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Technical paper

Performance evaluation of multi-scale data fusion methods for surface metrology domain

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ABSTRACT

With the rapid evolution of new engineered surfaces, there is a strong need for developing tools to measure and characterize these surfaces at different scales. In order to obtain all meaningful details of the surface at various required scales, data fusion can be performed on data obtained from a combination of instruments or technologies. In order to evaluate the fusion methods, typically, well-recognized images like 'Lena' are used. But surface metrology datasets are distinctly different from those images, as all the data points are in focus, compared to typical images with a subject in focus and background with various levels of out-of-focus. So, a performance study was conducted on a wide range of surface samples and it was shown that Regional Edge Intensity (REI) is the preferred fusion method for surface metrology datasets, and Regional Energy (RE) is the second preferred method, when single-scale performance metrics are considered.

1. Introduction

A major trend in manufacturing is toward miniaturization which leads to convergence of the traditional research fields to create interdisciplinary research areas [1]. For example, a successful lab-on-chip design requires expertise in four domains: micro-biology, micro-fluidics, micro-tribology and micro-optics. Interdisciplinary research efforts have started focusing on the development of multi-scale models and development of multi-scale surfaces to optimize the performance. Along with the growing demand of multi-scale surface analysis for development of mathematical models, there has also been an increasing development of designer multi-scale surfaces, exhibiting specific properties at different scales for a specific purpose. New patterned surfaces are being developed to utilize the interesting play of surface roughness on friction at different scales – textured surfaces could be used to increase friction in meso- and macro-scale, but reduce friction at micro-scale.

With the rapid evolution of new engineered surfaces for Micro Electro Mechanical Systems (MEMS), micro-fluidics etc., there is a strong need for developing tools to measure and characterize these surfaces at different scales. Consider a Fresnel micro lens array shown in Fig. 1a, where the individual features have varying aspect ratio. The figures show the top view of the 3D surface map, with false color spectrum mapped to actual height, obtained using a White Light Interferometer (WLI) system (Zygo NV6300® system [2]). The central features on individual lens are resolved much better compared to the region shown inside the black circled area, under the selected measurement condition (10× objective with a 0.5× magnification tube and 100 μm scan length). The features are better resolved at a higher magnification using the same 10× objective but with a 2.0× magnification tube, as shown in Fig. 1b. From both the figures, the potential advantage of combining multiple magnification datasets is evident – better capability for characterizing varying aspect ratios. By enabling fusion of data obtained using different magnifications/sampling intervals, the effective space of the instrument in the Amplitude–Wavelength domain could be expanded, resulting in better preservation of resolution at different ranges and increased confidence on data.

Most technologies tend to overlap in their ability to measure lateral and vertical dimensions of products to cater to some limited range of products. So, in order to obtain all meaningful details of the surface at various required scales, one is left with the only option of measuring the surface using multiple technologies using a combination of instruments. Under industrial settings, it becomes cumbersome to figure out all possible technologies and to cascade those into multiple systems, not to mention the cost burden involved with setting up the bridge type system with the selected technologies. The overlapping systems pose a limitation on the positioning accuracy of the stages, requiring the stages of an individual measurement system to be capable to meet positioning requirement of its successive system. The sensors communicate with each other, but data is not necessarily merged together. These

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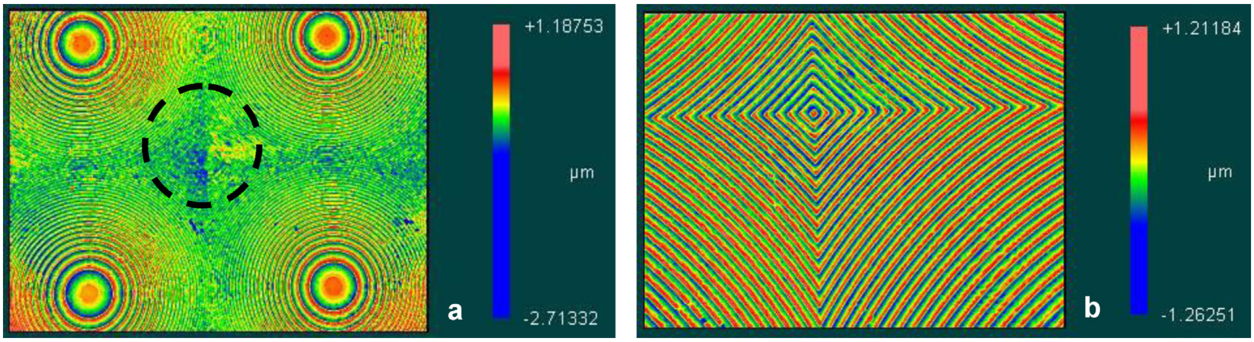

