BACK-TRAP AND HALF-TONE MOTTLE MEASUREMENT WITH STOCHASTIC FREQUENCY DISTRIBUTION ANALYSIS

ROY ROSENBERGER
Verity IA LLC
2114 Sunrise Drive
Appleton, WI 54914

DANIEL CLARK
Rochester Institute of Technology
999 Lomb Memorial Drive
Rochester, NY 14623-0887

DALE DRAKE
Fox Valley Technical College
5 Systems Drive
Appleton, WI 54912

ABSTRACT

A spatially sensitive stochastic frequency distribution analysis software algorithm, operating in a graphic arts quality scanner based image analysis system, has been applied to offset printed images. This algorithm is based upon the luminance value statistical variance within a target that is "tiled" in the image as opposed to other less reproducible techniques that employ the average of the luminance values. The algorithm is sensitive to the spatial distribution and relative size of skipped and lightly printed sub-visible areas that are correlated to half-tone mottle. It has been discovered the separation and arithmetic recombination of the digital image color bands used to acquire the digital image can be used to amplify the variances in different colored inks. Several examples of this method in use are provided with illustrations and a suggested measurement scale.

INTRODUCTION

Mottle is the non-uniform reflection from a surface or transmission of light through a translucent specimen. When the human eye inspects a mottled surface it recognizes changes in the luminance from one area to another. Small repetitious areas that have a consistent variation within them are called "Texture. The uniformity of the texture distribution, or degree of mottle, can vary across a wide range of spatial frequencies. Human cognition occurs when the intellect determines which mottle pattern forms specific images of interest. At any level of magnification, it is the spatial distribution of the transitions from one luminance level to another, or texture distribution variations, that determines the degree of mottle.

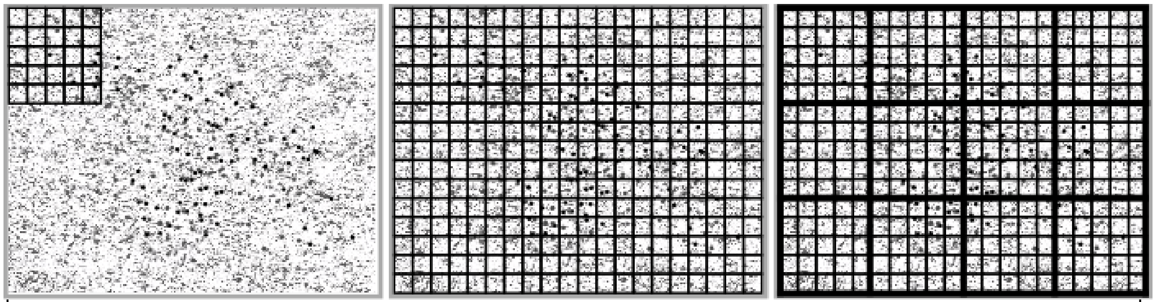
In the inspection of printed images containing half tones the current practice is to evaluate mottle by directly measuring the circularity, size, and luminance value of the discrete printed dots. An attempt is then made to relate these measurements to mottle. Because of the high resolution and magnification required, the apparatus currently employed in dot measurement examines only relatively small printed areas. As a result of the small areas of examination and the errors associated with exact dot size measurement it is difficult for the papermaker to correlate these results to process variations that impact large areas of the sheet.

Printed areas occupy thousands of square meters and, among other criteria, paper and film print quality is based upon the uniformity of ink transfer across the entire printed surface. Mottle can occur in spatially diverse areas. As a result, It can be inferred that the evaluation of large images is better than small in detecting and measuring mottle. The automated image analysis method discussed in the following can measure mottle in large areas as well as small.

