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ACOUSTICS-BASED SURFACE ROUGHNESS MEASUREMENT OF PAPER

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ABSTRACT

Surface roughness, one of the most important attributes of paper, it is largely determined by the different stages of the manufacture process, and its measurement is normally used in quality control applications. In the present work, an acoustical method for the determination of surface roughness of papers is described. The method uses the friction-induced acoustic noise produced when a small brush slides over the surface of the paper. Under the premise that different values of surface roughness will produce friction noise with different characteristics, a signal analysis algorithm was developed to discriminate different values of roughness from the acoustic noise. The algorithm consists of a frequency domain feature extraction routine and an artificial neural network to represent the variation of the spectral features in a roughness scale. The results are quite promising showing that an affordable system based on acoustics can be used to measure surface roughness of tissue papers and other soft surfaces not covered by standardized methods.

1 INTRODUCTION

Surface roughness is a very important feature of tissue papers which is largely determined by the different stages of the manufacture process. Currently, surface roughness measurements are used in quality control purposes, but additionally, online surface roughness measurement may perhaps be used in condition monitoring of cutting blades in production lines of tissue paper.

Currently, air leakage methods, including the Bendsten and the Sheffield methods, are the standard in the determination of surface roughness of paper [1][2]. These methods works measuring the rate of air flow between the test piece and a supporting platform. The test piece is placed between a flat plate and a flat circular platform. The air pressure on one side of the platform is atmospheric and the pressure on the other side is adjusted to create a specified pressure differential. The rate at which air passes between the platform and the test piece surface is used to as a measure of the surface roughness of the test piece.

Although the air leakage methods are applicable to most of paper and board, they are not suitable for papers which can allow a significant mechanical impression on its surface, or for high permeance papers which allow a significant flow of air through the sheet. Particularly, the air leakage methods are not applicable to embossed or creped papers, or papers which will not lie flat under the conditions of the test [1].

Currently, acoustical methods used to measure surface roughness of tissue papers use ultrasound. Making out-of-plane ultrasonic time-of-flight and attenuation measurements, it has been observed that ultrasonic impedance and mass specific ultrasonic attenuation are correlated to surface roughness [3]. Alternate optical methods includes, Fourier based methods [4], and optical coherence tomography [5]. These methods, however, although they produce good results can be very expensive, both in economical and computational terms.

In the present work, a new acoustical method for the determination of surface roughness of papers is described. The method uses the friction-induced acoustic noise produced when a small brush slides over the surface of the paper. Under the premise that different kind of surface roughness produces a friction noise having different attributes, a signal analysis algorithm was developed to discriminate different values of roughness from the friction noise.

The algorithm consists of a frequency domain feature extraction routine that calculates a set of high order statistical moments of the noise spectrum. Furthermore, an artificial neural network was used to represent the variation of these spectral features over an appropriate roughness scale.

Preliminary results are quite promising and confirm that an affordable system based on acoustics can be used to measure surface roughness of papers. Furthermore, the method is particularly suitable to measure tissue papers and others not allowed by current standard methods.

2 THEORETICAL BACKGROUND

2.1 Friction-Induced Acoustic Noise

Friction sound emanates from one or both components of a friction pair, and the differences in the sound they radiate primarily arise from the variation of contact forces at the interface where the sliding surfaces met. Light contact involving rough surfaces often produces sound, and clearly, the surface texture haves important effects of on sound radiation from friction excitation [6].

Modelling friction sound derived from surface roughness requires detailed representation of mechanical aspects of friction. The development of an accurate model which can predicts the spectral attributes of friction noise derived from the brush-paper interaction is beyond the scope of this work.

2.2 Spectral Feature Extraction

In order to found noticeable differences in the spectra, which enables the discrimination of different values of surface roughness, the acoustic noise was analyzed using a feature extraction algorithm. Feature extraction was done in the frequency domain using the statistical features given in equations (1) to (6), were $S(f)$ is the magnitude of the FFT spectrum, and N is the number of FFT points.

Energy
$$\int_0^\infty S(f)^2\, df \qquad \text{(Eq.1)}$$

r.m.s. value
$$\sqrt{\frac{1}{N}\int_0^\infty S(f)^2\, df} \qquad \text{(Eq.2)}$$

Standard deviation
$$\frac{\int_0^\infty (f-f_c)^2 \left|S(f)\right|^2 df}{\int_0^\infty \left|S(f)\right|^2 df} \qquad \text{(Eq.3)}$$

Normalized Kurtosis
$$\frac{\int_0^\infty (f-f_c)^4 \left|S(f)\right|^2 df}{\int_0^\infty (f-f_c)^2 \left|S(f)\right|^2 df} \qquad \text{(Eq.4)}$$

Normalized Skewness
$$\frac{\int_0^\infty (f-f_c)^3 \left|S(f)\right|^2 df}{\left(\int_0^\infty (f-f_c)^2 \left|S(f)\right|^2 df\right)^{3/2}} \qquad \text{(Eq.5)}$$

Centroid
$$f_c = \frac{\int_0^\infty f\left|S(f)\right|^2 df}{\int_0^\infty \left|S(f)\right|^2 df} \qquad \text{(Eq.6)}$$

In this way, a reduced number of parameters are used to represent the overall attributes of the noise spectrum.

3 DESCRIPTION OF THE ALGORITHM

Figure 1 depicts the main elements of the system including the data acquisition, the feature extraction algorithm, and the artificial neural network used to represent the roughness scale.

Friction-induced acoustic noise was obtained sliding a small brush over the surface of the paper sample at a constant linear speed of about 0.1 ms^{-1}. A condenser microphone attached to the brush was used to pick up the acoustic signal.

