Mottle Measurement of Wet Trap, Back Trap and Other Motley Images

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Abstract

A single objective mottle measurement is described that relates to the full subjective range of visible mottle from "Graininess" to "Patchiness" and multi-color "Wet Trap" to produce a single number ranking mottle within both large and small areas.

This new algorithm responds uniformly to all levels of visually apparent mottle in digital images of printed matter and those obtained by optical transmission for paper formation measurement. Any digital image of sufficient resolution to visibly display the mottle pattern may be used with the method. When set to do so, it also measures sub-visible mottle found in pitted solid print areas.

Mottle is usually a subjective measurement without uniform criteria for ranking specimens. To minimize the subjectivity the author has provided examples of the new algorithms use in two applications where the mottle has been created under controlled conditions. These applications produced expected mottle that when measured using the new method demonstrate its viability.

In an effort to achieve consensus on a common mottle measurement technique that works under all conditions the underlying logic and mathematics are disclosed.

Introduction

This method was developed in response to an immediate need for a reliable, reproducible mottle measurement that provides a single ranking number correlated to the full range of visual mottle. ISO 13660 5.3 and 5.4 are attempts to provide separate numbers for fine mottle, "Graininess", and coarse mottle, "Patchiness". As will be demonstrated, both ISO numbers fail to measure properly under most real operating conditions.

The algorithm satisfies the paper industry need to have a solid method of measuring optical formation and calender blackening. It also provides the print industry means to measure visual mottle in large areas for such applications as back trap mottle, wet trap mottle, IGT and Prufbau tests. As a result the application base for the algorithm is extremely wide.

What is Mottle?

Mottle is usually a subjective evaluation without formal guidelines or other criteria for ranking. It appears to be based upon several criteria:

In a monochrome image:

1. The overall degree or severity of contrast between light and dark areas.
2. The sizes of the contrasting areas.
3. Spatial distribution of the contrasting areas.

In a polychromatic image:

1. Variation in the relative intensity of the colors present.
2. The sizes of the colored areas.
3. Spatial distribution of the colored areas.

The applications, and the work that follows, concentrate upon the polychromatic motley image. These images are usually the result of multiple inks of different colors being printed in the same area as solids or half-tones.

Color Extraction – Wet Trap Mottle

Digital Color Image Requirement

The human eye detects mottle as non-uniform distribution of colors and shades. The most common form of mottle occurs in a printed image when two inks are printed one over the other, as in offset print wet trap. If the deposition of the inks in a solid print area is not perfectly uniform the eye will see a two color mottle. As a result one of the most important aspects of mottle analysis is the color content of the digital image to be analyzed.

Most cameras and scanners used in the industry will acquire full color, Red, Green and Blue (RGB), 24 bit, digital image. For further processing in mottle measurement, the commonly used techniques will convert these 24 bit color images into an 8 bit grayscale image. Because each of the original color intensities is acquired using the same digital scale and converted to a single virtual monochromatic grayscale image, the conversion looses essential information about the mix of color luminance intensities present in the original image.

To replicate a mottled color balance, the new mottle measurement method also uses a 24 bit, RGB, color image of the mottled area as a basis for measurement. The 24 bit image is actually composed of three images, one for each of the color RGB bands. Each of these three color band images is 8 bits deep having a range of luminance values for each pixel from 0 (Black) to 255 (white) or 256 shades of gray that are analogous to the intensity of the light striking that particular sensor in the imaging camera.

These color bands may be extracted to display and analyze specific color reflectance and absorption characteristics of the inks used in the original image.

An example of this split is shown in Fig.1. Color band separation and recombination is useful in evaluating solid print areas in pure cyan (C), magenta (M), yellow (Y) and black (K), and , as will be demonstrated, it is an especially valuable tool in the evaluation of “wet trap” where the same area is overprinted with different color inks.