STOCHASTIC FREQUENCY DISTRIBUTION ANALYSIS

Stochastic derives from the Greek word "stokhos" for the pillar or stake used in ancient times as a target for archers. Stochastic Frequency Distribution Analysis (SDFA) employs a contiguous virtual matrix of small square digital target areas within a digital image. All digitized images are composed of picture points that accrue to themselves the characteristics of the pixel or picture element to be printed or displayed and the dimensions of the square target are also expressed in picture points (pp). As shown in Fig1, the matrix of targets covers the entire area to be inspected and subdivides it into a uniform pattern of targets each containing exactly the same number of image picture points. In the SFDA the degree of variation among the picture point luminance values <u>within</u> each target and the variation <u>among</u> the targets themselves determines the degree of mottle.

A very small target, for example, could contain 25 pp. At 500 ppi this small area is visible and is what the eye would recognize as the texture of an image. Its numeric value is the pp luminance value variance. As shown in Fig1, these texture measurements are then grouped into larger targets and the variance of the textures <u>within</u> the larger targets then used to compute the variance <u>among</u> the larger targets which is then a measure of the spatial distribution of the patterns formed by the image texture. By using a range of target sizes based upon the underlying texture, SFDA provides a measure of mottle spatial distribution.



A B C

Figure 1 Stochastic Frequency Distribution Analysis: The statistical variance of the luminance values for all picture points within each of the small targets shown in A & B is computed and recorded in a matrix data base of the same dimensions as the target matrix. The overall texture of the image is proportional to the variance of the variances in the small targets shown in B, a total of 300. These individual variances are then grouped into targets containing the same number of smaller target variances, in this case 25 each. The variances of the variance of 25 small targets in each of the larger targets in C, a total of 12, is recorded in another data base where the variance of those variances is now proportional to the spatial distribution of the image texture.

The sensitivity of this measurement technique is proportional to the resolution of the image and the smallest target used to define the texture. The resolution can be quite coarse and the measurement will still respond to changes that are very fine by comparison. For instance, to predict half-tone mottle, an image of a solid black area can be acquired at 500 ppi and measured with a target that is 254 micrometers square containing 25 picture points. At 500 ppi the picture point sensor is gathering light from an area that is 0.0508 mm in diameter, slightly larger than the offset dot 30 micrometers diameter. Because of the high contrast between the black ink and the paper, any pore or void in this solid black image will change the luminance value of the picture point receiving the light from the pore proportional to the size of the pore. Since the picture point is part of the 25 picture points within the target, the luminance value statistical variance for that target will be changed. The variance of the variances among all the targets covering the image area then provides the mottle at a spatial distribution determined by the target size.

Target Size for Tests

Unassisted, the human eye can detect variations in luminance values in areas smaller than 1 mm square. When inspecting for visible image variations such as half-tone mottle it is therefore advisable to relate the visible to the sub-visible by measuring at a variety of spatial distributions at least one of which is visible. For half-tone mottle it was determined experimentally three target sizes with widths and heights of 5 pp (0.25 mm), 20 pp (1.0 mm), and 40 pp (2.0 mm) worked very well at an image resolution of 500 ppi (197 pp/cm) and are reported in the following data.

APPARATUS & MATERIALS

Image Analysis System: All specimens were processed using Verity IA 2000 Mottle analysis software in a high speed personal computer. The computer was supplied with a large 256 MB memory that enhanced the processing of large images generated by an AGFA DuoScan graphic arts quality full color flat bed scanner. This particular scanner incorporates axially symmetric dual specimen illumination bulbs. The dual bulb construction eliminated image shadows caused by paper cockle, protruding fibers and heavy ink. Although an imaging resolution of 500 ppi was used on all these tests, the scanner camera was capable of optical resolutions up to 2000 ppi. In each analysis all bands were averaged together to produce and equally weighted 8 bit , 0 255 luminance value image. No mathematic or image optimization techniques were employed in the analysis. Enhancements were used, where noted, however, to generate some of the graphics presented in the following.

