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THE APPLICATION OF IMAGE ANALYSIS TO EVALUATE SMALL SCALE BASIS WEIGHT VARIATIONS IN PAPER

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Abstract

An image analysis technique was developed by means of which the mass distribution of paper was characterised by measurements of the light transmitted through it. To establish the ability of the image analyser to assess the mass distribution accurately, comparisons were made with the established method of beta-radiography. On the basis of these comparisons it was concluded that the small scale mass distribution can be assessed by image analysis of the light transmitted through paper.

The remaining aspects of the study demonstrate applications of the image analysis technique which include: analysing the variation in the mean and variance of the optical densities of different commercial newsprint samples: investigating the relationship between the mass distribution of newsprint and machine type: and comparing this with other methods used to evaluate mass distribution and formation of paper.

Introduction

Considerable theoretical[1-3] and some practical developments[5-8] have been made in the area of measuring the microscale basis weight variations in paper. At the same time, its importance to the structure and properties of paper has been documented[3,9,10]. Nevertheless, only a relatively small effort has been made to apply these concepts to develop an acceptable commercial system. While there are probably several good reasons for this, one very important factor could be the availability of a reliable means of measuring mass basis weight variation quickly, accurately, and economically.

With the advent of image analysis, a new technique may be available to measure the mass distribution in paper. Image analysis in a general sense refers to the quantification of features of interest on a given image through the use of one of a variety of instruments. In the context of this study, the image is detected by a video camera whose output is quantified by an image processor and displayed on a video monitor. The primary advantage of image analysis is that it requires no moving parts and because it employs transmitted or reflected light, the analysis can be made rapidly. Qualitative image assessment is also easily done with image analysis. To date, image analysis has not been used extensively[11] to study the mass distribution of paper.

This paper is largely concerned with exploring the application of image analysis to characterise the mass distribution of paper. This was done by first obtaining the optical density distribution of paper by image analysis. Then, using handsheets of known basis weights and with the help of densitometry, a relationship was established between optical densities and basis weight of commercial newsprint samples. This was then used to determine the basis weights of the newsprint samples. Finally, comparisons were made between these results and basis weight derived by other methods.

Image analysis systems

The system used in this study consisted of an RCA TC1005/No.1 video camera, with a one-inch Newvicon target giving horizontal resolution of 800 dots. The video signals were processed by a Camberly Automation Image Analyzer. The processed image was displayed on an RCA TC1214 fourteen inch video monitor. Light transmitted through paper samples and beta-radiographs from a light box with uniform diffuse illumination served as the source for image analysis. The video camera employs a conventional 525 line format at a scan rate of 30 frames per second interlaced 2:1. Thus the odd scan lines are scanned in 1/60 second and the even lines are scanned in the following 1/60 second. The image processor responds to the voltage profile of the 525 scan lines which correspond to the light intensity of the image. Those areas of the image which are lighter than a given grey or threshold level are displayed as a percent of the total image area. The incoming signals are compared to the threshold level which elicits an all or nothing response. If the input exceeds the threshold, an output pulse is generated which remains until the input falls below the threshold level. This output pulse is known as the gating pulse. The image processor operates on an internal master clock which generates a pulse at a rate of 10 MHz. The clock and gating pulses are applied to the inputs of an AND gate which allows the clock pulses to pass only in the presence of a gating pulse. Thus, when calibrating the image analyser, a gating pulse is generated for all 525 scan lines allowing all the clock pulses to pass. The total number of clock pulses is then taken to represent 100% of the area.

The threshold level can either be adjusted such that all input voltages above it produce a gating pulse or a window can be set such that only those input voltages within the window produce a gating pulse. The image can then be scanned in increments according to the present window, thereby producing a distribution of percent area versus threshold level. If the feature under investigation is actually darker than the surrounding areas, a negative of the image can be created for processing. The gated clock pulses are mixed with the input signal for display on the monitor. This results in shading-in of those areas being measured, allowing the operator to see the scanned and measured areas. A fact to be noted here is that this is a very accurate method of determining optical density distribution. The pixel sizes involved in this case are extremely small and are rectangular in shape. The longer side of the rectangle is determined by the distance between any two adjacent lines of 525 scan lines of the camera. The limit is fixed by the size of the sample paper and lens system used. Pixel dimensions of the order of a hundredth of a millimeter are not difficult to obtain. Thus, even quite uniform intensities or mass variations can be detected and measured.