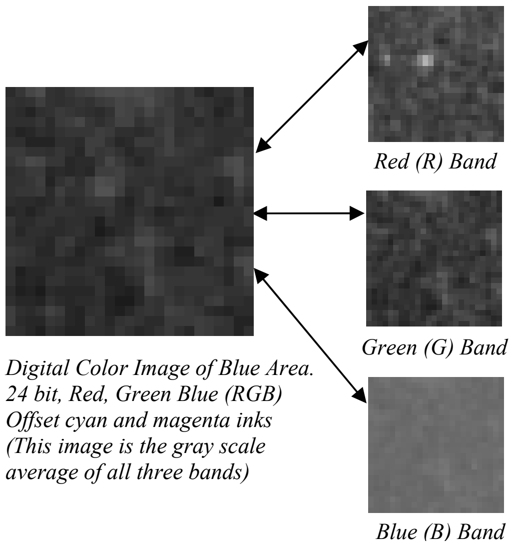

Figure 1: A digital color image as acquired by a camera or scanner is composed of three separate color bands. The pixel luminance value in each band varies from 0 (100% absorbed) to 255 (100% reflected). Thus the blue shows as the lightest gray tone. The red image shows the effects of the magenta mottle. When extracted as a single grayscale image, as shown in the original large area, these bands are averaged together at each pixel location.

Polychrome Mottle – Wet Trap Mottle

The need for color band separation and recombination is illustrated in a printed example of a conventional blue color. To print a blue color the printer first lays down a cyan ink and then overprints it with a magenta ink. If the properties of the paper, ink or press are not correct the result will be a motley blue with patches of magenta and cyan showing up in varying degrees.

Figure 1 shows a motley blue. It is a wet trap print of cyan and magenta inks split into its separate red, green, and blue color image components. So that it can be reproduced here as an uncolored print, it also shows the result of averaging together all the color bands to produce a gray scale image. If the reflected intensities of all the colors are the same, or very close, as is the case in this example, the averaging technique will not produce a grayscale image representative of the polychromatic mottle.

For example, the magenta and cyan inks used to create a blue image can reflect similar luminance intensities at different wavelengths specific to their color. In the camera or scanner, the filters on the red, green, and blue sensors will pass light only in their specific wavelength ranges and will respond proportionally to the luminance intensity received. Thus, in the extreme, a mottled image of cyan and magenta inks could, under certain conditions, produce a uniform gray scale image.

This problem is simply addressed by summing only the luminance values from the specific red, green and blue color bands that are reflected from the ink colors used in the original color image. The summed bands are then used to create separate virtual images specific to the inks used in the image prior to analysis.

CMYK Color Extraction

The cameras and scanners used to acquire digital images of printed images contain three separate matrixes of sensors; Red (R), Green (G), and Blue (B). Each of these three is capable of producing a separate grayscale image of the original image content in its specific wavelength sensitivity.

In the most common printing system four basic ink colors are used; Cyan (C), Magenta (M), Yellow (Y) and Black (K). The color camera collects, as best it can, the full spectrum of reflected light subdivided into RGB as described above. It is possible to separate the RGB bands and recombine them to create a virtual image containing only those reflected colors primary in the ink color of interest. To extract the reflected colors collected by the RGB camera image the following combinations are used:

Green + Blue = Cyan reflectance
Red + Blue = Magenta reflectance
Green + Red = Yellow reflectance

Conversely, bands absorbed by these inks are:

Red = Cyan absorbance
Green = Magenta absorbance
Blue = Yellow absorbance

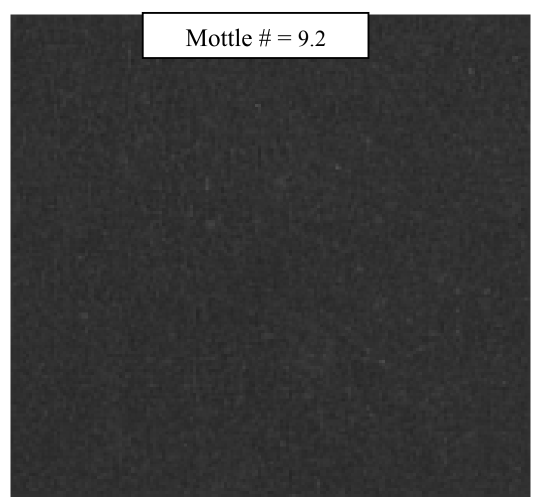

Figure 2: The gray scale image of a blue offset print made with magenta printed over cyan. The gray scale image is of the three 8 bit color bands averaged together to create this 8 bit image.

To draw conclusions about mottle in a polychromatic image, the human intellect evaluates the reflective intensity and spatial distribution of its colors. A solid blue wet trap can appear to be purple at a distance because, when viewed at short range, it is actually a motley mix of cyan and magenta. Figure 2 shows a typical grayscale image of a motley magenta/cyan blue. Because it has low contrast, any analysis based upon variances in luminance values in this averaged image will produce indeterminate results.

