Evaluation of the paper surface roughness on real time using image processing of the speckle pattern

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ABSTRACT

We present an experimental approach to measure of the roughness of the paper on the real time 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. The properties statistical of this speckle pattern are used for estimation and quantification of roughness parameter R_a and R_q. 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 and fringe projection.

Keywords: Paper surface, average roughness parameters, speckle, texture, co-occurrence matrix, autocorrelation function.

1. Introduction

At the moment paper roughness measurements require laboratory conditions. An automatic, on-line roughness measurement during the production process could cause significant economical savings. Immediate detection of change in paper quality could decrease the amount of low quality paper that is produced every time quality problems occur. On the way to this goal, optical measuring devices must be improved, and fast algorithms for processing measurement data must be developed. To find those features as well, there is a need to divide the sample into meaningful regions according to their qualities. Paper surface can be considered as a texture. A selection of methods exists to extract different texture features from the image.

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_q, are most frequently used [5], [6], [7], [8]. Theoretically, R_a is the arithmetic average value of departure of the profile from the mean line throughout the sampling length.

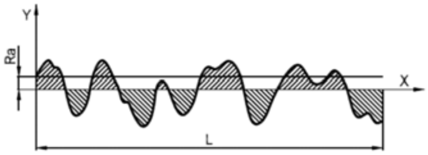
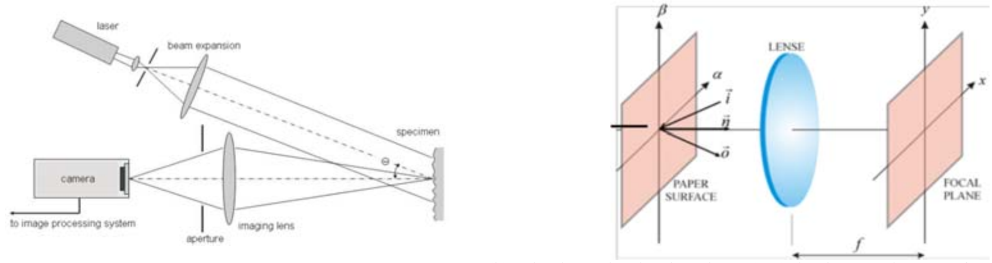


Figure 1. Definition of average roughness (Ra).

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

2. Methodology and Results

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 $h(\alpha,\beta)$

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 [9].

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

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 [9],

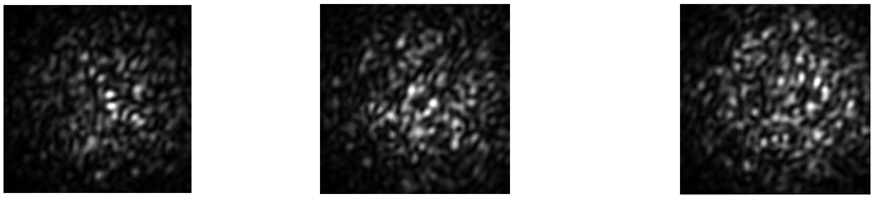
$$\sigma_\varphi = \sqrt{\ln\left(\frac{1}{\sum_{r_a>20}\mu_a(r_a)}\right)} \tag{3}$$

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 GLCM is based on second-order statistics, which deal with the spatial relationships of pairs of gray values of pixels in texture images. The method for extracting the surface roughness is described extensively in work we have done previously [3], [4], [10].

$$y = y_0 + k e^{-\frac{x}{\sqrt{\sigma}}} \tag{4}$$

Where x indicates the offset distance d and y is the energy descriptor value. The parameters of the function y_0 , k , σ are utilized to establishment the correlation with the correspondent values of the samples obtained by means of the of confocal microscopy, fringe projection and autocorrelation function. The parameter "y_0" is that maintains a very good correlation with the measures of rugosity obtained with the applied methods [3], [4], [10].

