Rapid method using deep learning with multi-focus microphotographs to measure submicrometric structures

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1. Introduction

Laser microscopes and X-ray inspection systems are commonly used for measuring dimensions of laser-processed objects. Nevertheless, both methods require some time for preprocessing and measurement, entailing high costs. We propose a simple, fast, and inexpensive method for measuring submicrometric structures using deep learning with multi-focus microphotographs taken by an optical microscope.

2. Proposed method

Figure 1(a) portrays multi-focus laminated images of a groove-processed material in the vertical direction; then cross-sections of the groove are sliced, as shown in Figure 1(b). These cross sections are used for deep learning "SegNet[1]"; the groove dimensions are estimated. Depth data from a laser microscope are used as training data.

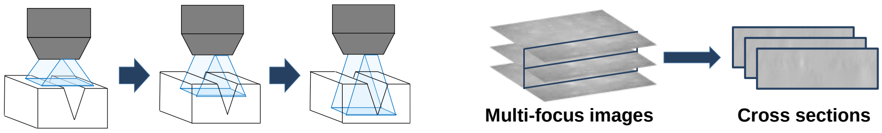

Figure 1 (a) Multi-focus images and (b) cross sections of the laminated multi-focus images.

3. Experiment results

Figures 2 and 3 exhibit measurements (laser microscope) and estimations (deep learning): groove and ridge processes in alumina ceramic material. Calculation time is 10 s for 128 cross-sections (Core i7-8700@3.20 GHz; Intel / GeForce GTX 1080; NVIDIA). In the groove process, their dimensions are approximated to three normal distributions of 1σ, 2σ, and 3σ for each slice. Three parameters of width *w* [μm], center *c* [μm], and depth *d* [μm] are estimated as shown in Figures 4(a)−4(c). In the groove process, their errors of average μ and standard deviation σ for all slices are shown in Table 1(a)−1(c). For width estimation in the 1σ distribution, μ = −1.64 μm and σ = 2.89 μm are obtained. Submicrometric estimation in the center and depth are achieved in the 2σ and 3σ distributions. The ridge is approximated to a trapezoid with four parameters defined: height *h* [μm], upper base u [μm], lower base *l* [μm], and center *c* [μm]. Figure 5 shows measurement and estimation examples; Table 2 presents errors. Heights, upper and lower bases, and center are shown in submicrometric order.

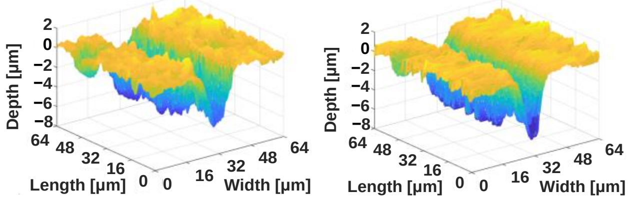

Figure 2 Groove: (a) laser microscope and (b) deep learning.

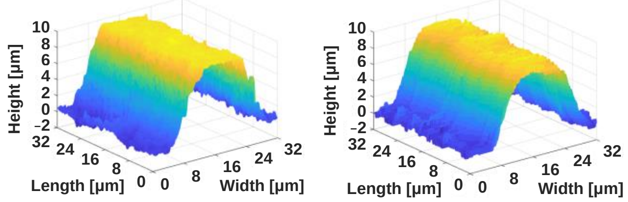

Figure 3 Ridge: (a) laser microscope and (b) deep learning.

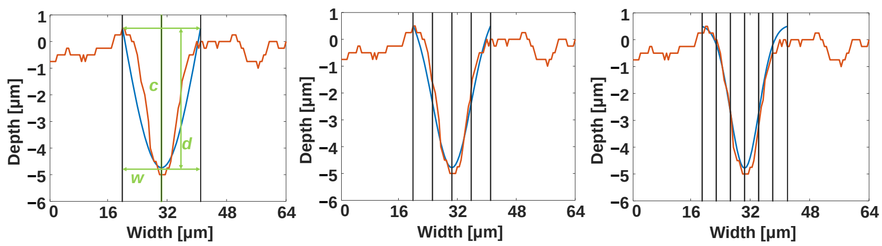

Figure 4 Approximation by normal distributions: (a) 1σ, (b) 2σ, and (c) 3σ distributions.

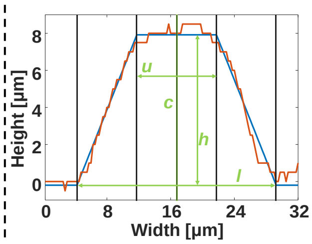

Figure 5 Approximation by trapezoid.

Table 1 Errors between measurements and estimations: (a) 1σ, (b) 2σ, and (c) 3σ distributions.

(a)

	μ	σ
width: ***w*** [μm]	**−1.6406**	**2.8910**
center: ***c*** [μm]	**−0.3984**	0.6997
depth: ***d*** [μm]	0.3426	1.7339

(b)

	μ	σ
width: ***w*** [μm]	−1.9609	2.9226
center: ***c*** [μm]	−0.4102	**0.6594**
depth: ***d*** [μm]	**0.1676**	0.8146

(c)

	μ	σ
width: ***w*** [μm]	−1.9063	3.1956
center: ***c*** [μm]	**−0.3984**	0.6651
depth: ***d*** [μm]	0.2114	**0.7126**

Table 2 Errors between measurement and estimation.

	μ	σ
height: ***h*** [μm]	0.4349	0.2806
upper base: ***u*** [μm]	0.0859	1.3560
lower base: ***l*** [μm]	0.9570	1.4410
center: ***c*** [μm]	−0.0869	0.4183

[1] V. Badrinarayanan, A. Kendall, and R. Cipolla, "SegNet: A Deep Convolutional Encoder-Decoder Architecture for Image Segmentation," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 39, no. 12, pp. 2481-2495, Dec. 2017.