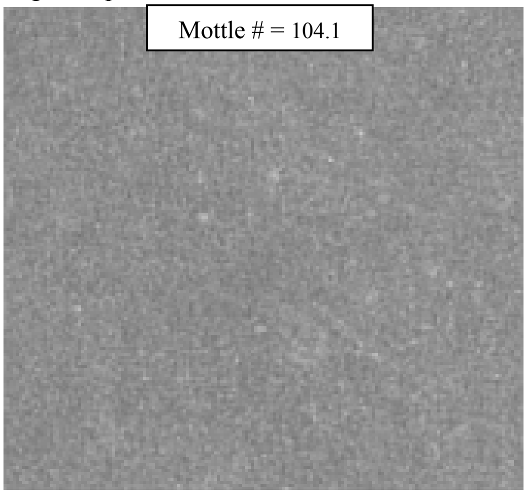

Figure 3: Cyan reflectance grayscale of the blue offset print shown in Fig.2 created by summing the green and blue bands from the original color image. Note the visibly higher contrast over the average of the bands shown in Fig 2.

Color Reflected, Color Band Summing

As described above, the reflective RGB image components specific to the reflected wavelengths of the ink color of interest in the original print can be recombined as a sum. The summing creates a new virtual image of the selected ink. Typical images of cyan and magenta extracted from a motley magenta/cyan blue are shown in Figures 3 & 4. These images clearly demonstrate a higher contrast than the average of all bands shown in Figure 2.

Color Absorbed

When printed as a solid area, the yellow ink normally has a very high reflectivity. Almost all of the red and green light striking it is reflected providing only the smallest of variance due to mottle. As a result, summing the red and green bands will produce a very low contrast image that is almost free of variance. But, in most cases, the absorbed band, blue, can produce a good high contrast single band image of the mottle within a solid yellow.

Digital Resolution

The resolution or calibration of the digital image need only be sufficient to display on screen, at any magnification, the mottle pattern to be measured. High resolutions such as the 600 ppi recommended by ISO 13660 are not necessary unless the image is to be inspected for sub-visible mottle. Typical resolutions for the new method range between 100 and 300 ppi (sensors per inch, spi).

At high resolutions of 600 ppi and higher, the mottle measurement is responsive to sub-visible variations useful in determining the concentration of pits and pores in contact printed surfaces, ink jet striping and toner deposit variations. As will be explained below, the range of tile sizes selected by the investigator can limit the measurement to the sub-visible and exclude the visible targets and vice versa.

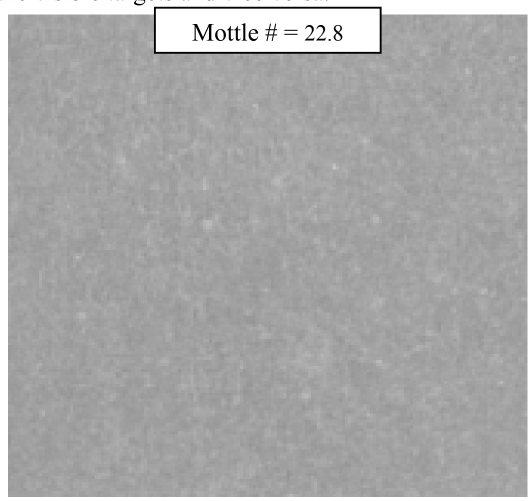

Figure 4: Magenta reflectance grayscale image of a blue offset print made from the sum of the red and blue bands. Note the lesser contrast than the Cyan extraction shown in Figure 3 but still greater than that shown in the average of all bands shown in Fig 2.

At 600 ppi (spi) the sensors in the camera are able to pick up reflections from areas as small as 42 micrometers in diameter. Nominally, the normal human can only see a pure black speck that is 50 micrometers in diameter against a stark white background using excellent illumination. Our work has determined a resolution of 300 ppi is sufficient to capture the image of mottled print and optical formation. At 300 ppi the sensor in the camera is gathering the light from an area 84 micrometers in diameter in much the same way as the eye would see this printed image at a short viewing distance.

Mottle Spatial Distribution

Fine to Coarse Mottle Profile, Tile Size Variation
The new mottle method employs a series of different size tiles that follow a binary dimensional progression. Each tile size is dedicated to a "Layer". Within each layer the tile is laid over the image in a pattern of non-overlapping contiguous tiles. As shown in Figure 5, this pattern is similar to that used in ISO13660 5.2.3 & 4. The mottle measurement made within each tile size layer is used to create a mottle profile of the range of tile sizes as shown in Chart 1. The average of all the layer mottle measurements becomes the mottle number for the image examined. The measurement profile and its average emulate the human intellect in its instantaneous evaluation of mottle in various spatial distributions.

