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Characterizing surface roughness by speckle pattern analysis

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Speckle photography is a non-destructive technique for making moderate sensitivity measurements for strain, rotation, vibration, plane displacements, and surface texture. This paper presents characterization of surface roughness by studying speckle patterns correlation and visibility during object displacement.

Keywords: Digital Fourier Transform, Fine displacement, Speckle correlation, Surface roughness

Introduction

Random intensity distribution "speckle pattern" in scattered light field from a rough surface has been studied in coherent optics[1-3]. In electronic speckle correlation method, coherent light illuminates a rough surface; diffracted waves from each point of surface mutually interfere to form a pattern that appears as a grain pattern of bright and dark regions[4-5]. Degree of correlation of two speckle patterns produced from same surface by two different illumination beams are used in characterizing surface roughness (Ra). Object is illuminated by a monochromatic plane wave with an angle of incidence with respect to normal to surface. Multi-scattering and shadowing effects are neglected. A CCD camera placed in focal plane of a Fourier lens is used for recording speckle patterns[6]. Fourier transform technique is most attractive techniques for fine dimensional measurement[7].

This study used Digital Fourier Transform (DFT) to determine SR of object using effect of visibility and correlation of speckle patterns[8].

Experimental Details

Proposed method involves use of a light source (He-Ne laser, wavelength 0.6328µm). A coherent plane wave emerging from a He-Ne laser is exposed to roughness specimen. Double exposures obtained at two different positions are recorded successively on same image. Degree of correlation of two speckle patterns produced from same specimen is analyzed. Consequence of varying location of the object is described as follows: i) Speckle pattern visibility is determined against displacement of different rough surfaces; ii) Speckle pattern is translated in a direction corresponding to angular displacement ($\delta\theta$) of the object; and iii) Correlation between first and the second speckle pattern decreases by increasing $\delta\theta$. Correlation depends on object roughness. DFT is applied to recorded speckle patterns, and Young fringes are produced.

Results and Discussion

Lateral and Angular Displacements

Out of five standard specimens (av Ra, 1.6, 2.3, 3.17, 4.5, 6.3 µm), each specimen was placed on a traveling micrometer to allow capturing images for the object at different positions (Fig. 1). A CCD camera [Cohu 3810 model] was used to record speckle. Every specimen was illuminated at angles θ (fixed at 16°). Visible speckle interference pattern for each displacement of specimens was recorded (Fig. 2). Variation of speckle contrast resulted from Ra variation at different linear displacements was plotted (Fig. 3). Object was rotated slightly ($\delta\theta$) and speckle patterns were recorded at each $\delta\theta$ (Fig. 4). DFT was applied digitally to record speckle patterns to obtain Young fringes in Fourier

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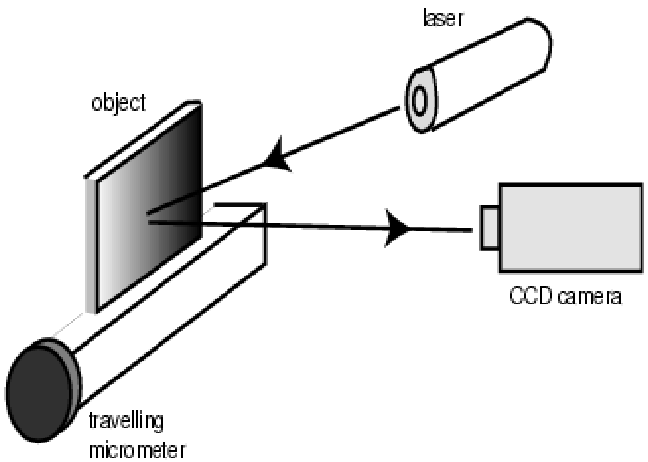

Fig. 1—Setup of measuring displacement

plane (Fig. 5). Visibility of Young fringes was calculated for each specimen at different $\delta\theta$. Values of -ln V were plotted (Fig. 6) for different values of Ra.

