High resolution three-dimensional optical profilometry

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General context:

The accurate characterisation of surface roughness is a major scientific and industrial challenge. In microelectronics, for example, the manufacture of semiconductors requires new advanced metrology solutions for the inspection of wafers and material deposition.

Optical light offers significant advantages for non-destructive testing: speed, low cost, small footprint, etc. However, commercial optical profilometers are limited in accuracy : their transverse resolution is about half a wavelength ($\lambda/2$) due to the so-called 'diffraction limit'. This limitation however concerns the size of the scanning spot of the profilometer. It is a *priori* not a fundamental limit on the possible resolution of the recovered surface profile. Actually, using Maxwell equations, one observes that the field reflected by the surface depends on all the spatial frequencies of the surface. It is only when using an approximate model (single scattering) that this dependence is simplified and involves only the surface spatial frequency below $2/\lambda$. Unfortunately, the interpretation of the data recorded by optical profilometers are presently all based on this simplified model and thus limited to a resolution of a few hundreds of nanometer. In this PhD thesis, we want to investigate more sophisticated reconstruction schemes accounting for multiple scattering and potentially able to recover surface profiles with a higher resolution.

Description of the work:

In the SEMO team at the Institut Fresnel, we are working on an optical profilometre using an inverse diffraction method based on a rigorous numerical method for simulating the diffraction of an electromagnetic wave by a rough surface. A reconstruction algorithm has been developed for one-dimensional (translationally invariant along one direction) roughness [1,2] and tested on experimental data [3]. To this aim, specific rough samples were manufactured by the Photonics and Nanostructures Laboratory and imaged by a tomographic diffraction microscopy set-up which measures the amplitude and phase of the diffracted field for various illumination angles. Our profilometer accounting for multiple scattering led to significantly better resolutions than the famous 'diffraction limit'.

In this thesis, we propose to extend this technique to realistic two-dimensional surfaces (3D objects). We will first develop codes able to simulate the diffraction by 2D surfaces. To reduce the computational cost, we will assume that the illumination is a focused beam that is translated at the surface. Hence only a small portion of the surface will contribute to the reflected light and only a small portion of the surface will have to be reconstructed at each position of the scan. This numerical and theoretical work will be completed with an experimental work on the home made profilometer.

For this essentially theoretical and numerical PhD, we are looking for a motivated student who has strong basis and appetence in mathematics, signal processing and programming. Knowledge in theoretical electromagnetism would also be appreciated.

References:

[1] S. Arhab, G. Soriano, Y. Ruan, G. Maire, A. Talneau, D. Sentenac, P. C. Chaumet, K. Belkebir, and H. Giovannini, Phys. Rev. Lett. 111, 053902 (2013)

[2] S. Arhab, G. Soriano, K. Belkebir, A. Sentenac, and H. Giovannini, J. Opt. Soc. Am. A 28, 576-580 (2011)

[3] S. Arhab, H. Giovannini, K. Belkebir, and G. Soriano, J. Opt. Soc. Am. A 29, 1508-1515 (2012)