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Three-dimensional measurements with a novel technique combination of Confocal and Focus Variation with a simultaneous scan

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Abstract

The most common optical measurement technologies used today for the three dimensional measurement of technical surfaces are Coherence Scanning Interferometry (CSI), Imaging Confocal Microscopy (IC), and Focus Variation (FV). Each one has its benefits and its drawbacks. FV will be the ideal technology for the measurement of those regions where the slopes are high and where the surface is very rough, while CSI and IC will provide better results for smoother and flatter surface regions. In this work we investigated the benefits and drawbacks of combining Interferometry, confocal and focus variation to get better measurement of technical surfaces. We investigated a way of using Microdisplay Scanning type of Confocal Microscope to acquire on a simultaneous scan Confocal and Focus Variation information to reconstruct a three dimensional measurement. Several methods are presented to fuse the optical sectioning properties of both techniques as well as the topographical information. This work shows the benefit of this combination technique on several industrial samples where neither Confocal nor Focus Variation is able to provide optimal results.

Keywords: Confocal microscopy, Focus Variation, Three dimensional measurements, Optical inspection.

1. Introduction

In the past few decades, three-dimensional measurement of technical surfaces with optical methods has gained a large portion of the market. Many technologies have been developed, the most prevalent being single points sensors that scan the surface, and imaging sensors that employ a video camera to obtain the height information of all the pixels simultaneously. The most common imaging methods for microscopic measurements are Coherence Scanning Interferometry (CSI), Imaging Confocal Microscopy (ICM), and Focus Variation (FV) [1].

CSI is the most precise all of them, since its ability to resolve small height deviations, translating into height resolution, merely depends on the coherence length of the light source and the linearity of the Z stage. CSI is capable of achieving height resolution down to 1 nm regardless of the magnification of the objective that is being used. Nevertheless, the requirement for an interferometer setup between the optics of the microscope's objective and the surface under inspection, restricts the overall optical system to relatively low numerical apertures (NA), this then being the cause of the technique's main drawback when measuring optically smooth surfaces with relatively high local slopes. Confocal microscopy overcomes this problem, however, as it uses high numerical aperture objectives, and thus is capable of retrieving signals from much higher slopes than CSI. At the highest NA in air (typically 0.95), a height resolution of 1 nm is achieved, and local slopes up to the optical limit of 72 degree are measureable. The main drawback of confocal microscopy is that height resolution is dependant on the NA, so that low magnification optics (that have low numerical aperture) yield less height resolution. The technique is therefore unusable on smooth surfaces that have to be measured with low magnification. On optically rough surfaces, confocal microscopy achieves significantly better results in comparison to CSI, but at very high roughness, or even on rough and highly tilted surfaces, it suffers from poor signal. In this particular case, focus variation provides the best results, as it is based on the texture present in the bright field image. Height resolution is difficult to specify, as it depends on the texture contrast, on the algorithm to extract the focus position [2], the numerical aperture and the wavelength. Optically smooth surfaces cannot be measured with FV, since no texture is present on the surface, and no focus position can be retrieved. Those surfaces that at a given wavelength and NA appear optically smooth (and are thus not suitable for focus variation), may appear as optically rough when decreasing the wavelength, or the magnification. This is the reason why FV is most typically suitable with low magnification, since most of the surface then appears as optically rough.

2. Method

The best instrument to cater to measurements on as many different kinds of surfaces as possible will be the one that has the capability to perform measurements with any of the aforementioned technologies. Nevertheless, there are some surfaces where neither of the three aforementioned technologies yield ideal results.

The combination of data from two of the three technologies could in principle provide better results. The most difficult technology to combine with any one of the others is CSI. The reason for this is due to the intrinsic design of an interferometer, where the reference mirror is always in focus. This leads to a bright confocal image in focus and a bright background all along the scan, decreasing dynamic range and bright field contrast of the surface texture. The combination of confocal and focus variation is much easier to realize in the sense that simultaneous images can be acquired. In the present paper we use a 3D optical profiler called S neox, from Sensofar-Tech SL, which uses scanning microdisplay (figure 1) [3] approach to scan the surface and acquire the confocal image.

One of the benefits of using a microdisplay to scan the field diaphragm of the microscope, is that it can be used to simultaneously acquire a confocal and a bright field image at the same vertical scanning position [4]. The aspect of grabbing both image series using the same vertical scan yields high accuracy and permits cross-correlation of data – were the two series of images to be drawn from two different vertical scans, repeatability and accuracy will be lower. We have analysed three different ways to fuse the data from the two series of images: topographical data fusion, image-to-image data fusion, and pixel-to-pixel axial response fusion.

