Measurement of random processes at rough surfaces with digital speckle correlation

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Received March 2, 2003; revised manuscript received August 11, 2003; accepted September 24, 2003

We present a detailed investigation of digital speckle correlation to measure small changes in the microstructure of random rough surfaces. The corresponding alterations in the scattered-light field are recorded by an electronic camera with subsequent numerical correlation. Among the classical theoretical approaches to describe the scattering at random rough surfaces, the composite-roughness model is advanced to calculate the speckle correlation in terms of parameters of the changes in surface microstructure. For an experimental verification, surfaces with similar microstructure are fabricated with a photolithographic technique. They are employed for comparative measurements with high-resolution scanning force microscopy and for correlation measurements under variation of experimental parameters. A good agreement between theoretically predicted and experimental correlation data can be observed. The results allow a quantitative whole-field monitoring of surface processes by remote optical means.

OCIS codes: 030.6140, 100.4550, 290.5880, 120.6150, 120.6660.

1. INTRODUCTION

The light field that is reflected from an optically rough surface under coherent illumination shows a characteristic grainy structure. This so-called speckle pattern results from the interference of wavelets with a random phase relationship.[1] Despite the random nature of the speckle formation, the specific pattern is strongly connected to the sp [illegible] surface topograp [illegible] print of the surfa [illegible]

Any changes i [illegible] are reflected by [illegible] speckle field, i.e [illegible] will distinguish [illegible] changes in the m [illegible] latter are the sub [illegible] face processes. If an imaging system is used to observe the surface under investigation, deformations consist of surface alterations on scales that are large compared with the resolution of the optical system, whereas surface processes can be viewed as alterations on scales that are small compared with the resolution of the optical system. Usually both types of change, deformations and surface processes, lead to a decorrelation of the speckle pattern. In this paper we will concentrate on the decorrelation that is due to microstructure changes, which will henceforth be called primary decorrelation. Although in all measurements it is important to distinguish between the two types of decorrelation, a separation is generally difficult to achieve experimentally.

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For about 30 years, a number of researchers have exploited speckle decorrelation to detect alterations in the surface microtopography, using several experimental correlation techniques to compare the scattered speckle fields. Holographic correlation is a method that provides a direct correlation of two speckle fields by analog optical means.[2–4] In double-exposure speckle photography, two images of the object under investigation, before and after surface alteration, are recorded on the same photographic film. When the developed negative is probed by an unexpanded laser beam, the resulting diffraction pattern consists of a set of Young's fringes, whose pitch and orientation give the local displacement vector and whose vis- [illegible] speckle patterns.[5,6] [illegible] interference of two [illegible] n initial and an al- [illegible] visibility of the in- [illegible] ation of the speckle [illegible] nge contrast for de- [illegible] ent can also be per- [illegible] holographic interfer- [illegible] ital speckle pattern interferometry, in which image plane holograms (interferograms) are recorded by an electronic camera and compared numerically by an image-processing system. A simple subtraction of two interferograms yields an image consisting of bright and dark fringes, which indicate one component of the deformation and show a visibility that depend on the correlation of the underlying speckle images.[9] It can be shown that all correlation techniques, despite their diverse experimental concepts, yield basically the same information, viz., the correlation coefficient of the scattered speckle fields at the position of the recording medium.[10]

In this paper we use the technique of digital speckle correlation (DSC); i.e., we simply record the speckle fields with an electronic camera and carry out the correlation numerically. Besides the great simplicity of the experimental setup, this method has the advantage that it allows an arbitrary comparison of the recorded speckle images and thus an arbitrary comparison of the different surface states during a surface process after the experi-

1084-7529/2004/020252-11$15.00