Gloss Mottle Measurement: Black, Dark Printed Areas, and Wet Trap

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Abstract: It is possible to measure the degree of mottle present in very low contrast full color digital images. Under normal illumination these prints may not display any visual evidence of mottle unless viewed in low incident angle light. Typically these images are from four color black offset print (400% black), dark offset wet trap colors and dark print areas using other printing techniques.

The methods employed and the results of tests used in the measurement are presented.

In order to encourage the adoption of an international standard for the measurement of mottle in general, the image analysis techniques and methods used to extract the mottle patterns and the equations used in the measurement algorithms are disclosed.

Introduction

As one aspect of the evaluation procedures at the Rochester Institute of Technology (RIT) print shop, mottle is routinely measured using the algorithms described in the appendix. Most quantitative mottle tests are run using color extraction for solid print area mottle analysis as described by the author in Rosenberger (2002). The evaluation of black gloss mottle is a recent addition.

The four color black is created by printing each of the subtractive ink colors, cyan, magenta, yellow and black, in the same area. This combination stresses the printing system of paper, press and ink to the maximum. The paper must perform at its best because it has received the maximum amount of ink possible on a four color press. The press and ink, likewise, are stressed to perform at the maximum. The six color press used to create the specimens used in this examination also exposed the images to back trap, i.e. multiple blanket exposures, before exiting the press.

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The result is an image that exhibits a variable amount of gloss mottle. Normally these images are evaluated subjectively by viewing them, unassisted, at varying incident angle illumination. The amount of mottle present is enumerated by an expert inspector and controlled specimens are usually ranked comparatively.

Attempts to improve the ranking process have been made using digital cameras to create images using low angle incident light. The evaluation of the images produced has remained subjective. This process is time consuming and cumbersome.

Until the procedures described in the following were developed, it was not possible to make a timely objective measure of the black gloss mottle that was so readily observed, but subjectively ranked, by print quality evaluators at the press.

Image Analysis System

All specimens were processed using Verity IA 2003 Multi-Function mottle measurement image analysis software in a high speed personal computer.

The computer had a 256 MB memory that improved the processing speed for large images. A TWAIN compliant Microtek 8700 graphic arts quality full color flat bed scanner was connected using “Fire Wire” that also improved the processing speed. The Microtek 8700 scanner was chosen because it like, the older and discontinued, AGFA DuoScan 2000 employs axially symmetric dual specimen illumination that eliminate image shadows caused by paper cockle, protruding fibers and heavy ink.

For all tests the specimen was held in position on the scanner face by a 2.2 kg, 200 mm x 200 mm, wooden mahogany block with a white vinyl face provided with the Verity IA mottle analysis software. The weight applies a uniform pressure to the specimen, causing it to lay flat against the scanner glass, overcoming any tendency to cockle from the local heat and provides an easy means of adjusting the specimen position.

Specimen Preparation

To test the validity of the measurement technique, two different sets of specimens of four color black (400%) were obtained from trials of various grades of paper printed at the Rochester Institute of Technology (RIT) on a sheet fed press Heidelberg Speedmaster 74 with Sun Chemical Naturalith II inks. Kodak 830A printing plates were used with Day International Patriot 3000 4-ply compressible blankets. The inks, plates and press conditions were held constant while the paper grade was varied. The specific paper grades and source was not disclosed but all grades were closely associated for the trial runs to test their relative performance.

Printed Area of Interest and Extracted Sample Area

Each sheet was fully printed with many different patterns and illustrations but one area was reserved exclusively for the evaluation of four color black.

The four color black printed area dimensions:

Test 1: 133 mm x 76 mm (5.25 in. x 3.0 in).
Test 2: 173 mm x 73 mm (6.8 in. x 2.8 in).

As shown in Fig.1, however, a smaller specifically positioned and dimensioned area of interest, 100 mm x 50 mm, was extracted from the scanned digital image of the printed area to create a second image to be used in the analysis.