All physical tile dimensions are based upon the original image pixel center to center distance. At high image resolutions, 600 ppi and above, the smaller tiles can contain sub-visible elements. Our work has determined a resolution of 300 ppi (spi), or even lower, is sufficient for most visible mottle evaluations.

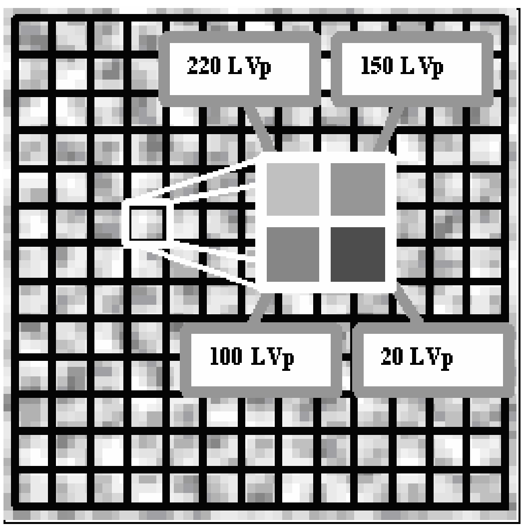

Figure 5: The basis for the new method is the 2 pixel x 2 pixel contiguous tile pattern shown in black.. Shown in white is the extraction of a single tile with the contained pixel luminance values. (LVp).

Figure 6 shows the new method creates a controlled series of tile sizes based upon the image pixel resolution. The tile sizes always begin with a 2 pixel by 2 pixel tile as shown in Figure 5. This is the smallest tile. Starting with the smallest, the tiles progress in size changes following a binary progression (in pixels): 2 x 2, 4 x 4, 8 x 8 … to a possible maximum of ten (10) sizes with largest possible being 1024 x 1024 pixels. The maximum tile size is set when the image dimensions cannot accept four contiguous tiles of the next tile size when both are measured in pixels.

Each tile size is assigned, in order, to a layer beginning with the first 2 pixel x 2 pixel tile. All calculations are made on, and reported for, each layer separate and independent from the others.

Tile Data Source – Successive Tile Sizes
The binary progression in tile sizes is used to determine the spatial variation component of mottle, fine to coarse. As explained above, the sizes are set using a binary progression starting with a 2 x 2 pixel tile and ending with the largest the image will accommodate. Each successive tile size is based upon the average of the pixel luminance values (LVp) in the preceding tile size. This averaging makes each successive tile size independent of variations among the pixel LVp in the preceding tile size. All tiles contain four (4) elements regardless of their physical dimensions or position in the layer sequence. This calculation is presented graphically in Figures 7 & 8.

Because it is based upon the average of the luminance value data in four contiguous tiles from the previous layer or, as in the first layer, pixels, each successive layer contains 25% of the number of elements as does the previous layer. The physical dimensions of the tile in the layer remain based upon the original image pixel dimensions.

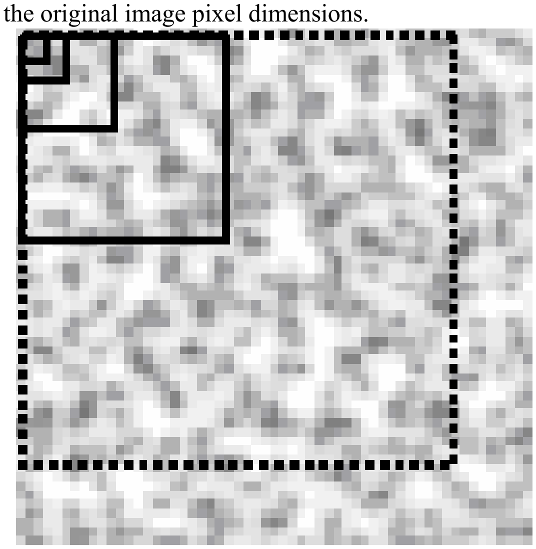

Figure 6: The first four tile sizes that would fit inside the image as shown. The new mottle method requires at least four of any one size inside the image. In this case only the first four sizes in the binary size progression will fit inside the image pixel dimensions. Following the rule that at least four tiles of a given size must fit, the fifth and larger sizes are not used

Frequency Leveling Between Layers
The effect of this progressive averaging of the luminance values in the 2 x2 tile from one layer to the next is to level out the element to element luminance value transitions. This averaging tends to have the measurements in each layer independent of one another by removing the higher frequency transitions found in the previous layer.

