# Non-Contact Ultrasound Characterization of Paper Substrates

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**Abstract-** Different kinds of paper varying in basis weight, thickness, etc. and finishing characteristics such as cast, gloss, matte were analyzed with and without deposited ink. A 1.7 MHz Ultran non-contact ultrasound focused transducer was operated in the pulse-echo mode to investigate the samples following a raster scan on a 1.5 cm by 1.5 cm area. Both sides of each sample were imaged under this protocol.

A pre-designed pattern consisting of some text and a rectangular solid block was printed on the front side of the samples using a Xerox Nuvera120 laser printer and the imaging protocol repeated.

C-scan images created from the envelope detected data provide a promising means to investigate and visually differentiate the mechanical properties of the samples as ink is deposited, as well as to differentiate front and back sides of each sample.

The second normalized intensity moment and Signal to Noise Ratio (SNR) of the signal envelope are investigated to test their validity to discriminate between different kinds of paper as well as differences in scattering properties when ink is deposited.

## 1.0 Introduction

Recent developments have shown the advantages of using non contact ultrasound for the evaluation of paper substrates [1],[2],[3],[4]. Fiber orientation, basis weight, thickness as well as surface roughness are some of the properties that distinguish one paper from another.

In this work we assume that surface characteristics change when ink is deposited. To test this hypothesis experiments were designed to interrogate a variety of papers using non-contact ultrasound in the pulse-echo mode. Data are collected for six samples having thicknesses from 0.1 mm to 0.21 mm and various finishing characteristic properties such as gloss, matte, super gloss and cast.

In medical applications it has been demonstrated that ultrasonic classification of tissues may be accomplished by analyzing the statistical properties of the intensity signal [5]. According to Eq. 1, Non-Rayleigh statistics provide a valuable model when the second normalized intensity moment ($I_2$) deviates from its Rayleigh limit of 2 [6],[7]. Specifically, if there is sufficient number of scatterers in the cell volume with spacing at or near integer multiples of half the wavelength, a coherent phasor can build up in a random walk problem [8]. The probability density function follows a Rice distribution and $I_2$ manifestly attains a value below 2.

$$\frac{\langle I^2 \rangle}{\langle I \rangle^2} = 2 + \frac{1}{M_{eff}} \tag{1}$$

Where I is intensity and it is equal to the square of the magnitude, and $M_{eff}$ is the effective number of scatterers within the ultrasound beam.

## 2.0 Experimental methods

Six paper samples with and without ink on the top surface were used for experimentation. They are (1) Domtar Luna matte, (2) Xerox gloss, (3) Rey Success Super gloss, (4) Mead West Vaco ultra cast, (5) Sappi Voltage gloss, and (6) Rey Success gloss.

A non-contact Ultran 1.7MHz focused transducer was used to performed a raster scan on an area of 2.25cm$^2$ on the top and bottom faces of each paper sample as is shown in Figure 1. Text and a solid block were printed with a Xerox Nuvera120 laser printer and the protocol repeated. The step size of the scan was 500μm. Data were collected using a 500MHz LeCroy Waverunner 6051 digital oscilloscope which controlled the x-y stepper motors.

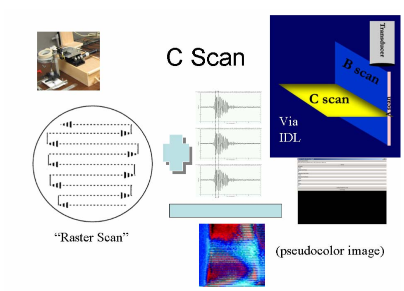


**Figure 1**. Experimental setup.
A C-scan is formed from a collection of A-lines
at a plane perpendicular to the propagation axis.

The Hilbert transform is applied to the RF data (A-line) to obtain an imaginary part. The envelope is then calculated as the magnitude of the complex signal with Eq. 2:

$$E(f(n)) = \sqrt{\Re(f(n))^2 + \Im(f(n))^2} \tag{2}$$

Intensity is the square of the amplitude, as expressed by Eq. 3:

$$I(f(n)) = E(f(n))^2 \tag{3}$$

A C-scan is calculated from the envelope of the A-lines comprising the raster scan.

## 3.0 Results and Analysis

Figure 2 shows a plot of the second normalized intensity moment for the top and bottom surfaces of six paper samples. The x-axis of the plot corresponds to the six paper samples numbered in the previous section. The variation in the second normalized intensity moment for samples without ink is explained by means of Eq. 1. The effective number of scatterers that contribute to the backscatter signal arriving at the transducer varies from paper to paper. Based on estimates of the speed of sound in paper for normal incidence [3] we assume a wavelength of 0.3 mm in paper. Individual scatterers in the paper substrate are not resolved, rather, it is the coherent interference of their echoes that determines the statistical behavior of the intensity signal. On the other hand, when ink is deposited, it is observed that the second normalized intensity moment is lower than in the corresponding samples without ink, furthermore it is observed that it remains fairly constant across samples at 1.40±0.1, which is below the Rayleigh limit. In this case, it is the toner particles that are responsible for the scattering. Since the same pattern was printed on all samples using the Xerox Nuvera120 laser printer this result was expected.