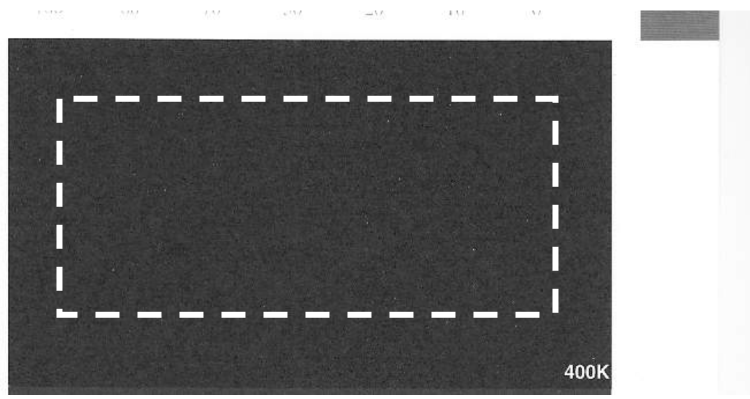


Figure 1: Full digital image of a typical four color black offset print showing the extracted 100 mm x 50 mm sample area of interest as a dashed white and black outline. The indentation minimizes the effects of glare parallax from the surrounding white border.

The sample (extracted) area of interest is specifically selected to be at least one centimeter within the borders of the black area. Sampling within the borders of the printed black image area minimizes or eliminates the effects of glare or parallax from the white paper surrounding the printed area entering the image area of interest. The mottle computation, as described in the appendix, responds directly to the pixel luminance value contrast and, as a result, this parallax effect can cause a false measure of mottle by slightly brightening the pixels at the digital image edge.

To illustrate this effect, Fig. 2 shows the full digital image of a four color black digital image. Fig. 3 shows a magnified extract from the image in Fig 2 that has been binarized at its mean pixel luminance value to show the effect of extracting an image to be used for mottle measurement too close to a highly reflective surrounding border. If included in the image area to be evaluated, the artificially brightened pixel luminance values near the border will effect the mottle measurement.

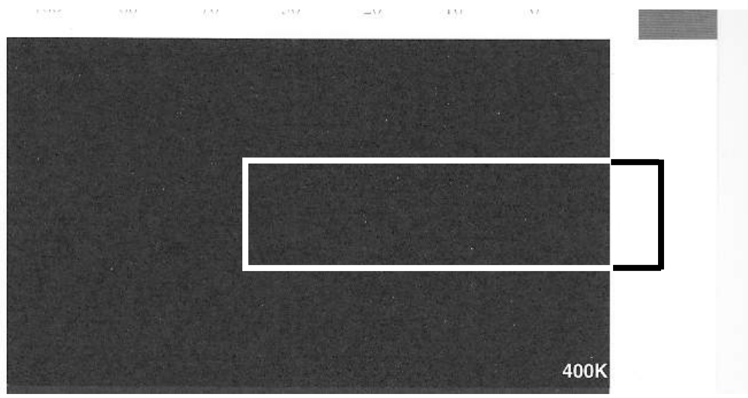


Figure 2: Full digital image of a typical four color black offset print. The white and black outline shows the area extracted for enhanced examination of glare parallax in Fig. 3.

Figure 3: Enhanced extraction from the four color black digital image shown in Fig.1. The enhancement shows the increased brightness at the right edge of the image caused by the parallax of reflection from the white border surrounding the black image.

The Test Procedure

The specimens were printed on a variety of undisclosed paper grades. The paper was selected to be closely related with one notable example where an uncoated grade was included with a group of coated sheets.

The sheets were trimmed to be of a uniform size with the black area of interest located in a way that made for easy and uniform positioning on the scanner. The RIT press room staff manually classified all specimens within each set by degree of visible gloss mottle under the same illumination.

Representative sheets selected:

Test 1: Six - each of a different grade

Test 2: Four - each of a different grade

As shown in Fig 1, an area 100 mm x 50 mm was scanned in full color at 300 ppi resolution inside each black printed area. During the scan, the specimen was held in position on the scanner face by the white faced weight.

