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Decorrelation-induced speckle phase noise in two-wavelength digital holographic profilometry

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Abstract: This paper proposes a realistic wavelength decorrelation induced speckle noise simulator. The investigation of the dependence of the coherence factor versus the surface shape, the surface roughness and the wavelength change is carried out.

OCIS codes: (090.1995) Digital holography; (090.2880) Holographic interferometry; (100.3010) Image reconstruction techniques; (290.5880) Scattering, rough surfaces;

1. Introduction

Digital holographic two-wavelength profilometry is a very efficient technique for the measurement of surface shapes [1-6]. Due to the surface roughness, the phase extracted from each numerically reconstructed image is speckled. It follows that the phase difference permitting to measure the surface shape is corrupted by speckle decorrelation noise. This decorrelation phase noise is closely related both to the angle of illumination and/or the angle of observation and to the small change in the speckle pattern when changing the wavelength. This paper considers the influence of the wavelength shift. In recent work, the coherence factor of the speckle field was used for quantitative appraisal of the impact of decorrelation noise [7]. It was found that a coherence factor higher than 0.85 is required to perform high quality measurements. Although speckle decorrelation was deeply studied by few authors [8,9], especially from the point of view of intensity [10], the dependence of the phase versus the surface roughness and wavelength has not been investigated. In this paper, we present a realistic wavelength decorrelation induced speckle noise simulator considering the surface shape and roughness. The investigation of the dependence of the coherence factor versus the roughness and the wavelength change is carried out and permits to determine sets of wavelength couples, for a given shape and roughness, which yield a convenient coherence factor.

2. Realistic two-wavelength holographic simulator

In order to evaluate the influence of decorrelation noise in the process of 2-wavelength digital holography, a realistic numerical simulation was developed. The goal of the simulation is to produce phase map at two different wavelengths with corruption by speckle decorrelation noise having the adequate probability density function. In experiments, the amount of speckle phase decorrelation is naturally controlled by the numerical aperture of the setup and by the surface shape and roughness. The arrangement to produce speckle phase decorrelation at two wavelengths is depicted in Fig. 1.

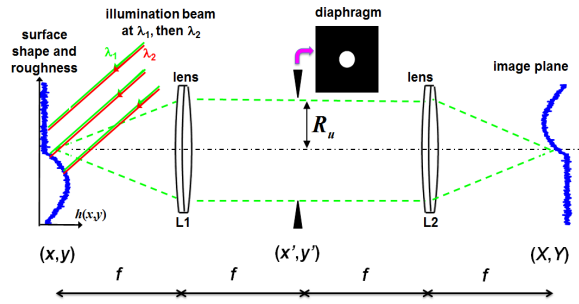


Fig. 1 Basic scheme of the realistic simulator of decorrelation-induced speckle phase noise in two-wavelength digital holographic profilometry.

The surface has a given surface shape. Its roughness has Gaussian statistics and correlation length. The surface is sequentially illuminated at normal incidence by a plane wave at, first, λ_1 , last λ_2 . The value of R_u is adjusted to control the speckle grain size in the image plane and to simulate realistic images. The surface shape with roughness, $h(x,y)=h_0(x,y)+\rho(x,y)$, generates an optical phase $\psi=4\pi h/\lambda$. The surface is simulated with the membrane MATLAB function with realistic amplitude of any micro-object ($\sim 100 \mu\text{m}$). In order to get the phase change due to two-wavelength illumination, and including speckle phase decorrelation, the procedure is as follows: first calculate the speckle image at λ_1 , second at λ_2 , last calculate their phase difference and evaluate the speckle noise. From the realistic simulator, the speckle phase decorrelation noise follows the theoretical statistics as given in [9]. Figure 2 shows data from the simulator: Fig. 2(a) shows the simulated surface and roughness, Fig. 2(b) exhibits a zoom on

the surface roughness having Gaussian statistics, and Fig. 2(c) shows the probability densities obtained from theory and simulation. So, the noise simulation is quite realistic and corresponds to what is observed in real experiments.

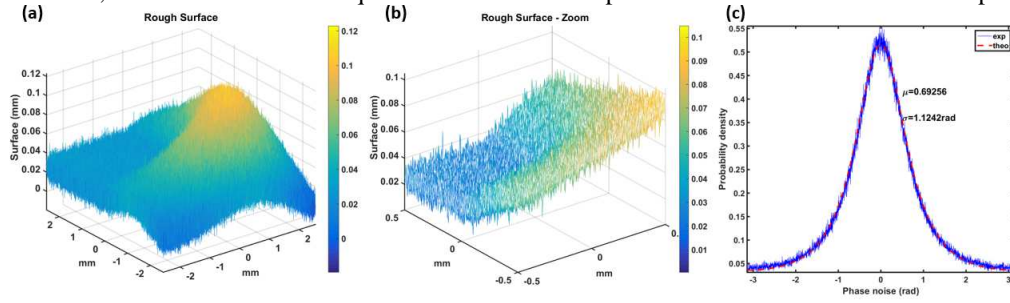


Fig. 2 Examples of outputs from the simulator, (a) surface with roughness, (b) zoom on roughness, (c) probability densities of the speckle noise (blue: simulation, red: theoretical)

3. Results

Several surface roughness and wavelengths were chosen as inputs of the simulator. The speckle size in the image plane was chosen to 4 pixels per speckle grain. This amount corresponds to the experimental conditions in digital off-axis holography. The surface roughness was varied from $0.98 \mu\text{m}$ to $6.35 \mu\text{m}$ and the wavelength shift from 0.1 nm to 10 nm (initial wavelength at $\lambda_1 = 0.6328 \mu\text{m}$). Figure 3 shows the coherence factor versus the wavelength shift and the surface roughness. The variation range of the coherence factor is included between 0.14 and 0.99 .

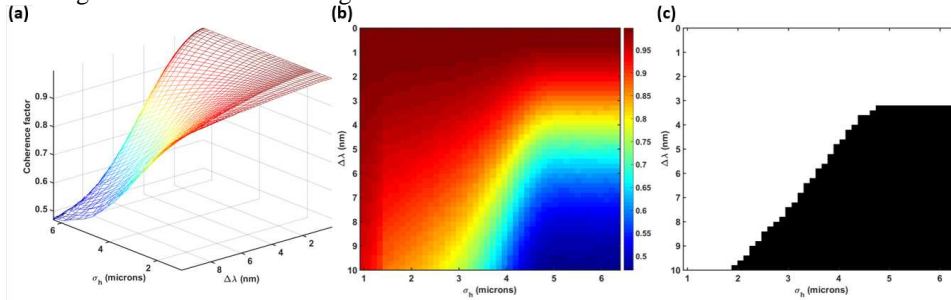


Fig. 3 Coherence factor vs the roughness and the wavelength shift, (a) 3D view, (b) 2D view with colormap (c) Binary image with coherence factor ≥ 0.85 (white) and coherence factor < 0.85 (black)

Figure 2 and Fig. 3 demonstrate that the proposed simulator is adapted for studying noise induced for measurement of surfaces with roughness several times higher than the wavelength. It is quite adapted to quantitatively predict the amount of noise in experiments. According to Fig. 3, the more the roughness increases the more the wavelength shift decreases to remain in the high-quality measurements zone.

5. Conclusion

This paper presents a realistic wavelength decorrelation induced speckle noise simulator considering the surface shape and the surface roughness. Future work includes comparison with theoretical analysis and experimental data.

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