Presses: Two different Heidelberg offset presses were employed: At the Rochester Institute of Technology (RIT) in Rochester, NY, a six color sheet fed and at the Fox Valley Technical College (FVTC) in Appleton, WI, a four color sheet fed offset printing press.

Color Images, Color Bands, and Image Math

Inside a color scanner the color image is acquired with a digital camera usually having three rows of sensors, red, green, and blue (RGB), arranged in ranks one above the other. The individual RGB sensors are compacted horizontally to a density defined as the resolution expressed in North America as points per inch (ppi). When an image acquisition session is complete, the scanner driver software realigns the RGB picture point sensor rows to superimpose one upon the other and compute the color vector for each sensor point before the image is filed away, displayed on screen, or transferred to the image analysis software.

The color picture point sensors create three separate images, or color bands, that record, as a numeric value, the intensity of the light striking the sensor dedicated to that picture point location. In all image processing these three values are within the luminance vector so they can be reproduced and analyzed as a color image.

If necessary the SFDA mottle algorithm can take advantage of the RGB color separation by analyzing each band selectively or by combining the digital luminance values in each image mathematically. The separate RGB color luminance values range from 0 to 255, from dark to light respectively. These numeric luminance intensity values can be divided and multiplied together to create new images and provide a potential tool for the analysis of multicolor back-trap.

MEASUREMENT OF SINGLE COLOR, CYAN BACK-TRAP MOTTLE

Single color Set-up: The six color sheet fed offset press at RIT was used to test the ability of the SFDA algorithm to measure the effects of ink overprints, or back-trap, using heavy weight flat sheets, 18 point cover stock. The pattern shown in Fig 2 was used to print 100% cyan in three different areas of the pattern on unit 2. Two of these areas were then over-printed once more, one on unit 5 and the other on unit 6. The purpose was to determine if the SFDA algorithm could define differences in the degree of mottle induced by the multiple blanket exposures and the effect of blanket exposure on ink on ink. The print on unit 2 would experience 4 more blanket surfaces before exiting the press. The overprint at unit 5 would experience not only the effects of back-trap but one more blanket exposure. The overprint at unit 6 experienced no more blanket exposures.

Fig.3 shows an enhanced image of the printed pattern. The enhancement used an equalization tool that redistributes the image luminance values across the full 0 to 255 8 bit digital range to make visible the subtle differences measured by the SFDA algorithm.

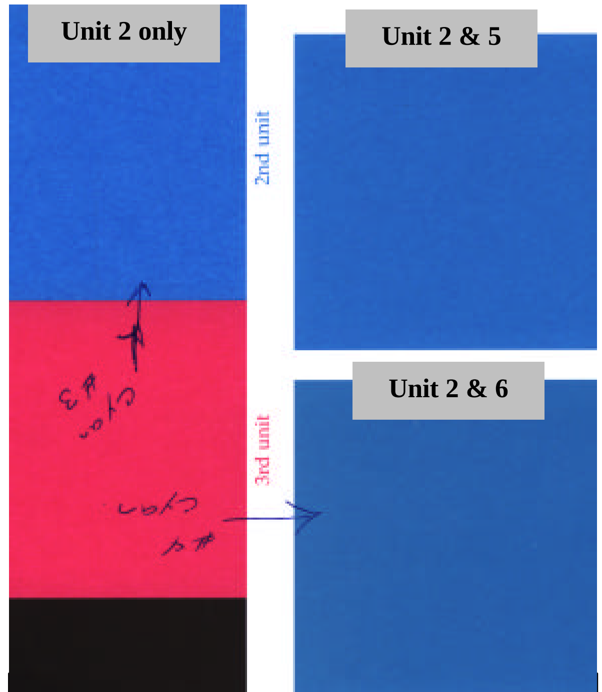


Figure 2 A scanned image of the pattern printed in cyan, magenta and black. Only the cyan is of interest and was printed in this order: starting top left, on unit 2 only; top right unit 2 then again on unit 5; lower right on unit 2 then again on unit 6.