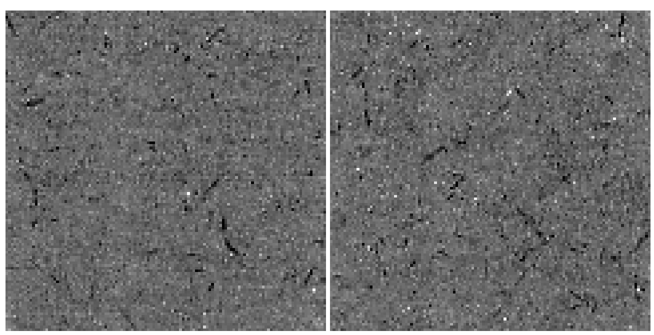
Test Setup Parameters – Mottle Tile Size Range

There are two setting variables that were adjusted for the test:

1 - The image acquisition resolution for the scanner

2 - The tile size range for the mottle measurement software.

Before running the tests the mottle measurement settings were adjusted using the specimen judged to have the worst gloss mottle by visual inspection. An example of this choice is shown in Fig.4. Using these same settings, the specimen visually judged to have the least gloss mottle, best as in Fig.4, was also tested to see if the settings would confirm the subjective ranking. The expectation, of course, was that the settings would subsequently provide a uniform ranking of the remaining specimens between these extremes.



Best **Worst**

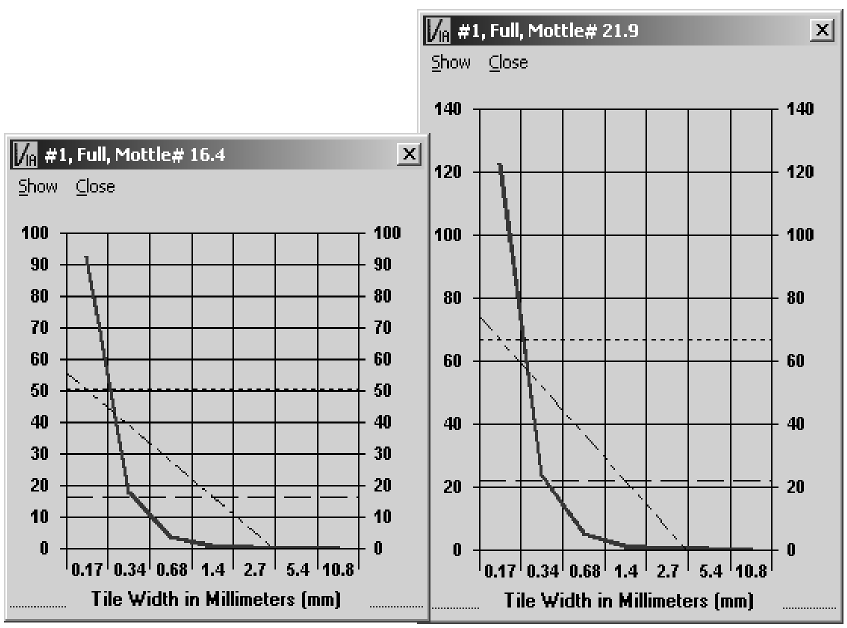
Figure 4: Images of 1 cm x 1 cm areas of the best and worst specimens of black gloss mottle from series 2. Before enhancement both images were pure black with no visible mottle. Images were enhanced for this illustration with an interpolation of 3 and a brightness gain of 48.

Resolution:

The primary variable is the image resolution which was set at 300 ppi for this series. At 300 ppi each pixel, when resolved to a visible square, is 0.084 mm in diameter. This is a visible area. Nominally, under normal viewing conditions, the human eye can detect the presence of a solid black dot with a diameter 0.050 mm.

The algorithm, a description of which is found in the appendix, calculates the difference in luminance value among four contiguous pixels arranged in a 2 x 2 square. As a result, at 300 ppi, the most sensitive part of the mottle measurement algorithm, i.e. the smallest tile, is measuring what we can nominally see at a normal viewing distance.

