref (µm):		**1.354**	**1.359**	**1.518**	**1.519**	**3.131**	**3.142**
Non Rec	Mean	0.002	0.003	0.003	0.004	0.003	0.003
	Std	0.023	0.024	0.020	0.002	0.019	0.019
Rec	Mean	-0.001	-0.001	-0.0006	-0.0006	-0.0004	-0.0004
	Std	0.0007	0.0007	0.0005	0.0005	0.0005	0.0004

Slope-based							
Sa ref (µm):		**1.354**	**1.359**	**1.518**	**1.519**	**3.131**	**3.142**
Non Rec	Mean	0.033	0.033	0.200	0.190	0.260	0.026
	Std	0.026	-0.026	0.067	0.063	0.087	0.080
Rec	Mean	-0.0055	-0.0055	-0.0065	-0.014	-0.0034	-0.0028
	Std	0.0031	0.0031	0.0030	0.0039	0.0020	0.0038

4. Conclusions

In this work, the effect of void pixels on the determination of 3D parameters on turned surfaces was investigated. Randomly distributed and slope-dependent void pixels distributions were simulated and a comparison of Sa parameters obtained from reconstructed and non-reconstructed topographies was presented. Results demonstrate that the Sa results evaluated on reconstructed topographies are more accurate, especially for percentages of void pixels higher that 1%.

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