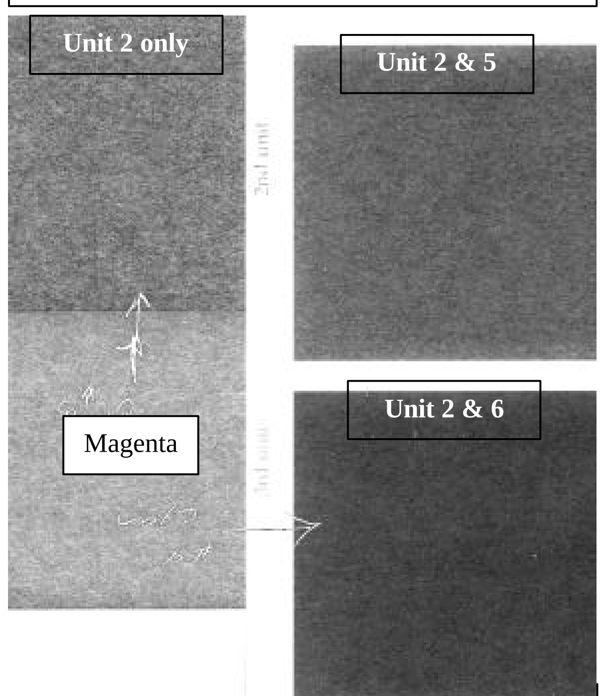
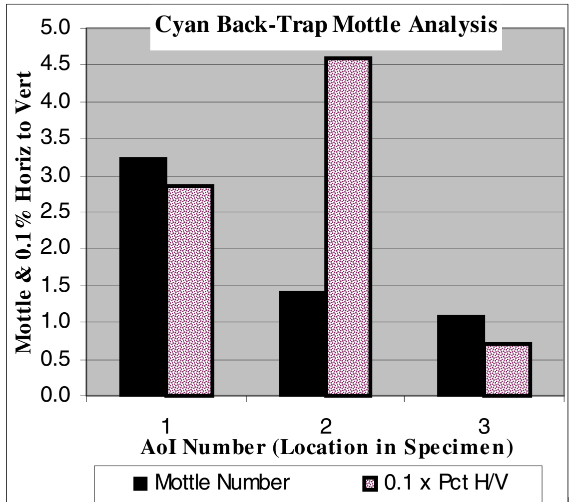


Figure 3 The printed pattern in Fig. 2 has been equalized across its luminance range to 0 to 255 in order to visually display the subtle contrasts measured by the SFDA algorithm.

SFDA Measurement: Fig. 4 shows the data from the SFDA measurement. Each area of the pattern was measured and data were reported independently.

Interpretation: As was anticipated the level of mottle declined proportional to the number of blanket exposures the wet ink received. In addition to the overall mottle measurement, the SFDA algorithm also extracts the horizontal and vertical components. What was unanticipated was the orientation phenomenon at unit 5 where the ink on ink was given an additional blanket exposure. In Fig. 4 the percentage difference between the horizontal and vertical components was scaled to 0.1 to fit the mottle scale.



	Mottle	Horiz	Vert	% (V-H) /V
Unit 2	3.24	1.76	1.37	28.5
Unit 2 & 5	1.41	1.05	0.72	45.8
Unit 2 & 6	1.10	0.79	0.85	7.1

Figure 4 SFDA measurements for each print area in Fig.2 & 3. The large shift in the scaled percentage difference between the horizontal and vertical mottle components at unit 2 & 5 indicates the blanket exposure to the wet ink has somehow subtly oriented the mottle pattern.

MEASUREMENT OF BACK-TRAP MOTTLE ON DIFFERENT GRADES

The offset press at the Fox Valley Technical College was used to test the ability of the SFDA to measure back trap mottle in different grades of paper. An experiment was defined using different grades of paper from various suppliers to determine if the SFDA algorithm could distinguish between them and perhaps provide data to determine a grade scale. The pattern shown in Fig. 5 was digitally produced and directly etched on the plates. The ink lay down order was: Black, Cyan, Magenta, Yellow. The printed sheets were dried several days before testing.