There is a caveat, however, to the universal use of 300 ppi resolution: These particular four color black specimens do not demonstrate a large amount of pitting. There is evidence of several pits that show up as very light gray specks in the digital images of some of the specimens, but, in this particular series they do not appear to be a factor. But consider the case where only one color is printed and there is only one or two layers of ink, these pits then can become a factor in correlations to visual ranking. It has been determined that at 300 ppi resolution the mottle algorithm will detect and factor the pits into the reported mottle number. On the other hand, the human inspector may not. It is speculated these pits are usually overlooked by the human inspector as background to the more dominant, and often confusing, mottle caused by back trap and wet trap.

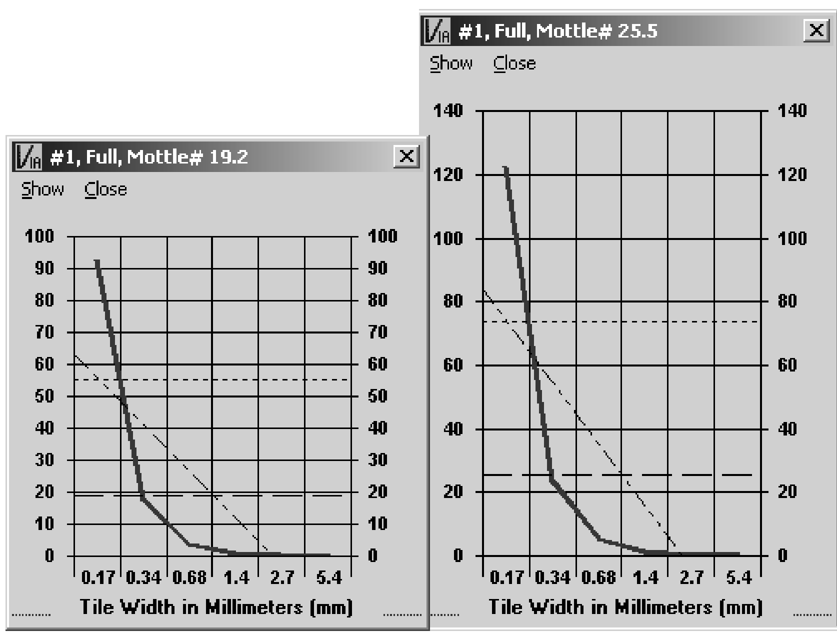


Best : Mottle # 16.4 **Worst: Mottle #21.9**

Figure 5: Tile Size mottle # charts for the best and worst of series 2. Note that the largest tile sizes, 5.4 mm and 10.8 mm show almost no mottle and that the Y axis scale is different in the two charts. The final mottle number is the average of all tile size mottle numbers. At least one of these upper tile sizes can be clipped from the measurement to increase the resulting mottle number. The mottle number is the average of all tile size mottle numbers.

When pits are present and should not be factored into the mottle measurement, it was found that the tests should be run at a resolution of 150 ppi. The lower resolution yields a nominal pixel width of 0.169 mm which in practice has been found to bridge the pits and overlook their presence just like the human does but it is less sensitive to the fine mottle patterns.

Tile Size:
The appendix describes the mottle measurement algorithm in detail. In brief, the algorithm employs a range of tile sizes that vary following a binary progression to determine the spatial distribution of the mottle pattern. The smallest possible tile size is always a 2 pixel x 2 pixel tile and the largest is 1024 pixels x 1024. The physical width of the tile is determined by converting the dimensions in pixels using the image resolution. In this test the resolution has been set at 300 ppi thus the smallest tile (2 x 2) is 0.169 mm wide by 0.169 mm high.



Best : Mottle # 19.2 **Worst: Mottle #25.5**

Figure 6: After clipping the 10.8 mm tile, tile size mottle # charts for the best and worst of series 2.