Accuracy of Measurement

Fringe visibility is lower than unity because two speckle patterns are not fully correlated. Visibility is a decreasing function of angle $\delta\theta$ and Ra. Visibility measurement will lead to detect Ra. Surface must be perfectly conducting and multiple scattering and shadowing effects have been neglected. Incident wave is plane and linearly polarized. Fraunhofer approximation is used for diffraction pattern of the surface. Accuracy of such method depends on light source used for illumination, effect of environmental condition, accuracy of Ra values, resolution of imaging system (CCD camera), and repeatability of measurements. Ra values were calculated for different specimens at four rotating angles (Table 1).

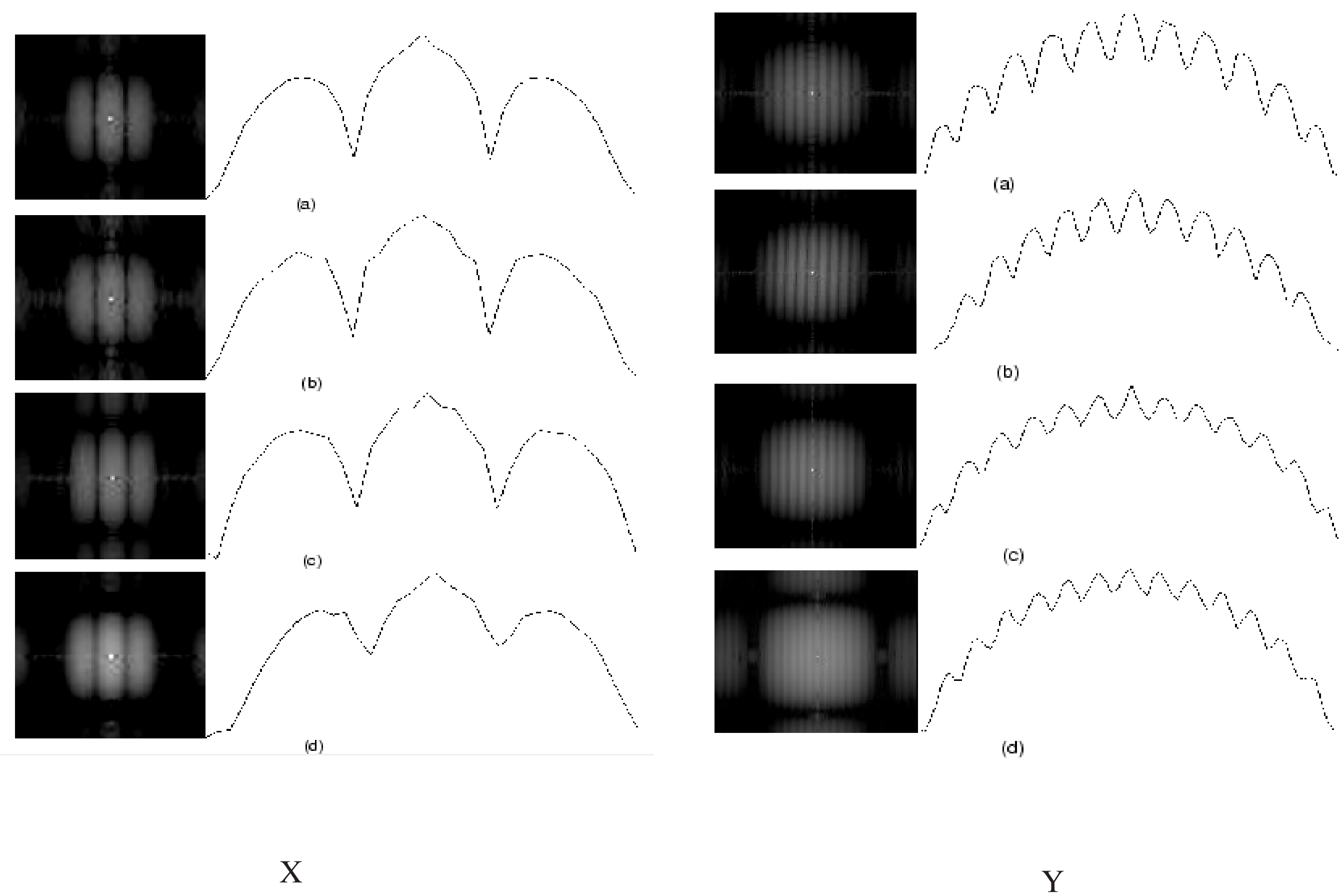

Fig. 2—Interference fringes and relative intensity distribution of specimens [(a) Ra = 1.57 µm; (b) Ra = 3.1 µm; (c) Ra = 4.5 µm; (d) Ra = 6.25µm] at displacement: X) 20 µm; Y) 100 µm