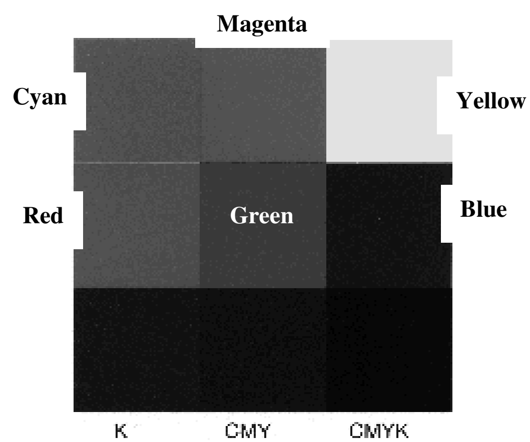


Figure 5 The multi-colored pattern used in the multi-grade tests is shown here in monochrome. Each of these printed squares is 25.4 mm square. The unit color order on the press was KCMY.

Paper Grades Evaluated

These are the trade name descriptions provided by the suppliers. In some cases there was no metric basis weight provided.

1- Coated, Gloss, 60# Recycled Offset
2- Coated, Gloss, 100, Cover
3- Coated, Matte, 148 g/sq M, 100# Text
4- Uncoated, 104 g/sq M, 70# Text
5- Uncoated, 135g/sq M, 50# Cover

There were 5 sheets selected from the run and labeled A through E.

Single Sheet Test – Test Setup

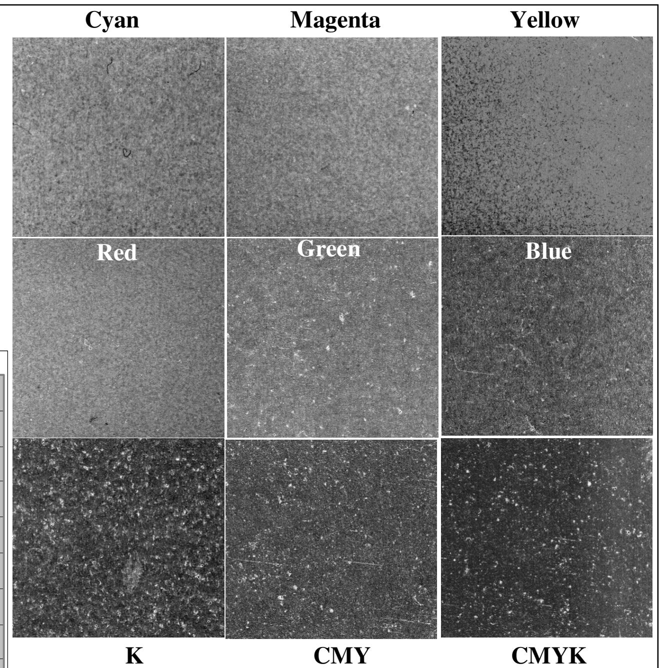
Specimen 1A was selected from the group to evaluate and set the test parameters for the remaining specimens.

Interpretation of Data, Specimen 1A

These data are displayed in Fig. 6. Results show an orientated mottle pattern not apparent to the naked eye. The chart in Fig 6 graphically illustrates the orientation phenomenon trending from the left towards the right side of the pattern. There is a subtle streak running down the right edge of the pattern that is visually apparent when the image equalization algorithm is applied to each area. The measurement indicated this streak and numerically evaluates it.

The blue, a back-trap composed of the cyan and the magenta inks, and the yellow primary, each of which are printed immediately above the CMYK, all demonstrate the same streaking tendency.