The software will attempt to fit as many tile sizes into the analysis image as is possible with the caveat there must be a minimum of 8 tiles of the largest size in the image. Fig. 5 shows the charts for the best and worst of series to with the software permitted to auto fit the tile size range. Note that the largest tile size, 10.8 mm wide, has a very low mottle number in both cases. Since the final mottle number is calculated as the average of all tile sizes this very low reading serves as a weight to the final mottle number and could be eliminated to raise both mottle numbers as shown in Fig 6.

Based upon this preliminary examination the tile size range was set for 0.17 mm (2 x2 pixels) to 5.4 mm (64 x 64 pixels)

The Test Results

Mottle tests on the two sets of printed images were run using the set-up described above:

> Image resolution: 300 ppi
>
> Image size: 100 mm x 50 mm
>
> Mottle Tile size range:
>
> > 2 pixels x 2 pixels (0.17 mm wide) to
> > 64 pixels x 64 pixels (5.4 mm wide)
>
> No color extraction other than the normal reduction of the color image to an average of all colors to produce a gray tone image was performed as part of the analysis.
>
> No enhancement (interpolation, contrast or brightness) was performed as part of the analysis.

Test 1: Six (6) images printed on sheets from an undisclosed source. The first five sheets appeared to be coated stock; the last, uncoated.

All printed sheets were examined and visibly ranked for gloss mottle prior to testing. This is a particularly difficult specimen set to rank visually. There was some disagreement about which of the two best was the absolute best but it was agreed that the two best were the best of the lot. The worst one was easily isolated but there was no agreement among the evaluators about the remaining three except to say they were all better than the worst and worse than the best two. As shown in Chart 1, Test 1, the automated mottle test confirmed the visible ranking of the best and worst and was able to discriminate among the rest.

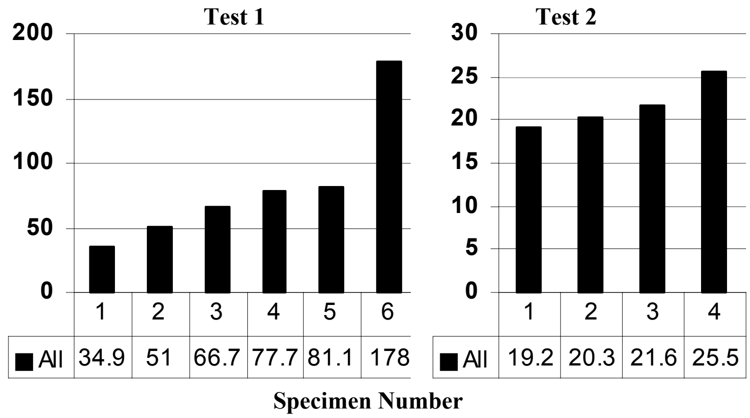


Chart 1: Mottle measurements, average of all color bands, made with no enhancement or color extraction of four color black offset printed images demonstrating visible low incident angle gloss mottle. Image area: 100 mm x 50 mm extracted from printed area of 133 mm x 76 mm. Paper grades were unidentified.

Test 2: Four (4) images printed of sheets from an undisclosed source. All sheets appeared to be on coated stock.

There were only four specimens in this set. They were much more homogenous than the first set. Again there was no argument over the worst and best and only one evaluator reversed the order of 2 and 3.

Figure 7: A 2000 ppi image showing the lower right corner of a four color black offset print showing the name of the image . Note below the “4” is a black speck. This speck was visibly identified as a high gloss area reflecting low angle incident angel light. The area surrounding it did not. Fig. 8 shows this speck enhanced.

What the Instrument Sees

A small section of one of the specimens was examined closely to isolate a glossy area from a less glossy area. Such a speck is shown just below the "4" in Fig. 7. The "4", with the glossy speck, is shown magnified and enhanced in Fig. 8.