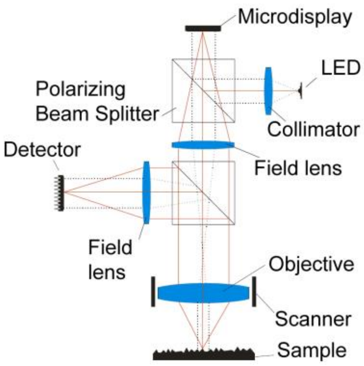

Figure 1: Optical setup of a microdisplay scanning confocal microscope.

2.1 Topographical fusion

Fusion of the data coming from the two isolated topographies seems to be the most easy and straightforward approach. With this method, the two series of images result in two topographies. The most precise of the two will be the one coming from the confocal series of images, but it will also have a greater number of non-measured points when a safety threshold is used. The focus variation topography is less precise, but due to its algorithmic nature, it will provide topographical data on high slope and rough regions, despite larger overall noise than for confocal. Topographical fusion is achieved by identifying the non-measured points on the confocal topography and creating a mask that is applied to the focus variation topography. This masked result is smoothed and copied to the confocal topography. Figure 2 shows the result of this method on a laser drilled surface. The cross-section profiles are shown for the raw FV (in light grey) and the fused data (red line).

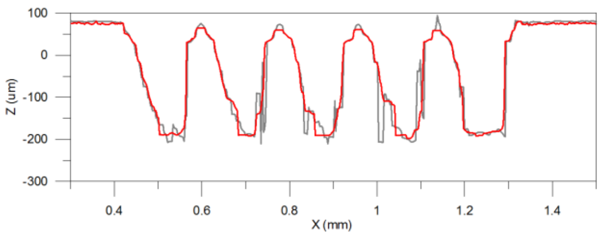

Figure 2. Three-dimensional measurement of a laser drilled surface. Cross-sectional profiles of the focus variation data (light grey) and of the fused data (red line).

2.2 Image fusion

Image fusion is a plane-by-plane technique. A focus variation image on a single plane shares similarities to an optical section, with less depth discrimination compared to a confocal image. In this technique, the mean value of each image pair is computed, and the FV image is offset to match the signal of the confocal image. By doing this, the confocal series retains the original signal, while the FV is dynamically adjusted. This plane-by-plane approach results in a third, fused series of images, from which the three dimensional result is computed.

2.3 Axial response pixel by pixel fusion

Axial response fusion is similar to the image fusion technique, but on a pixel-by-pixel basis. For each pixel of the two series of images, the mean value and maximum value of both axial responses are computed. The FV axial response is then adjusted to match the offset and maximum value to the confocal image, and additionally both axial responses are processed. This method dynamically adjusts the signal of the FV for each pixel, while preserving the confocal signal. The benefit of this method is the retention of the confocal information for those regions where the confocal signal is good, while shifting the signal to FV for those regions where confocal signal is low. Figure 3 shows two axial responses (light grey line confocal, red line FV) for two regions of the surface of the figure 2 (top surface left and sloped area right).

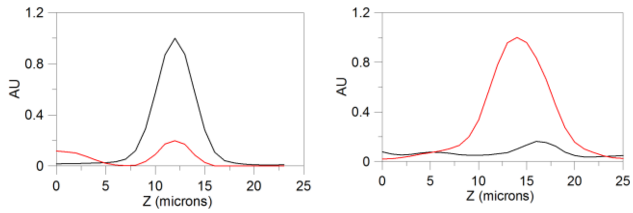

Figure 3. Axial response of confocal (light grey line) and focus variation (red line) for two different regions of the surface, illustrating very different behaviour.

3. Conclusion

Three different methods are proposed to combine data coming from two series of images for confocal and focus variation scans. Simultaneous scanning is realized by utilizing a microdisplay scannning confocal microscope, thus allowing high cross-correlation of height position between two series of images. Topographical fusion provides nice results, but does not adjust dynamically to the surface characteristics. Image fusion and axial response fusion dynamically adapt the focus variation signal, plane-by-plane or pixel-by-pixel respectively, to match the confocal signal. This novel technique of data combination provides better three-dimensional measurements for those surfaces with partially rough and partially smooth regions in combination with high slope.

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