Mottle Computation

The First Level Calculations – Data Bases

Figures 7 and 8 show graphically the two calculations made on each 2 x 2 tile: The percent difference among the elements in the tile and their average. The result of each calculation is stored separately in one of two data bases each of which is exactly ¼ the size of the original image as measured in elements.

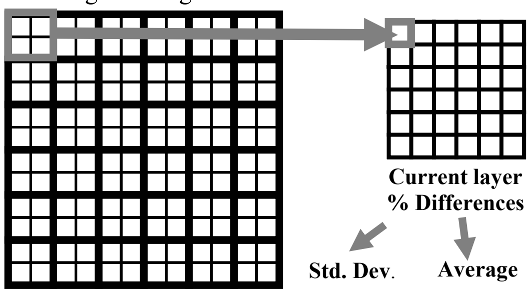

Figure 7: From the differences among the 2 element x 2 element previous layer create a data base to be used as the basis for the current layer mottle measurements. The standard deviation and average of these are two terms in the mottle calculation.

Data Base 1. Percent Difference Among Pixel LV

First, the method calculates the percentage difference among the pixel luminance values (LVp) within each tile pixel size based upon a 256 luminance value scale.

$$\textbf{PctDiff} = 100 \times \Sigma(\text{Abs}(\text{Diff}_{P1\ to\ P4}))/(6 \times 256)$$

Where: $\text{Diff}_{P1\ to\ P4}$ is the absolute arithmetic difference among the four(4) pixel luminance values in the tile. There are six(6) absolute differences: abs(1-2), abs(2-3), abs(3-4), abs(1-4), abs(1-3), abs(2-4).

As shown in Fig.7, these differences are recorded in a data base from which they are extracted for further calculation of the standard deviation among them and their average.

Data Base 2. Average of the Pixel LV

Then, as a second function, the average of all the pixel luminance values is calculated and stored in the database location for that tile.

$$\textbf{AveLV} = \Sigma_{1\ to\ 4}(\text{LVp})/4$$

Where LVp is the pixel luminance value

Data base 2 serves two purposes: First, as shown in Fig. 7, it is used in the mottle calculation for the tile pixel size under current evaluation and, second, it is used as the basis to create a virtual image or data base for the next layer or tile size.

Mottle Calculation for Each Tile Size

These two data bases are then used to calculate the mottle number for the layer. Each layer is dedicated to a specific physical tile size.

$$\textbf{Layer Mottle\#} = SD_{Diff} \times AVE_{Diff} \times SD_{Averages}$$

Where:

SD_{Diff} = Standard Deviation of Data Base 1

AVE_{Diff} = The average of Data Base 1

$SD_{Averages}$ = Standard Deviation of Data Base 2

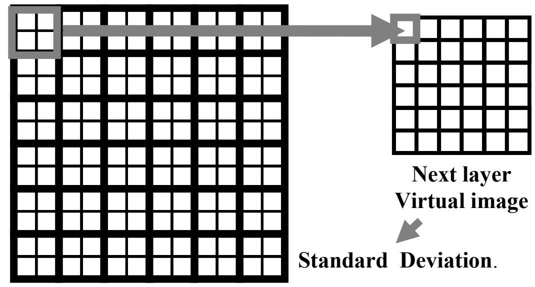

Figure 8: From the averages of the 2 element x 2 element previous layer create a new virtual image to be used as the basis for the next layer measurements. Each element of the subsequent layer is composed of the average of a 2 element x 2 element average of the previous layer. The standard deviation of the data in this layer is a term in the mottle calculation.