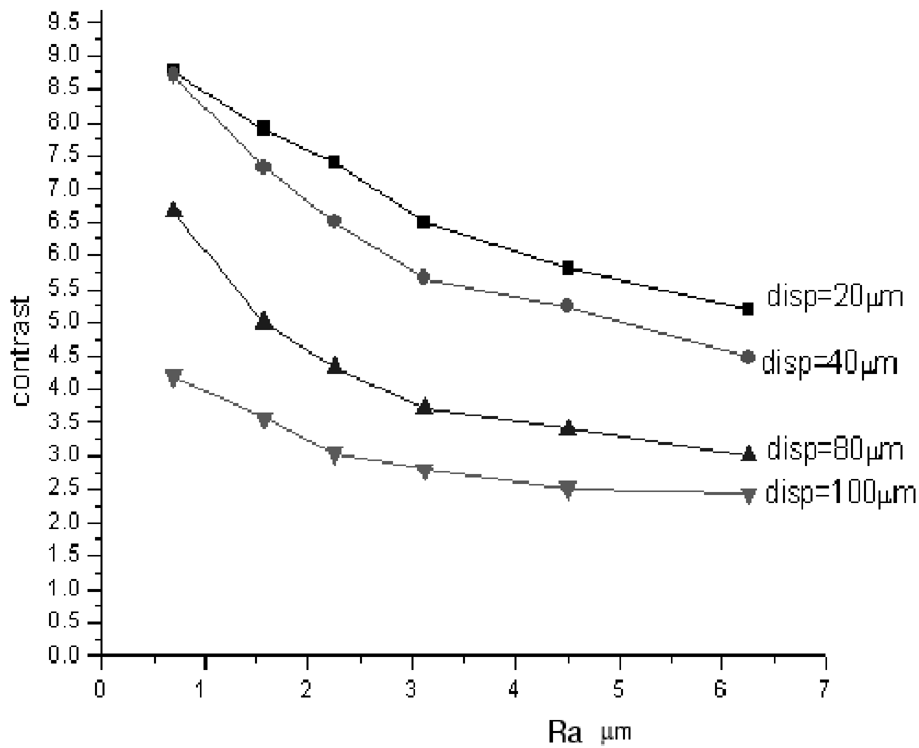

Fig. 3—Speckle contrast variation for different surfaces at different linear displacement