	Mottle	Horiz	Vert	% (V-H) /V
Cyan	1.18	0.97	1.00	3.0
Magenta	0.69	0.68	0.60	13.3
Yellow	0.49	2.62	4.61	43.2
Red	0.75	0.84	0.78	7.7
Green	0.54	0.42	0.49	14.3
Blue	0.81	0.33	0.59	44.1
100% Black	1.07	0.28	0.31	9.7
CMY	0.37	0.18	0.16	12.5
CMYK	0.36	0.09	0.11	18.2



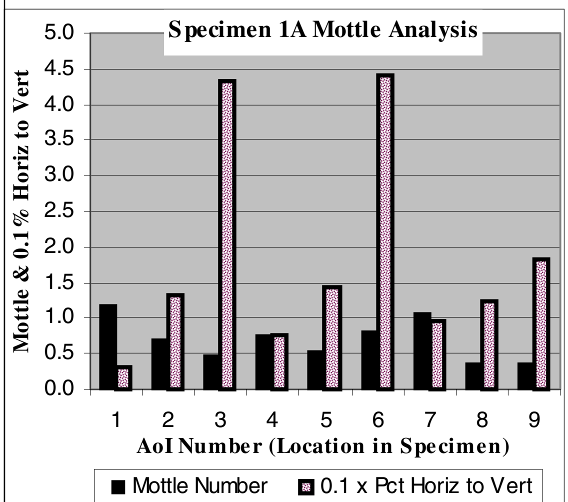


Chart Key - #Area of Interest (AoI):
1 – Cyan **2 – Magenta** **3 – Yellow**
4 – Red **5 – Green** **6 – Blue**
7 – Black **8 – CMY** **9 - CMYK**

Figure 6 Texture mottle with a 5 pp square target on specimen 1A**.** The image of each square as shown in Fig 5 has been equalized in gray scale to show the mottle more clearly in monochrome half-tone print. Of special note is the right to left variations in the Yellow – Blue – CMYK column. There is an apparent streak either in the paper or the press that is causing this phenomenon. As shown in the chart, although there was less overall mottle in these areas, the measurement picked up on this left to right aberration.

Mottle	**Ctd 1**	**Ctd 2**	**Ctd 3**	**UnCtd 1**	**UnCtd 2**
Cyan	1.03	1.01	0.73	2.16	3.29
Magenta	0.66	0.43	0.58	1.55	1.58
Yellow	0.47	0.41	0.06	0.17	0.13
Red	0.55	0.53	0.89	1.39	1.03
Green	0.51	0.35	0.45	1.57	1.46
Blue	0.72	0.59	0.69	1.72	1.75
100% Black	1.08	0.83	0.44	1.15	1.41
CMY	0.48	0.19	0.49	1.25	0.64
CMYK	0.33	0.17	0.53	1.00	0.36
Ave CMY	0.72	0.62	0.46	1.29	1.66
Ave RGB	0.60	0.49	0.68	1.56	1.41

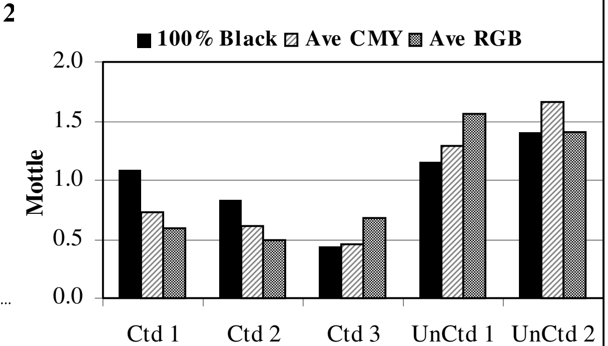


Figure 7 SFDA mottle test using a 5 pp square target. These data are the average of five specimens from each grade, each printed with the pattern shown in Fig 5. To generate the chart, data were grouped and averaged as CMY and RGB, and 100% Black is as reported. There is a clear distinction between the coated and uncoated grades. Note in the data, the YELLOW does not follow the trend of the Cyan and Magenta, it has a lower mottle level in the uncoated grades with the matte finish coated grade exhibiting the least mottle.