Image analyser measurements

All image analysis measurements in this study involved scanning the image from lightest to darkest areas with a threshold window corresponding to 0.1 optical density. The window size was established with the use of neutral density filters of known optical density. To express the results in terms of basis weight or optical density, it was first necessary to determine a calibration equation relating threshold values and the desired units. For both paper samples and beta-radiographs, threshold levels of references with known values of either basis weight or optical density were measured from which the corresponding calibration curve was generated. Thus when scanning the image, threshold values were converted to the appropriate values of basis weight or optical density producing a distribution of percent area versus the converted units. Figure 1 illustrates a typical calibration curve and percent area distribution of the optical density of a paper sample. The mean, $\overline{OD}$, and standard deviation, σ, of the optical density, OD, was then calculated from the distribution using the following equations:

$$\overline{OD} = \frac{\sum \%(AREA)(OD)}{\sum \%(AREA)} \qquad (1)$$

$$\sigma^2 = \frac{\sum \%(AREA)(OD) - \overline{OD}}{\sum \%(AREA)} \qquad (2)$$

For some samples, mass distribution was described in terms of the coefficient of variation, COV, which is defined as follows:

$$COV = \frac{\sigma}{\bar{X}} \times 100 \qquad (3)$$

This description of measurements was the basis of all image analyser results obtained in this study.

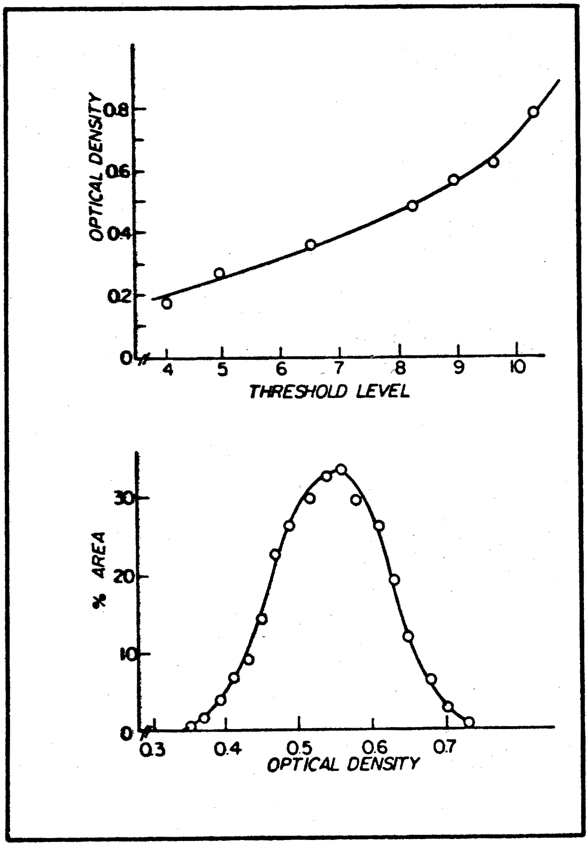

Fig 1—A calibration curve and corresponding % area distribution of the optical density of a paper sample measured with image analysis.

Aperture size and measuring area

To characterise small scale mass distribution accurately, consideration must be given to aperture size and measuring area. The sample area on which each measurement is made is known as the aperture size. In terms of a video system, aperture size is determined by dividing the image height by the number of scan lines (525). Since the electron beam scanning the video target within the camera tube is orthogonal, the value obtained corresponds to either the height or the width of the aperture.

The selection of the proper aperture size depends on both the sample being measured and the anlysis to be performed. When examining paper samples, the aperture must be large enough not to be sensitive solely to light scattering by the fibres, but small enough to allow the detection of small scale mass variations. On this basis, Sara(12) has determined that the aperture should be no smaller than 0.1 mm.