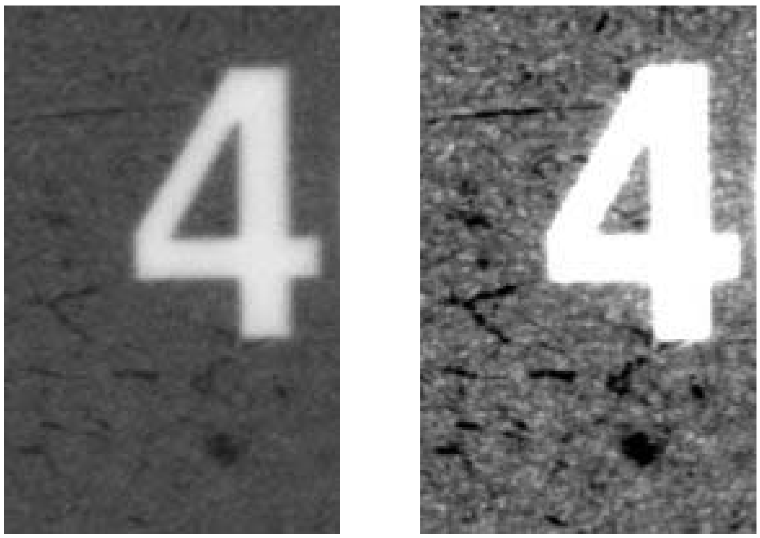
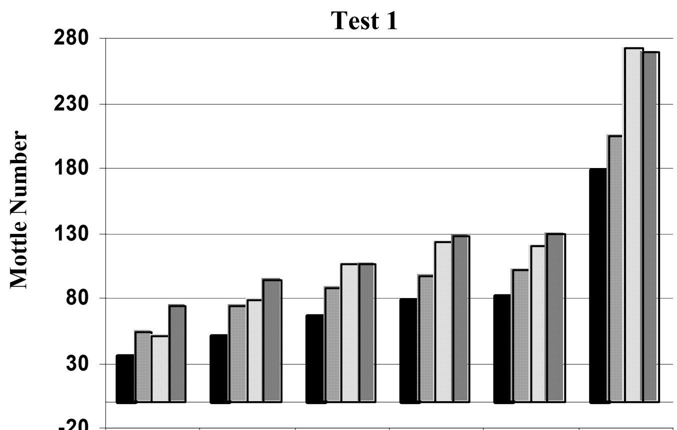


Figure 8: On the left a magnification showing the speck just below the "4" in Fig 7. To the right is the same area enhanced by interpolating the pixel luminance values to a factor of 3.

It appears the scanned image shows the gloss areas as blacker than the less glossy areas and as a result the mottle algorithm responds to the blacker areas as mottle. The human eye is unable to detect small differences in luminance value without the assistance of enhancement by interpolation and magnification. It appears the algorithm does respond to these unseen changes

The Source of Variation

Test I and Test 2 were run under similar printing conditions but as shown in Chart1 there is a significant shift in the degree of mottle in the two sets. A visual comparison of the two sets showed an obvious difference between them. With the exception of Specimen 6, those in Test 1 exhibited far less gloss than those in Test 2. These specimens were obtained from proprietary tests run at RIT and as a result no information is available about coating, calendering, size, or other treatments the paper may have received. Our task was to discriminate among the black gloss levels. There is, however, a lot we can tell about the press conditions by examining the color content of these four color black patches.



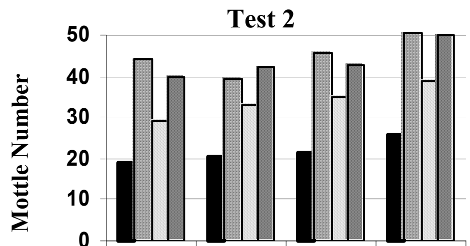
	1	2	3	4	5	6
All	34.87	51.02	66.73	77.74	81.08	178.1
Cyan (R)	54.18	73.61	88.01	97.61	101.5	204.1
Mag (G)	50.69	78.94	106.6	122.7	120.1	271.6
Yel (B)	74.04	93.57	105.4	127.6	129.2	269.8

Specimen Number

Chart 2: Test 1 specimen set: Mottle measurement of each color band in the original RGB 24 bit image. The bands were split from the original to form four separate images. The "All" band was created by averaging the red, green and blue bands to create a true composite balance of the luminance intensities in each band.