The New Mottle Number

The final mottle number is the arithmetic average of the individual tile size mottle numbers as calculated above.

$$\textbf{Mottle} = (\Sigma_{1\ to\ N}(\text{Layer Mottle \#}))/N$$

Where:

N = the number of layers or physical tile sizes

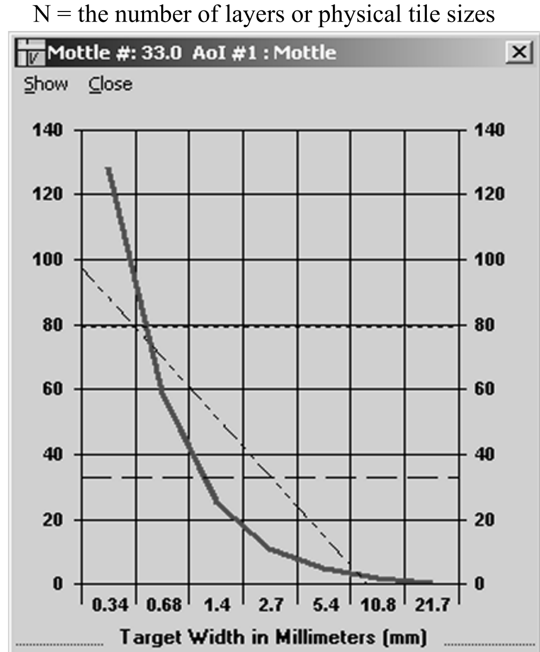

Chart 1: The mottle number in the upper left corner, 33.0 is the average of the individual mottle numbers for each of the seven (7) tile sizes or "Targets" shown in the chart.

Chart 1 shows a typical graph of the values obtained from the application of the new mottle method. In this example the largest size tile that would fit at least four (4) tiles in the image is 21.4 mm square and the smallest target is 340 micrometers square.

.Applications

The new mottle algorithm is currently being used at the Rochester Institute of Technology (RIT), In Rochester New York. The offset print operations there evaluate paper, inks and on press technology variations for the general industry. The purpose of all evaluations is to report on the quality of the print.

Paper quality can vary across relatively large areas. There can be variations in performance from one square centimeter to the next. As a result the on press evaluations at RIT usually lay down print areas in excess of 10 sq cm and can be as large as 350 sq cm. The quantitative mottle measurement in these large areas must be reproducible and consistent across the complete spectrum of mottle patterns from what is normally classified as “Grainy” to that which is “Patchy”.

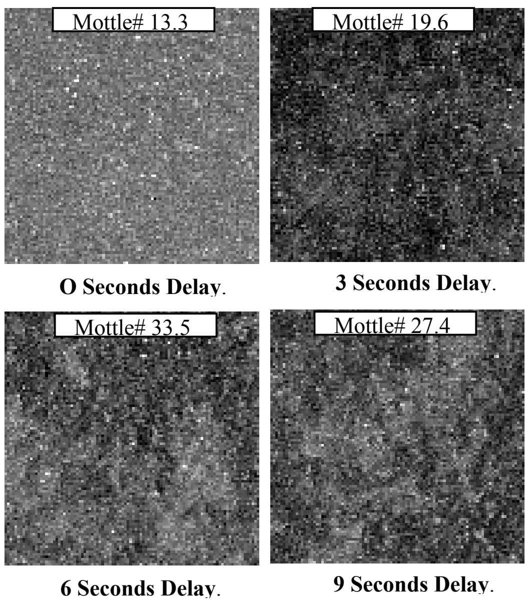

Figure 9: Magnified extractions from a series of IGT A5 test strips showing cyan ink overprinted at various time intervals. These images were extracted from the larger full scale images, magnified and contrast enhanced for reproduction here. The mottle numbers shown are for the full image un-enhanced.

IGT A5 Apparatus, Wet Trap Evaluation

A particularly definitive measurement is the IGT A5 test strip which is used at RIT to evaluate the wet trap performance of both ink and paper.

Mottled print is particularly difficult to show in this printed format so enhanced magnified images are shown in Figure 9. The measurements displayed in Tables 1 & 2 were not taken from these images but were obtained from the original full size images without enhancement.

As can be observed the inspectors agreed upon the ranking for the two best and two worst but disagreed upon the ranking within the worst category. The new mottle measurement agreed with two of the three inspectors on all rankings.

The ISO measurements did not agree with any rankings except by eliminating the specimen with the best appearance by all criteria!

Delay	0 Sec	3 Sec	6 Sec	9 Sec
New Mottle	13.3	19.6	33.5	27.4
ISO Mottle	2.7	1.4	2.8	2.2
ISO Grain	143	130	136	134

Table 1 Various mottle measurement methods applied to overprinted cyan ink using an IGT A5 at various time delay settings between the initial print and the overprint.

