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Stitched Acousto-Optic Modulator Stroboscopic Interferometry for characterizing larger microstructures

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ABSTRACT

Large field of view with higher resolution has become a strong requirement for the present measurement technology. Currently used sub-aperture stitching methods are suffering from the inaccuracies of computer controlled stages. In this work three different simplified stitching methods are presented. The stitching process proposed here is based on Acousto-Optic Modulator Stroboscopic Interferometry (AOMSI) of fixed field of view (FOV) and it does not require any computer controlled stage. A large microcantilever was tested in two stages, one from the root and the other from the tip portions separately, and the complete profile of the cantilever was extracted using the proposed stitching methods. The same cantilever also was tested using a commercial profilometer with a full field of view. There was a good agreement between the results from the proposed methods and a commercial profilometer. Obtaining extremely low amount of variation using the presented stitching methods validates the proposed stitching methods for large microstructures.

1. Introduction

Acquiring a large field of view (FOV) along with high resolution is one of the main requirements of present imaging interferometric technologies. As an example, large field of view is essential in order to study the anatomy of organisms with 3D high-resolution image [1]. The most advanced technology which is used for imaging with high spatial resolution is suffering from the limitation of FOV, while those imaging system with large FOV have the problem of spatial resolution. Hence, a system that can provide images with high resolution with large field of view would be useful. Sub-aperture stitching method is considered as a practical method which can overcome both FOV and resolution limitation [1].

The sub-aperture stitching method involves obtaining a series of sub-aperture maps from entire specimen and combining them to get a full field map of the object [2]. Sub-aperture maps can individually have enough accuracy and combining of these maps would enable a full aperture map of the specimen with required resolution. Usually there is a trade off between field of view and resolution [3] as it is difficult to obtain both in the same time and usually an optimization procedure is employed in order to obtain reasonable results. A stitching method suggests 20% [4] overlap between subsequent images as an optimized tradeoff between FOV and resolution.

Although the present sub-aperture stitching technology aims to minimize the errors of stitching, they are not sufficient to provide the precision required for some applications [4]. As an example, those measurement systems which are using microscopic stage for tilting the specimens are not able to provide enough accuracy as the physical coordinates provided by the microscope stage are not precise enough to allow reconstruction ("Stitching") of the whole image from individual image stacks [1]. Scanning the wave front or the sample with respect to the other increases the FOV without affecting the spatial resolution, and they are not able to provide real time measurements.

Various stitching methods with different ways of describing the overlap area have been used for stitching

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long specimens. Although having an overlapping area is common in all stitching methods, its length can be a significant and effective parameter for stitching process [4]. It is known that having long overlapping region can make the result more accurate when there is no constraint on the number of images. But, in contrary, more maps would result in more errors due to the variation in imaging conditions. As result, an optimized overlapping length should be considered in stitching methods.

Furthermore, consideration of data in overlapping region is another significant issue in stitching process. In some areas, where the displacement is high and not accurate require only averaging of the data sets of overlapping portion. While in the case of requirement for higher accuracy, the data in the overlapping portion should be analyzed using different mathematical functions. Hence, different coarse and fine strategies have been developed for the overlap area in order to obtain higher accuracy in stitching process [1].

For any measurement system including stitching, obtaining a suitable mapping system with higher resolution is essential. Interferometry technique which is usually used for the test of microstructures carries higher resolution [5,6]. Hence many accurate profilers have been made on the basis of interferometric system [7]. In this work three simple stitching methods employing an Acousto-Optic Modulator Stroboscopic Interferometer (AOMSI) without requiring any calibrated high precision stages are proposed. This interferometer system using Temporal Phase-shifting (TPS) method is able to extract surface information of the microstructure with a few nanometers resolution. The applicability of these methods for micro devices is discussed and the results of different stitching approaches are presented in comparison with the results obtained using a commercial profilometer with full-field of view.

2. Stitching methods

Stitching is required when the FOV of measurement system is smaller than the size of the specimen. Stitching procedure requires having a common area in two adjacent images to merge the data from two images onto one image. In this paper three different stitching methods based on geometric reference, size reference and combination of them are presented for stitching large specimens.

2.1. Size reference method

In size reference method, a known size of the specimen is considered as a reference. This allows identifying overlapping areas in two sequential images (as shown in Fig. 1) and enables stitching. There is no constraint for the shape of specimen in this method except that entire specimen must be covered in two adjacent acquired images. The specimens that are equal or lager than two FOVs cannot be characterized using size reference methodology. Figs. 1 and 2 illustrate the scheme of 1-D and 2-D specimen for sub-aperture mapping, respectively. The FOV of adjacent acquired images with overlap area and references for full mapping of the specimens using stitching method also has been shown. In this method of stitching with known length of specimen and the FOV, the length of overlap area can be calculated as shown in Fig. 1.

For using the size reference for stitching, two methodologies based on edge or overlap area consideration is introduced in this section and the results of experiment for both approaches are also presented in this paper. While in "overlap area consideration" approach obtained data for overlap area in two adjacent images is used in stitching, in "edge consideration" approach just the data for overlap area from either first image or second image of two adjacent images is used for stitching and the remaining portion of the specimen from other image is added to it. In "edge consideration" approaches the top or bottom lines (see Fig. 1) of the images in the FOV is considered as reference for stitching. Stitching using size reference can be applied to both 2-D and 1-D specimens. While for 1-D specimen the reference is a line, for 2-D specimens two line references, which can be a corner or edge, are required for stitching as shown in Figs. 1 and 2.

The second methodology in size reference is based on "overlap area consideration". Unlike previous method that data just in one of the adjacent images for the overlap area was used in stitching process, in "overlap area consideration" methodology both the data for overlap area obtained in two adjacent images are used in the stitching process. The way of using the data sets in overlap area, can be different depending upon the measurement system, specimen and required accuracy [2] while a simple function would be averaging the data in overlap area. The overlap area consideration approach provides a better accuracy than edge approach, as it uses both the data in overlap area for stitching.

2.2. Geometric reference method

Various components such as micro mirrors arrays and cantilevers require a high accuracy characterization, but limitation in the FOV of measurement systems makes this difficult. For devices with at least one structural discontinuity, geometric reference can be used where the structural discontinuity are considered as references for stitching of the images. In this method, extracted information from all images is added to each other with equalizing the date in reference points. Figs. 3 and 4 show schematic of 2-D and 1-D specimens respectively in which the structural discontinuity and the FOV of adjacent acquired images are shown. While for 1-D specimen the discontinuity is a line, for a 2-D specimen a corner or edge can be considered as reference. These references for presented examples have been shown in Figs. 3 and 4. This method solely is not applicable for specimens which do not carry any geometrical change in the structure or having them while the distance between them is larger than the FOV of the acquired image.

2.3. Combination of size and geometrical references method

Combination of geometric reference and size reference is considered as a more practical method for larger specimens. This method provides the possibility of characteriz-