The effect of aperture size on the standard deviation was determined for image analysis. A newsprint sample was divided into increasingly smaller squares ranging from 200 x 200 mm^2 to 12.5 x 12.5 mm^2. The magnification was varied such that the height of each square corresponded to the full 525 horizontal camera scan lines. Thus, the aperture sizes ranged from 0.381 mm to 0.04 mm. The standard deviation of the threshold values was measured with each aperture and the resulting relationship is shown in Figure 2. It can also be seen that the standard deviation levels off at aperture sizes greater than 0.180 mm. This is in agreement with the recommendation of Sara(12), who suggested that ideal aperture sizes lie between 0.1 mm and 1.0mm.

The measured area is the total sample area over which the mass distribution is determined. The area measured must be chosen such that it is larger than the average floc size, but small enough to exclude the effects of large scale variation.

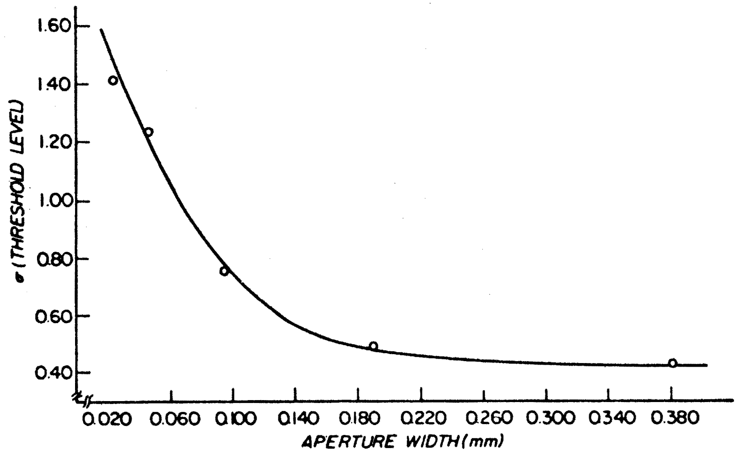

Fig 2—The effect of aperture size on the standard deviation of the image analyzer threshold level for newsprint.

The relationship between the optical density of paper and its basis weight

Since the objective of image analysis is to determine the basis weight distribution of paper, the following study was undertaken to derive the relationship between optical density distribution and basis weight distribution. With this information, we could then compare the results of image analysis of paper to those of beta-radiography. For this purpose, nine handsheets were prepared from samples of newsprint ranging from 38 to 55 g/m^2 in basis weight. The average basis weight was determined gravimetrically. As a result of the reduced consistency achieved by using an extended sheet mould, these handsheets may be assumed to be random.

Sheet optical density was measured on both a densitometer (1.0 mm aperture) and the image analyser (0.116 mm aperture). Table 1 shows these results as well as the calculated mean, standard deviation and COV for each method. Linear regression was used to determine the line of best fit and the correlation coefficients for each method are included in Table 1. A slightly better correlation was obtained with the densitometer.

Basis weight (g/m^2)	Densitometer Mean (OD)	Densitometer Std. dev. (OD)	Densitometer COV	Image analyser Mean (OD)	Image analyser Std. dev. (OD)	Image analyser COV
38.40	0.52	0.030	5.77	0.516	0.077	14.92
39.96	0.54	0.026	4.81	0.602	0.076	12.62
42.69	0.59	0.029	4.91	0.617	0.075	12.16
45.10	0.64	0.025	3.91	0.647	0.069	10.66
46.71	0.66	0.025	3.79	0.681	0.048	7.05
48.15	0.67	0.023	3.43	0.683	0.049	7.17
51.49	0.70	0.027	3.86	0.709	0.057	8.04
52.57	0.74	0.028	3.78	0.732	0.049	6.69
55.23	0.76	0.033	4.34	0.761	0.043	5.65

Lines of best fit

Densitometer: Basis weight = (63.84)(OD) + 2.52
$r^2 = 0.991$

Image analyser: Basis weight = (74.26)(OD) - 2.38
$r^2 = 0.966$

Table 1
The effect of mean basis weight on the optical density distribution of news-print handsheets.