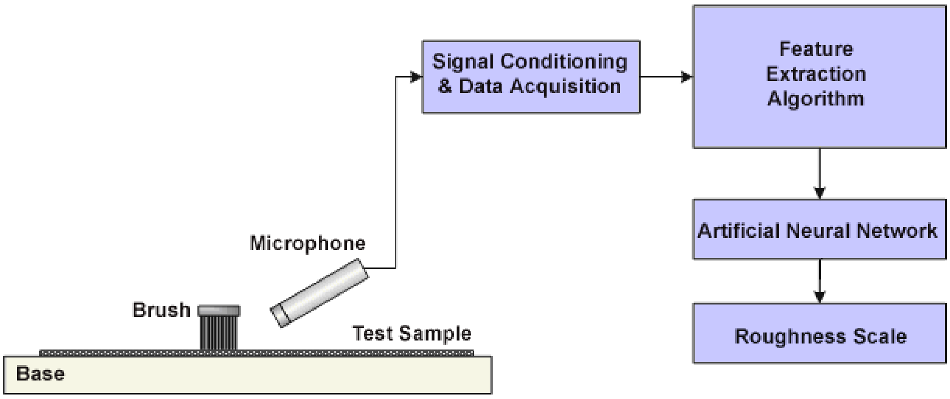

Figure 1.- Block diagram of the acoustics-based surface roughness measurement system.

The microphone signal feeds the signal conditioning and data acquisition module in which the signal is converted to the digital domain using a sampling frequency of 44.1 kHz and 16 bit of resolution. The resultant time series are pre-processed by adjusting it to have zero mean and unity variance.

The feature extraction starts calculating the magnitude of the FFT spectrum of the noise. For analysis purposes, we first consider the spectrum in a region from 300 Hz to 10 kHz. Additionally, frequency averaging is used for smoothing the spectrum. Once the spectrum is bounded and smooth, the set of six high order statistical features of the spectrum described by equations (1) to (6) are computed. The result of this is the feature vector that describes the spectrum of the noise.

Artificial neural network was a of backpropagation type with linear transfer functions. It was trained using the Levenberg-Marquardt algorithm.

4 EXPERIMENTAL RESULTS

Plots of figure 2 show the spectra of two different tissue paper samples. Clearly, the shapes of the spectrum are slightly different, proving a first approximation to the roughness discrimination from the friction noise.

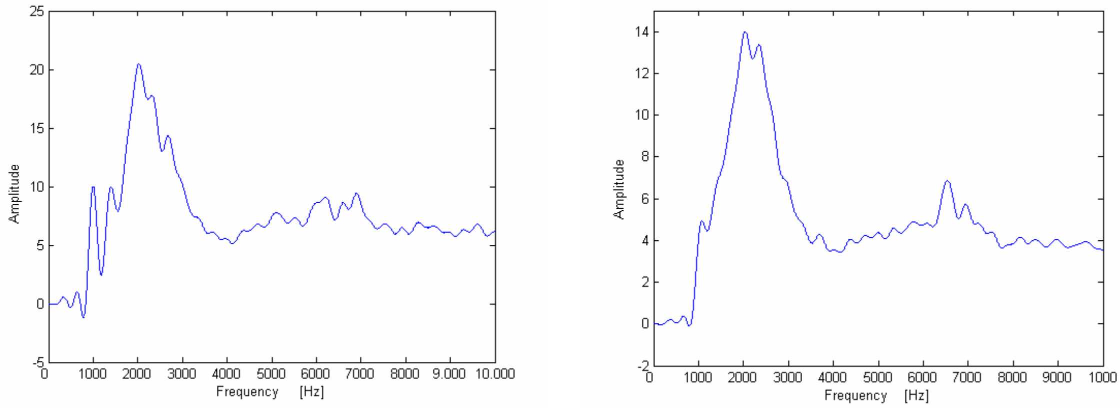

Figure 2.- Typical frequency spectra of tissue papers samples (left: Nova; right: Hygienic 724).

Table N°1 contains typical values of the noise spectrum features which are used in our roughness measurement system.

Table 1.- Typical values of spectral features of different tissue papers.

Tissue Paper Type	Energy	r.m.s.	St. Dev.	Kurtosis	Skewness	Centroid
Nova	909192.8	10.66	6.31	2.22	0.28	4502.61
Bathroom tissue 50	431728.2	7.34	4.39	1.98	0.29	4500.49
Jumbo 37	782558.0	9.89	5.67	1.99	0.11	4476.37
Jumbo 86	960352.4	10.95	6.43	2.122	0.27	4486.16
Bathroom tissue 724	1938916.6	15.56	8.57	1.86	-0.16	4409.79

The preceding results have shown that some statistical features of the frequency spectrum of the friction-induced acoustic noise produced when a brush is made to pass over the surface of the tissue paper have significant variation for each type of paper. In this sense, up to 7 different values of surface roughness were discriminated using feature extraction and neural network algorithm.

5 CONCLUSIONS

The preceding results have shown that surface roughness measurement of tissue papers can be done using acoustics signal analysis.

The results are quite promising and show that an affordable system based on acoustics can be used to measure surface roughness of tissue papers and other soft surfaces not allowed by the standardized methods.

So far, the proposed system has been tested on a small set of tissue papers with encouraging results. It is planned to expand both the number of tests as well as the kinds of papers to encompass a greater variety of cases in order to establish a roughness scale which can be comparable with the results obtained from other surface roughness measurement methods.

Further experiments are suggested, including vibration analysis and determining the forces acting between the brush and the paper surfaces in order to model the phenomena of friction sound.

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