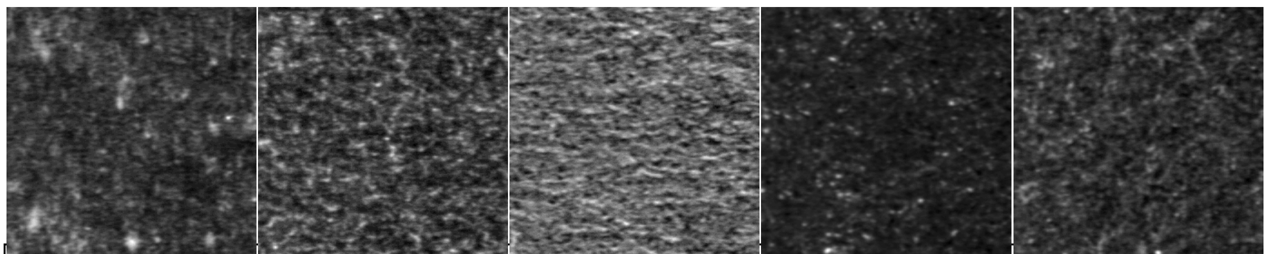
Multiple Grades Test

About 100 sheets of each grade were printed with the pattern shown in Fig. 5. From each grade sample 5 sheets were selected at random and tested using the SFDA mottle algorithm and a target size of 5pp wide. Data from these 5 specimens from each grade were averaged to create the table shown in Fig 7.

Interpretation of Data, Multi-Grade Tests

There was a plethora of data produced very quickly from the tests of the nine (9) areas on each sheet. Prior to generating the chart in Fig 7, these data were further grouped by averaging together the cyan, magenta and yellow primaries, and then the red, green and blue back-trap, within each grade. These data were then charted along with the 100% black. The individual sheets showed variations with in the specimen group but were not significant enough to warrant charting the individual specimen results.

Using any criteria except yellow, these results clearly demonstrate the ability of the algorithm to distinguish between the coated and uncoated sheets and to grade them. The yellow ink behaves differently and in fact may have a right to left streak that persists through the entire test series. Hints of this phenomenon are provided in the data in Fig 6. The detail data, not shown here, indicate there may bean erratic appearance of the streak.

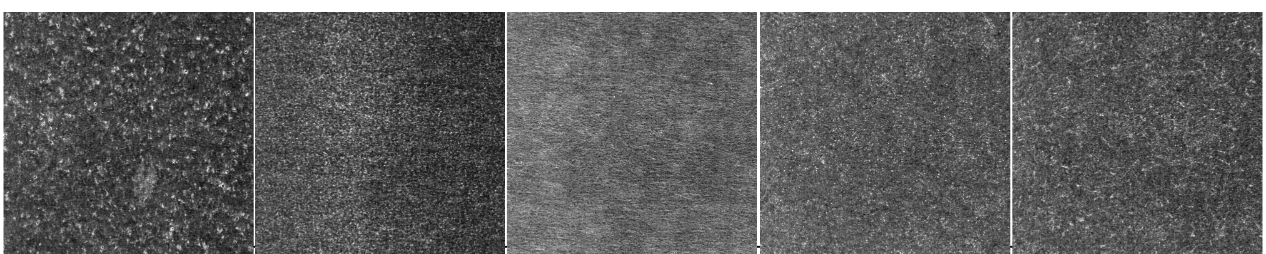


Ctd 1 – 0.75 **Ctd 2 – 0.18** **Ctd 3 – 0.12** **UnCtd – 0.48** **UnCtd 5 – 2.25**

Figure 8 A small section of the 100% Black areas from each of the five grades scanned at 4000 ppi and image equalized to show the mottle. The mottle measurements were made at 500 ppi using a texture (small) target size 5 picture points square (0.25 mm) cascaded into a target 20 picture points square (1.02 mm).