The relationship between the optical density and basis weight of handsheets, as measured by the densitometer, was then used to determine the basis weight distribution of commercial newsprint samples from their optical density distributions obtained by image analysis. Beta-radiographs of samples 16 and 17 were prepared from which basis weight distributions were determined using image analysis[1-3]. Optical density distributions of the paper samples were also measured with the image analyser. Though not shown here, it was found by densitometry that the conversion curve for optical density to basis weight of commercial newsprint paralleled that of the handsheets. Thus, an intercept correction was found. This was then used to derive the curve of optical density versus basis weight for commercial newsprint. This relationship was then used, in image analysis, to position the commercial newsprint curve relative to the handsheet curve. The regression calibration curve is given by the following equation.

$$\text{BASIS WEIGHT } (g/m^2) = 63.84 \text{ (OPTICAL DENSITY)} + b$$

where the intercept correction is determined by the following.

$$b = \overline{B.W.} - 63.84\ (\overline{O.D.})$$

Comparison of Basis Weights from Image Analysis with Beta-radiography

Six commercial newsprint samples were used for this purpose. Their optical density distributions were obtained by image analysis. Then, with the help of densitometry and newsprint handsheets, their basis weight distributions were obtained. These were compared to the results obtained from beta-radiography with 2σ confidence intervals. Figure 3 shows that while both methods give the same average basis weight, the standard deviation of the derived values is in all cases less than the measured values. These results indicate that the basis weight of newsprint can be obtained from measurements of transmitted light and reinforce the close identity between the optical density and the mass when determined by image analysis.

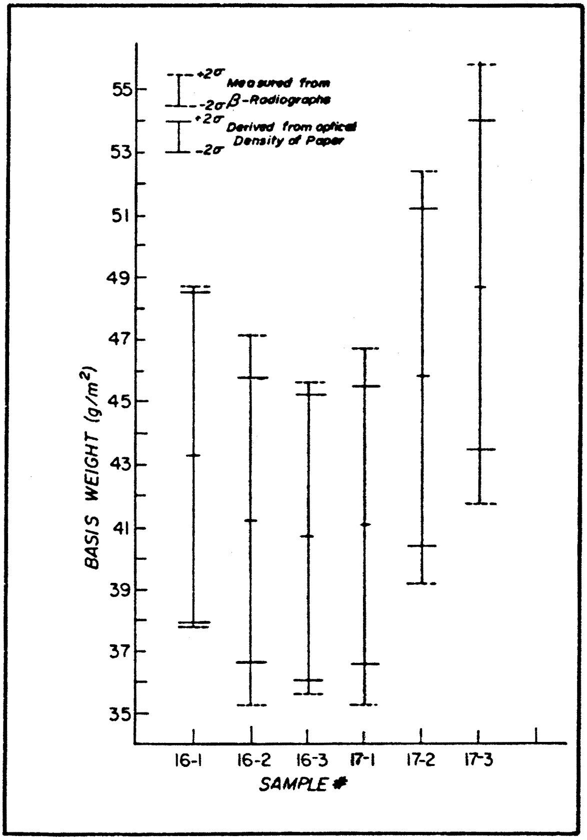

Fig 3—A comparison of the measured and derived basis weight distributions of commercial newsprint.

Some applications of image analysis

Commercial Newsprints

When making an instrumental assessment of the uniformity of the basis weight of paper, it is important to determine the ability of the instrument to distinguish differences between similar samples. Such an analysis was performed with the image analyser. The optical density distributions of a series of commercial newsprint samples were determined using an aperture size of 0.381 mm and a measuring area of 200 x 200 mm^2. 95% confidence intervals were constructed for the mean and variance of each sample as shown in Figure 4.

