An experimental study for characterizing surface roughness by speckle pattern analysis

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Abstract

We presented a method of measure of the rugosity based in the analysis of the texture of the speckle's pattern. We used GLCM to extract the rugosity. Our experimental results correlates appropriately with autocorrelation function.

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We present an experimental approach to measure of the roughness of the paper based in the analysis of speckle pattern on the surface. The image formed by speckle in the paper surface is considered as a texture, and therefore texture analysis methods are suitable for the characterization of paper surface. We applied digital image processing using statistics of second order, specifically the gray level co-occurrence matrix (GLCM), so this method can be considered as non-contact surface profiling method. The results are contrasted to confocal microscopy, autocorrelation function. Different parameters can be used for the characterization of surface roughness of the paper. Statistical parameters such as the arithmetic mean of the roughness, R_a and the root mean square surface roughness, R_{rms}, are most frequently used [1]. Theoretically, R_a is the arithmetic average value of departure of the profile from the mean line throughout the sampling length.

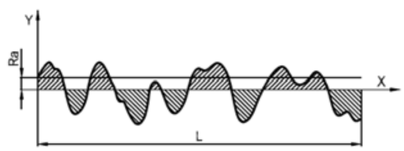
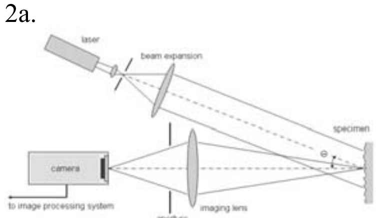


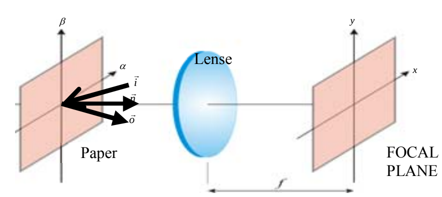
Figure 1. Definition of average roughness (Ra).

$$R_a = \frac{1}{L}\int_0^L \left|y(x)\right| dx \tag{1}$$

The setup is built with a CCD camera Pike F-032B with 640 x 480 effective pixels, with 8 bits per pixel, a 5mW, He-Ne laser with a wavelength of 632,8nm, and a beam expander. The camera is located in the sample normal direction. The format of the images was 200×200 pixels, with 256 gray levels and a 10 mm diameter speckle pattern, Figure 2a.



(a) Experimental system



(b) The intensity in the plane (x,y) is the Fourier transform of the normalized covariance function of the waves leaving the surface in the plane $h(\alpha,\beta)$ [5].

Figure 2.

The relationship between the height variations of the surface and the amplitude variations of the scattered wave is, in general, an extremely complex one, influenced by variations of surface slope and their effect on reflection, multiple scattering, and shadowing. We adopt an oversimplified model that implies that the scattered complex amplitude just above the surface is related to the surface height by a geometrical approximation that assigns a phase

"φ" to the scattered complex amplitude that is the phase delay associated with propagating to the surface and scattering from the surface [2-3], [5].

$$\varphi(\alpha,\beta)=\frac{2\pi}{\lambda}\left(-\vec{i}\cdot\vec{n}+\vec{o}\cdot\vec{n}\right)h(\alpha,\beta) \quad (2)$$

where "φ" is the phase, $h(\alpha,\beta)$ is the surface height, "λ" is the wavelength and "$\vec{i}$", "$\vec{o}$", and "$\vec{n}$" are the unitary vectors of incidence, reflection, and normal to the surface, respectively are shown the Figure 2b. Making approximations the variance of the phase shifts "σ_φ" is related to the variance of the surface height fluctuations "σ_h" through [5],

$$\sigma_\varphi=\sqrt{\ln\left(\frac{1}{\sum_{r_a>20}\mu_a(r_a)}\right)}\propto\sigma_h \quad (3)$$

Information extraction from texture images can be obtained by different texture analysis methods [1], [2], we investigated the surface roughness evaluation method using the gray level co-occurrence matrix (GLCM), a statistical method. The method for extracting the surface roughness is described extensively in work we have done previously [4], [5], [6].

$$y=y_0+ke^{-\frac{x}{\sqrt{\sigma}}} \quad (4)$$

Table1
Results of the measurement of the roughness obtained with confocal microscope, sum of the values of μ_a (r_a > $20r_c$), the equivalent roughness "σ" and parameter "y_0" for 14 specials papers.

Samples	Ra Confocal (μm)	$y_0(15^0)$	$y_0(20^0)$	$y_0(25^0)$	$\sum_{r_a>20}\mu_a(r_a)10^{-2\ a}$	$\sigma=\left[\ln\left(1/\sum\mu_a\right)\right]^{1/2}$
1	6,9	0,22697	0,22706	0,23091	0,0284	2,45
2	6,2	0,24293	0,23889	0,24417	0,0261	2,44
3	6,1	0,24225	0,22893	0,22319	0,0284	2,42
4	6,0	0,21642	0,22363	0,23153	0,0304	2,41
5	6,0	0,22521	0,22961	0,21347	0,0256	2,44
6	5,7	0,19341	0,19647	0,18724	0,0282	2,42
7	5,5	0,19469	0,18372	0,18301	0,0333	2,39
8	4,2	0,13409	0,12980	0,12798	0,0366	2,37
9	3,8	0,13086	0,14450	0,14277	0,0373	2,36
10	3,7	0,10835	0,10583	0,10003	0,0458	2,32
11	3,4	0,10442	0,10695	0,09895	0,0508	2,30
12	3,4	0,08785	0,08758	0,08906	0,0523	2,29
13	3,4	0,08406	0,09464	0,09177	0,0531	2,29
14	3,3	0,10202	0,10910	0,11397	0,0501	2,30

The surface roughness measurement technique is effective to characterize the paper surface roughness from R_a=3,00μm to R_a=6,9μm. The parameter "y_0" of the exponential trend of the energy feature for a specific paper surface is computed from only a single speckle pattern texture image of the surface. This means, after the measurement system is calibrated by standard samples surfaces, that the surface roughness of the paper surface composed of the same material in the same way as the standard samples surfaces can be evaluated from a single speckle pattern texture image.

[1] ASME B46.1-2002 (Revision of ASME B46.1-1995) surface texture (surface roughness waviness, and lay). The American Society of Mechanical Engineers, Three Park Avenue, New York, NY 10016-5990, 2003.

[2] J. W. Goodman, Speckle Phenomena in Optics: Theory and Applications, Roberts & Company Publishers (2006).

[3] Chandley, P. J. and Escamilla, H. M., "Speckle from a rough surface when the illuminated region contains few correlation areas: the effect of changing the surface height variance," Opt. Commun. 29, 151-154 (1979).

[4] Gadelmawla, E. S., "A vision system for surface roughness characterization using the gray level cooccurrence matrix," NDT & E Int. 37, 577–588 (2004).

[5] A. Pino, J. Pladellorens, O. Cusola, J. Caum, "Roughness measurement of paper using speckle". Optical Engineering 50(9), 093605, 2011.

[6] A. Pino and J. Pladellorens, "Measure of roughness of paper using speckle". Proc. SPIE, Vol. 7432, 74320E (2009).