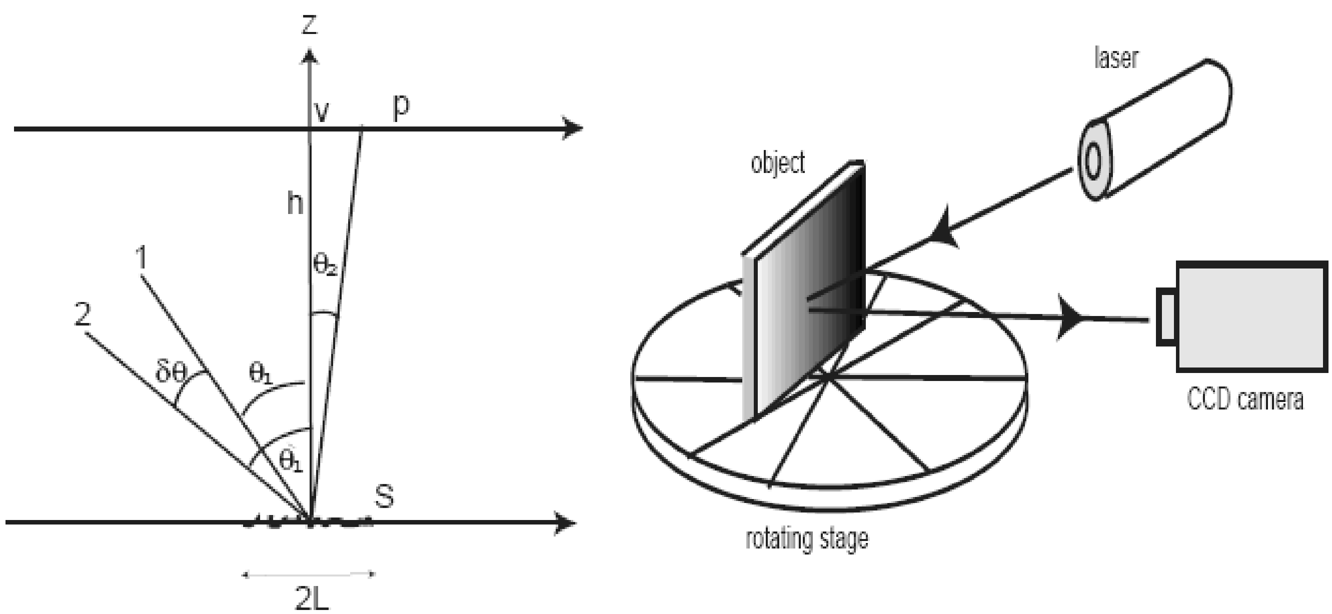

Fig. 4—Geometrical description of angular displacement of specimen

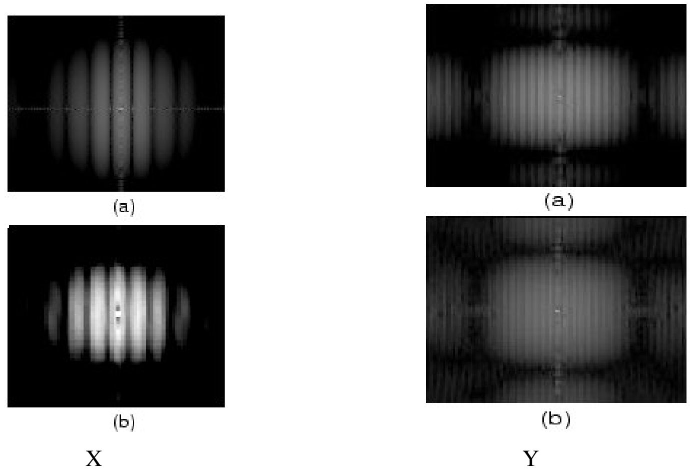

Fig. 5—Young's fringes for surfaces of Ra [(a) 1.6µm, (b) 3.17µm] at: X) $\delta\theta$=0.5°; Y) $\delta\theta$=1.5°

Table 1—Measured Surface roughness (Ra) values at illumination angle (θ = 16°)

Nominal average Ra µm	Ra œm $\delta\theta$ =0.5°	$\delta\theta$ =1 °	$\delta\theta$ =1.5 °	$\delta\theta$ =2 °	Measured average Ra µm
1.60	1.784	1.832	1.524	1.628	1.692
2.30	2.545	2.286	2.048	1.899	2.195
3.17	3.145	3.257	2.893	2.448	2.936
4.50	4.573	4.159	3.932	3.675	4.085
6.30	5.77	5.898	5.091	4.955	5.429

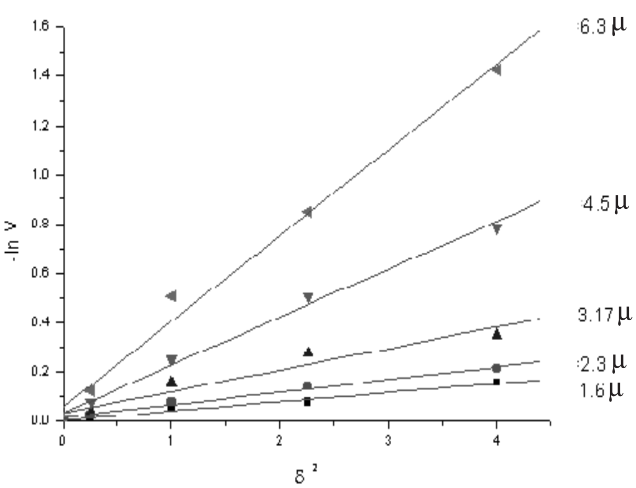

Fig. 6—Relation between $\delta\theta^2$ and -lnV at θ =16^0

Conclusions

A simple method is proposed to characterize surface roughness for objects using digital Fourier transformation of speckle pattern recorded on a CCD camera at different objects locations. Measured values were plotted against visibility of interference fringes.

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