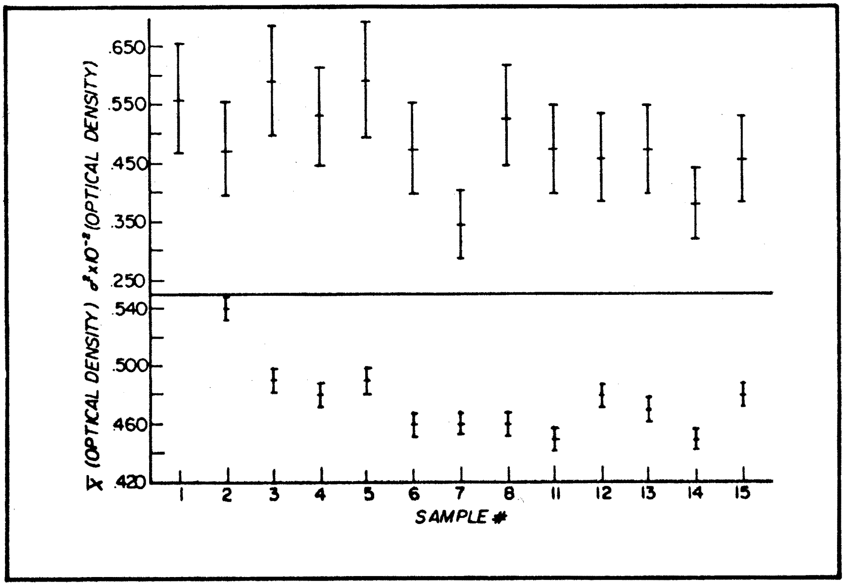

Fig 4—The variation of image analyzer measurements in commercial newsprint samples.

When comparing the samples, differences can be assessed according to the amount that the confidence intervals overlap. It is interesting to note that the variances are not related to their corresponding mean values.

COV as a function of machine type and furnish

According to Aaltonen(4), instrumental measurements of mass distribution indicate a greater uniformity among Fourdrinier-made papers than paper made on twin wire machines. Visual assessment, however, indicates a greater uniformity of twin wire-made paper than that made on a fourdrinier.

COV was calculated for the preceding commercial newsprint series and compared to machine type and furnish composition as shown in figure 5.

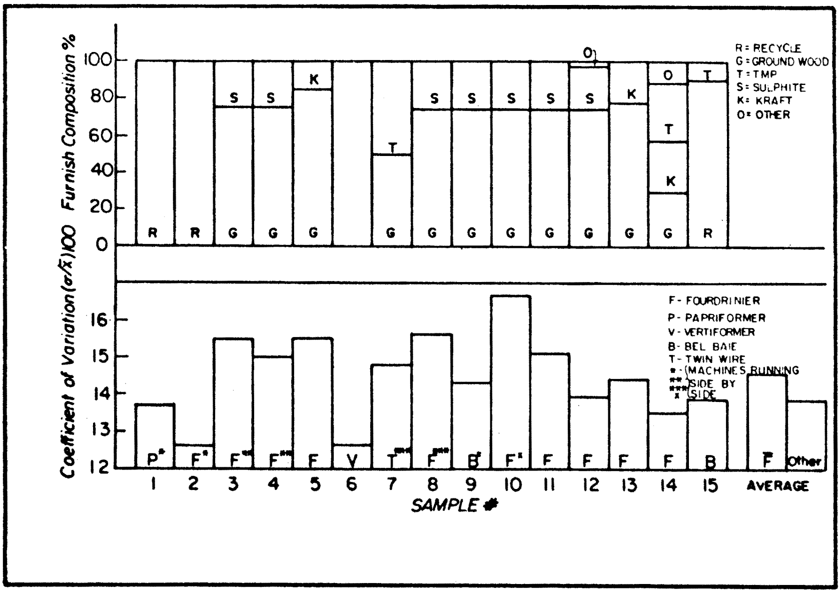

Fig 5—The mass distribution of commercial newsprint as a function of machine type and finish.

It can be seen that on the average twin wire made sheets showed a more uniform mass distribution than sheets made on a Fourdrinier. Considering the findings of Aaltonen(4), one would conclude from these results that image analysis seems to agree better with visual assessment than other methods.

Comparisons between Image Analysis and Other Mass Distribution Measurements

Comparisons were made on common samples between COV obtained from image analysis (200 x 200 mm^2 sample size, 0.381 mm aperture) and three other methods used to evaluate mass distribution. These were a beta-scanner, the QNSM formation tester, and visual ranking.

Table 2 shows the comparison with a beta-scanner which measures basis weight along a continuous line with a 1.0 mm aperture. The COV was calculated for both methods and the values were ranked from most to least uniform. The rank correlation coefficient was calculated using Spearman's rank correlation analysis, and the null hypothesis, that the ranks are independent, was tested at the 90% confidence level. The rank correlation of 0.64 indicates that the two rankings are dependent.

	Image Analyser		Beta-scanner	
Sample	COV	RANK	COV	RANK
1	13.70	4	8.87	4
2	12.59	1	8.17	2
6	12.61	2	7.98	1
7	14.78	6	8.70	3
8	15.56	7	10.03	6
13	14.47	5	10.85	7
14	13.55	3	9.38	5

Rank correlation coefficient = 0.64

Table 2.