Streaking & Spatial Distribution

The data presented in Fig 6 show the measurement of streaking. Fig. 9 shows enhanced views of the 100% Black areas with the horizontal to vertical percent differences. It is visually evident in these equalized views that the mottle measurement is representative of the mottle present in the printed image.



Ctd 1 – 0.75	**Ctd 2 – 0.18**	**Ctd 3 – 0.12**	**UnCtd 4 – 0.48**	**UnCtd 5 – 2.25**
- Hor: **0.28** Ver: **0.31**	Hor: **0.15** Ver: **0.37**	Hor: **0.20** Ver: **0.15**	Hor: **0.45** Ver: **0.40**	Hor: **0.58** Ver: **0.60**
- % diff : **9.6**	% diff :**59**	% diff :**33**	% diff :**12**	% diff :**3.3**

Figure 9 The entire area of the 100% Black areas scanned at 500 ppi and image equalized to visually show the mottle. The overall mottle measurements are the same as those in Fig.6 for the texture measurement but with the added Horizontal and Vertical component analysis and their ratio. The ratio in # 2 is quite high and the vertical stripe is noticeable in the enhanced image. A similar but a subtle difference exists in #3 where it is the horizontal component that is exhibiting the difference. All of these calculations are very low but should be zero for an image with no mottle.

SPATIAL DISTRIBUTION

Mottle may be recognized by the human eye on several different levels at the same time. Up to this point in the work only the smallest target has been used to measure mottle which, at a resolution of 500 ppi, this target is 5 pp wide or 0.250mm, making it visible to the unassisted eye. This small target is measuring the texture of the image by analyzing data acquired from the underlying sub-visible pixels.

By grouping these small targets into larger targets the spatial distribution of the underlying visible image texture can be measured also. To illustrate its use, the 100% black area on one sheet of each specimen set was equalized and shown in Fig 8 & 9. These same areas were measured for all five sheets in the sets and the data averaged to produce the chart shown in Fig. 10. Uncoated 2 demonstrates a definite variation in the texture distribution at the 1mm level. This effect can be visualized in Fig 8 as blotchiness. It also shows up in Coated 2 but to a lesser extent primarily because of the uniform right to left streaking phenomenon also present.

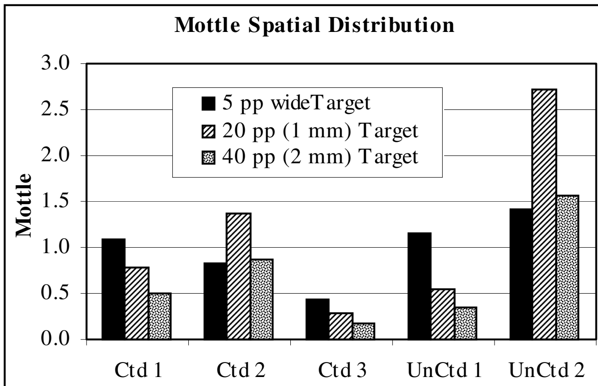


Figure 10 To measure mottle spatial distribution, three different target sizes were used on the 100% Black area. The chart shows the average values for the 5 grades tested. Of special interest is the 1mm mottle exhibited by specimens 2 and 5 that can be observed in Fig. 8 & 9.

For complete homogeneity the target measurements should be inversely proportional to their size as demonstrated in specimen sets Coated 1 & 3 and Uncoated 1.

CONCLUSIONS

Stochastic frequency distribution analysis yields a dimensionless number derived from the underlying digital image pixel luminance value statistical variance. It provides an objective means to evaluate the influence of press, ink, and paper upon the resulting printed image. In particular, it provides a method to evaluate the effect of ink formulation and properties, blanket performance, effects of multiple applications of wet ink, and the response of the paper to press conditions and the distribution of pits and voids in the sheet surface.

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