Delay	0 Sec	3 Sec	6 Sec	9 Sec
Insp. 1	1	2	3	4
Insp. 2	1	2	4	3
Insp. 3	1	2	4	3

Table 2: The IGT test shown in Figure 9 and evaluated in Table 1 as ranked by three inspectors. All inspectors agree that 6 & 9 seconds delay are the worst.

RIT Back Trap/Water Interference Evaluation

This is an offset press evaluation for the performance of paper printed at two different units of the press to determine how well the paper fixes the ink prior to multiple blanket exposures. It also will indicate if the paper is properly absorbing the water after multiple unit exposures prior to printing on the last unit of the press.

Visual Criteria - Back Trap/Water Interference

The interesting aspect of this evaluation is the comparison between two very large printed areas that were created with the specific intention of having different mottle patterns. The specimen from unit 2 has received multiple blanket exposures with no further applications of ink before it comes off the press. Whereas the specimen from unit 6 has experienced multiple water exposures before it receives an application of ink and has had no blanket exposures. With a given paper the two mottle patterns should be distinctly different.

New Mottle	1	2	3	4
Unit 2	207	199	260	220
Unit 6	89	60	47	84
Difference	118	139	213	136

Table 3: Back trap mottle / water interference; Solid cyan printed at unit 2 and unit 6 in areas 165 mm x 236 mm. Shown are results of the new mottle algorithm measurement.. The specimen order is the visual ranking of unit 2. Unit 6 was not ranked visually and is presented to as a basis of comparison; the last unit printed should have much less mottle than unit 2.

If the mottle is greater on unit 6 than that on unit 2 the paper is subject to water interference. A difference in the mottle patterns is readily apparent in this evaluation and by visual inspection none of these specimens indicated the presence of water interference. As a result the specimens were subjectively ranked only for back trap mottle on unit 2.

Objective Measurement

Table 3 shows the visual ranking of the 2nd unit mottle pattern. There is complete agreement between the two worst and two best specimens but the order of rank is reversed for the two worst. This is not an unusual event in subjective mottle evaluations.

The important aspect of the measurement is the comparison between unit 2 and unit 6 where the intention is to create a difference. The new method demonstrates its ability to clearly distinguish between the two to a degree that is visually confirmed.

As shown in Tables 4 & 5 the ISO 13660 techniques are unable to measure mottle in this same set of specimens.

ISO Mottle	1	2	3	4
Unit 2	21	22	21	22
Unit 6	30	23	15	25
Difference	-9	-1	6	-3

Table 4: ISO 13660 Mottle applied to same specimens as shown in Table 3. The difference between the two measurements is almost in total disagreement with the known differences between the specimens.

ISO Graininess	1	2	3	4
Unit 2	317	316	314	315
Unit 6	305	319	312	314
Difference	12	3	2	1

Table 5: ISO 13660 Graininess applied to same specimens as shown in Table 3. The difference between the two measurements is almost non existent.

Summary

The new mottle calculation has been proven to work in a variety of mottle evaluations. It closely emulates the human ranking of a variety of specimens by:

1. Providing a means of separating and recombining the color bands in the original color image to reconstruct the original ink reflected or absorbed values. Thus, the method is able to measure multi-color wet trap mottle and low density images.

2. The construction of successive image layers using the average of the picture elements or luminance data tile size from the previous layer provides a measure of mottle spatial distribution for each layer independent of the preceding layers containing smaller tile sizes.

3. Providing a means of adjusting the mottle measurement to the resolution of the image evaluated in order to set the mottle evaluation to the visible range.

4. The calculation of a coefficient proportional to the number and intensity of the tile element transitions present in the tile size evaluated. The tile size mottle number is calculated based upon both this number and applied to the variance among the average of these same tile elements.

5. The calculation of the average of all individual tile size mottle numbers to report the new mottle number for the image area evaluated.

The new mottle method has demonstrated its ability to objectively measure mottle in large and small printed areas.

Acknowledgements

The author has received some excellent assistance from Dr. William Heeschen of the Dow Chemical Company in Midland Michigan, USA. Dr. Heeschen provided insight to the original analysis algorithms developed by the author that led to the developments described in this paper.

Daniel Clark of the Rochester Institute of Technology in Rochester NY, USA conducted on machine evaluations of a staggering number of revisions to this software prior to its being the finished and working algorithm described above.

Christine Canet of the Quebec Institute of Graphic Communications in Montreal Quebec, Canada also conducted a large number of trials of this algorithm to confirm its ability to conform to visual ranking of both printed specimens and calender blackening.