Rank comparison between image analysis and a beta-scanner

Table 3 shows the results of a comparison between COV measured with image analysis with the Lin C values obtained with a QNSM-meter formation tester. Rank comparisons resulted in a correlation coefficient of 0.33 at a 90% inference level. One would conclude from this result that the values are independent. It is not clear why the correlation is so weak, since both measurements use a similar measuring principle. According to Burkhard et al[6], The Lin C values indicate the overall uniformity of the sheet. Higher Lin C values would correspond to a less uniform sheet.

	Image Analyser		QNSM-meter	
Sample	COV	RANK	Lin C	RANK
11	15.11	5	57	3
12	13.96	2.5	46	1
13	14.47	4	59	4
14	13.55	1	50	2
15	13.96	2.5	62	5

Rank correlation coefficient = 0.33

Table 3
Rank comparison between image analysis and the QNSM-meter.

Table 4 shows the rank comparison of COV and visual assessment on filled sheets (ash content varied from 2 to 14%). Each sample was ranked by three observers and assigned a value from 1 to 5 (best to worst). Spearman's rank correlation coefficient of 0.83 indicates a strong dependence between the two methods. It would seem that for these paper samples the COV as measured with image analysis simulates human perception of mass uniformity.

	Image Analyser		Visual	
Sample	COV	RANK	RATING	RANK
20	12.20	1	1.3	1
21	12.30	2	2.0	2
22	12.77	3	4.3	6
24	13.06	5	3.3	5
25	13.66	6	3.0	4
26	12.80	4	2.3	3
28	16.70	8	5.0	8
29	14.24	7	4.0	7

Rank correlation coefficient = 0.83

Table 4
Rank comparison between image analysis and visual assessment

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Transcription of Discussion

Discussion following the prepared discussion given by
Dr. P. Luner

Dr. J. Mardon, Omni-Continental, Canada

There is a lot more in that last slide than you discussed. Firstly, you did not point out that the x-axis shows first pass fines retention, which is unusual. One of your points shows a first pass fines retention of 90%, which is a most uncommon figure.

Dr. P. Luner, ESPRI, USA

It certainly was. These data were taken from fast machine trials in which large quantities of chemicals were used to obtain the high retention values. The paper was not for sale.

Dr. J. Mardon

If we could obtain first pass fines retention of 90% on a fast machine we would both be millionaires!

Dr. P. Luner

Maybe we should get together!

Dr. D. Wahren, IPC

I am very impressed by both your and Prof. Ebeling's attempts to find quick and accurate ways of measuring formation, and of analysing the relationships between it and paper machine variables. A note of caution though. We know that when a fibre suspension flocculates the intensity of the mass distribution doesn't change very much, i.e. the coefficient of variation of density increases only slightly. What does change though, is the scale of the variation, especially on the microscale.

It is important therefore, when using your image analysis technique to evaluate also the scale of the variation. This should be quite straightforward, using either Fourier analysis or correlation.

I would also like to comment on the Lin C values given by the QNSM formation tester. This instrument is not compensated for paper opacity, and so is not normalised. If you plot the value for different machines against opacity and compensate for the influence of opacity on the readings you will get different rankings. The theoretical relationships were presented here eight years ago.

Prof. P. Luner

Thank you for these comments. There is always great pressure to compare results, especially those which are novel. However, it is always important to consider how a measurement has been derived, and so I thank you for drawing attention to this point.

Dr. M.B. Lyne, Paprican

People who have tried to predict the uniformity of print density from the basis weight distribution of the sheet, find disappointing correlations between the coefficient of variation of the basis weight and that of optical density in a black print on the same sheet. However, an old associate of mine compared a beta radiograph negative of a sheet of paper with the same sheet printed with a solid black. When they were superimposed, the optical density appeared perfectly uniform. Similarly, Byron Jordan, of our Institute, has used the image analyser to show that the first order statistic, the coefficient of variation, does not correlate well with printability, though the second order statistic, describing the distribution of flocs and distribution of optical density, does. So, to extend this work to print uniformity, I would recommend using second order statistics.

Dr. P. Luner

Thank you very much.