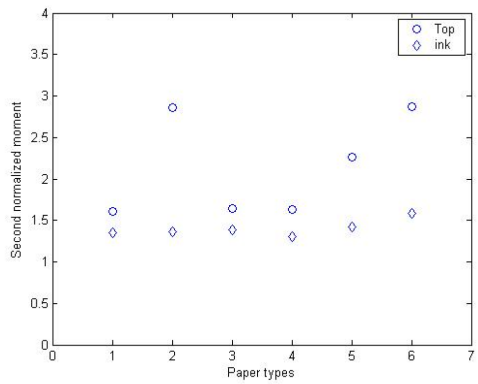


**Figure 2**. Second normalized moments of paper samples with and without ink on top surface. 1-Domtar luna matte, 2-Xerox gloss, 3-Rey supper gloss, 4-Mead ultra cast, 5-Sappi gloss, 6-Rey success gloss

The signal-to-noise-ratio (SNR) of the intensity signal was also investigated for the same samples. Results are shown in Figure 3. The SNR for samples with ink is consistently higher that in samples without ink. Once again, this result was expected since the variance for samples with ink was lower than in samples without ink.

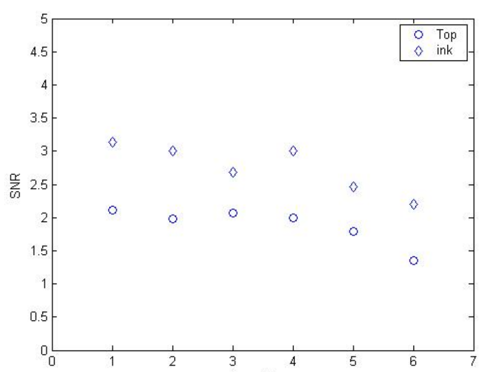


**Figure 3.** SNR of the envelope data

Both SNR and second normalized moments appear to have validity as classification parameters. Clustering results are shown in Figure 4.

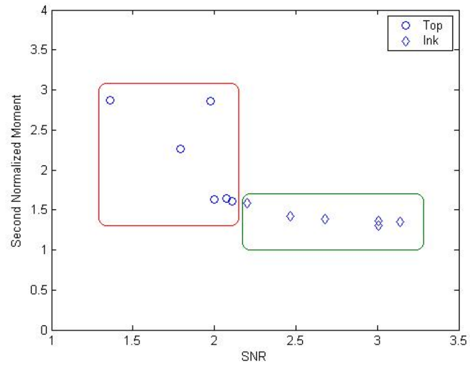


**Figure 4.** Classification of paper substrates with and without ink.

Figure 5 shows C-scan pseudo-color images of a 2.25 $cm^2$ area of the different paper samples with and without ink, front and back sides. It is observed that the C-scan images differ as ink is deposited on the top surface of the paper samples. The difference in appearance is due to different modes of propagation of ultrasound waves as they propagate on the paper.

Characteristics such as grain, surface roughness, color, can be used to differentiate paper samples. For example, the Rey Success Color Lasser super gloss, Domtar Luna matte paper samples have elongated pits . Whereas for Sappi Voltage gloss and Rey success Color Laser gloss pits are not apparent. These characteristics seem to match the wave pattern shown in the corresponding C-scan images.

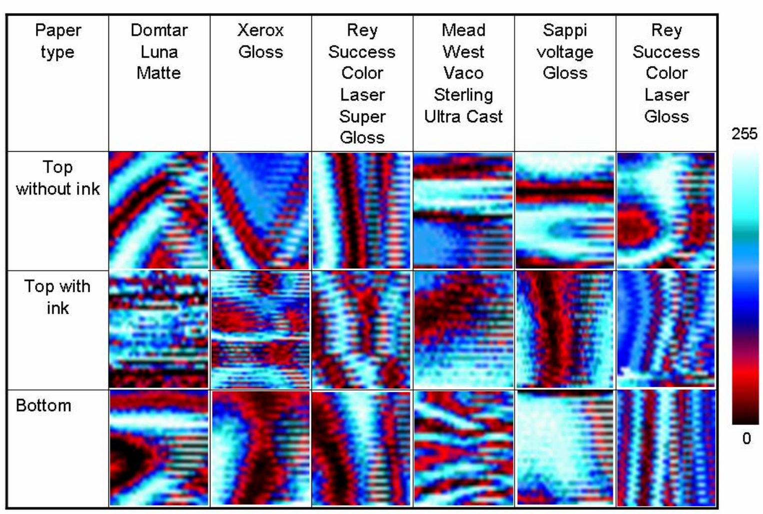


**Figure 5.** C-scan images of 6 paper samples showing top surface with and without ink, and bottom surface.

## 4.0 Conclusions

A non-contact pulse-echo ultrasound protocol was designed to study the scattering of papers varying in basis weight, caliper, surface roughness and surface finishing. Samples where analyzed with and without ink. The second normalized intensity moment and SNR of intensity signal appear to be valuable parameters for classification of samples. On the other hand, C-scan images provide a promising means to investigate and visually differentiate the mechanical properties of the samples as ink is deposited, as well as to differentiate front and back sides of each sample.

This work concentrated in the analysis of the spatial (temporal) backscattered signal in order to avoid complications brought about by leakage and aliasing in the frequency domain.

## References


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