Fig. 1. Fresnel micro lens array at (a) 5× magnification and (b) 20× magnification.

systems enable the user to obtain different surface maps using various technologies, but user doesn't readily have the ability to combine all the obtained data into one single dataset. But for effectively characterizing the multi-scale surface, all the datasets need to be aligned with respect to each other. It is not sufficient to just perform measurements are multiple scales, but also be capable of characterizing the entire multi-scale surface. The authors [3,4] have previously demonstrated the feasibility of multi-scale/multi-sensor data fusion on surface and dimensional metrology datasets and discussed [5] the method for selection of fusion metrics. The fused data replaced into the corresponding location in up sampled version of low magnification data is shown in Fig. 2. *X* and *Y* axis are in pixel coordinates and *Z* axis is in μm, shown in spectrum color map. The fused data location is shown in Fig. 3. The box with dashed black colored line is used to show the location of the fused data and a red colored box near the fused location is shown to illustrate the resolution issues when low magnification is used.

Standard images like 'Lena or Lenna' are normally used to conduct performance study on fusion metrics and fusion methods, but typical engineered surface datasets are obtained with 'infinite focus' condition, as each individual data point is at the best focus condition. Surface metrology datasets are distinctly different in that all the data points are in focus, compared to typical images with a subject in focus and background with various levels of out-of-focus. Some engineered surfaces are also designed to exhibit multi-scale and fractal nature. Hence there is a need to evaluate the performance of the fusion metrics and methods for the surface metrology domain. This paper discusses the performance evaluation results of three data fusion methods on surface metrology data sets.

2. Multi-scale data fusion

Joint Directors of Laboratories [6] defines data fusion as, "multi-level, multi-faceted process handling the automatic detection, association, correlation, estimation and combination of data and information from several sources." A generic framework for multi-sensor data fusion (MSDF) (based on [7]) is shown in Fig. 4. The basic steps involved in MSDF are discussed in detail.

2.1. Pre-condition

If the data is very noisy due to vibration issues or system's dynamic noise level, it is recommended to de-noise the data by statistical methods either in the Fourier or wavelet domains [8,9]. If there is no reference surface available, the data is leveled using a least squares plane. The dataset with the higher sampling interval is down sampled to match the dataset with the lower sampling interval.

2.2. Coarse registration

After the datasets have been pre-conditioned, the next step is to roughly align both datasets, which is called coarse registration. Coarse registration can be either done manually by locating unique fiducial markers such as edges in both images, or an automated program utilizing the Sum of Absolute Differences (SAD) and/or the Normalized Cross Correlation (NCC) [10] could be used to find

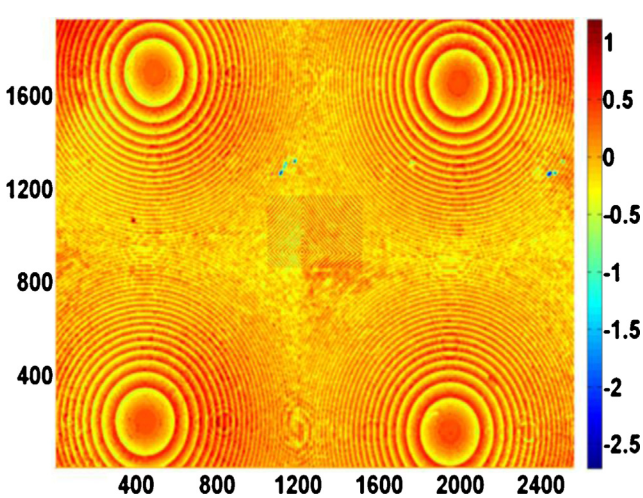

Fig. 2. Fused data on Fresnel lens.

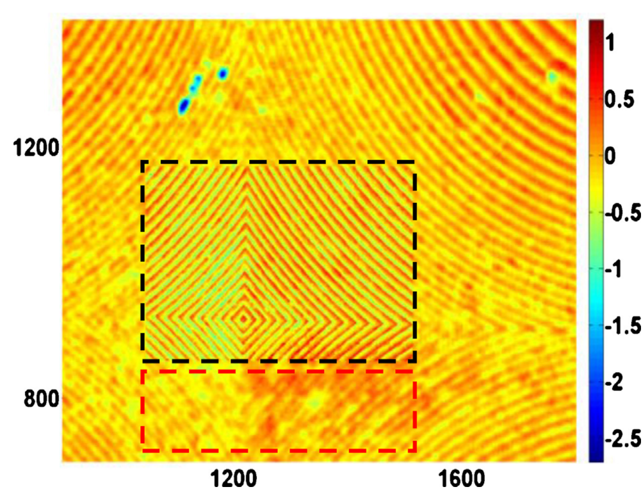

Fig. 3. Zoomed in view of fused data on Fresnel lens.