We characterized the roughness of 14 different types of specials papers with R_a between 3,3 and 6,9 μm and similar optical proprieties using optical methods. Figure 3, shows three images of the speckle pattern variations for different rugosities. This implies that the speckle pattern texture properties change with the surface roughness, and it is possible to extract the surface roughness from the speckle pattern texture images using the normalized autocorrelation function, fringe projection, confocal microscopy and parameter "y_0" from co-occurrences matrices.



F-7 Ra=5,5µm F-8 Ra=4,2µm F-12 Ra=3,4µm

Figure 3. Speckle pattern variations against the specials paper surface roughness.

Samples	Ra Confocal (µm)	Ra Fringe Proj. (µm)	y_0	$\sum_{r_a>20}\mu_a(r_a)10^{-2}$ [a]	$\sigma=\left[\ln\left(1/\sum\mu_a\right)\right]^{1/2}$
F-1	6,9	7,51	0,22706	0,0284	2,45
F-2	6,2	7,45	0,23889	0,0261	2,44
F-3	6,1	7,00	0,22893	0,0284	2,42
F-4	6,0	7,66	0,22363	0,0304	2,41
F-5	6,0	7,37	0,22961	0,0256	2,44
F-6	5,7	7,53	0,19647	0,0282	2,42
F-7	5,5	6,98	0,18372	0,0333	2,39
F-8	4,2	3,39	0,12980	0,0366	2,37
F-9	3,8	2,80	0,14450	0,0373	2,36
F-10	3,7	2,61	0,10583	0,0458	2,32
F-11	3,4	2,55	0,10695	0,0508	2,30
F-12	3,4	2,52	0,08758	0,0523	2,29
F-13	3,4	2,30	0,09464	0,0531	2,29
F-14	3,3	2,92	0,10910	0,0501	2,30

[a] We multiply by 10^{-2} to avoid negative numbers in the logarithm

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.

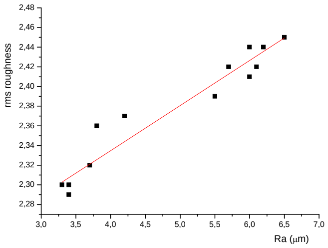


Figure 4. Comparison between the measurements using confocal microscope and our method $R^2 = 0,925$

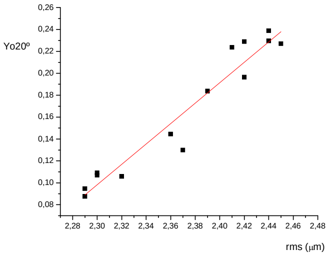


Figure 5. Comparison between the measurements using texture analysis (GLCM) and our method $R^2 = 0,932$

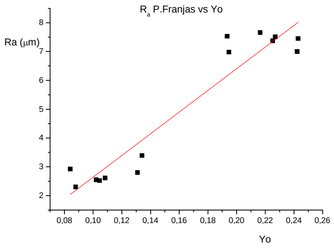


Figure 6. Comparison between the measurements using confocal microscope and our method $R^2 = 0,936$

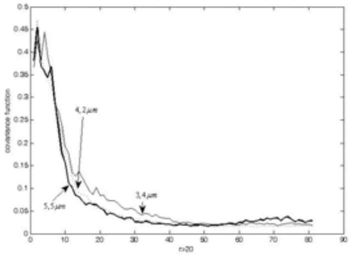


Figure 7. Values of the covariance function for three different papers

3. Conclusions

From the experimental results with the paper surface roughness samples, the surface roughness measurement technique is effective to characterize the paper surface roughness from $R_a = 3,00\mu m$ to $R_a = 6,9\mu m$. For different samples surfaces by specific methods, the range of the surface roughness, which can be characterized by the method, may be different. This means the surface roughness measurement technique we have developed needs calibration beforehand. In the surface roughness measurement technique, the speckle pattern texture images are taken by a very simple setup configuration consisting of a laser and a CCD camera. 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.

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