These images are made from the serial application of Black, Cyan, Magenta, and Yellow inks to the same area. This offset printing process is known as "wet trap", where one wet ink is laid on top of another wet ink. To create the four color black image wet trap occurs three times. In a press having more than four colors the last ink printed receives, in this case, yellow, additional exposures to the carrier blanket even though it is not being printed.

The digital image of this four color black print is acquired by a scanner. The camera in the scanner uses individual Red (R), Green (G) and Blue (B) sensors to acquire the image. The digital luminance values from these individual sensors are combined to create the color image data base transferred to the computer. In the analysis software this image can be split into its component RGB parts to examine the effect of the printed Black (K), Cyan (C), Magenta (M) and Yellow (Y) Inks. Figures 9 and 10 show the RGB color split of the original images of specimen 1 from each set. These images were enhanced for the illustrations but enhancement was not used any mottle measurements.



	1	2	3	4
All	19.15	20.33	21.6	25.51
Cyan (R)	44.25	39.17	45.48	50.53
Mag (G)	29.31	33.02	34.81	38.9
Yel (B)	39.63	42.26	42.53	49.87

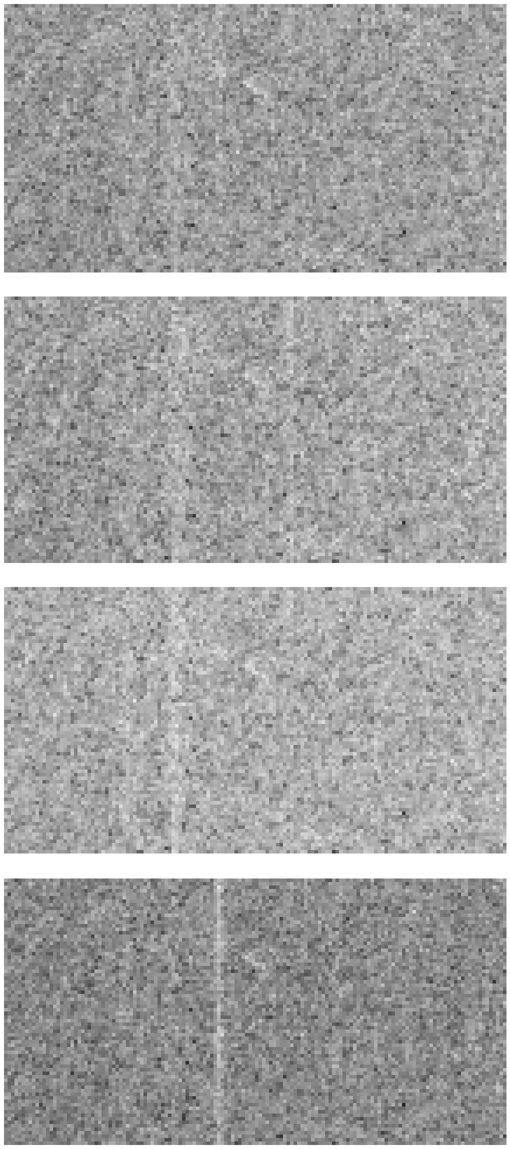
Specimen Number

Chart 3: Test 2 specimen set: Mottle measurement of each color band in the original RGB 24 bit image. The bands were split from the original to form four separate images. The "All" band was created by averaging the red, green and blue bands to create a true composite balance of the luminance intensities in each band.

All of the tests in this series are run on the "Average of All" images. These images are produced by splitting the original color digital image into its component RGB bands and computing the average of these three separate bands to create a gray image called "Average of All". It does not conform to the NTSC standard of a "gray" image which uses the green band only.

Although the process was not used in this series of tests, the separate color bands can be combined to create virtual images of the light reflected by the cyan (Blue + Green bands), magenta (Blue + Red) and yellow (Green + Red) colors. The companion to the reflected light images of the cyan, magenta, and yellow are the absorbed colors for these three, i.e. red, green, and blue, respectively

Fig 10 shows Specimen 1 of Test 2. When the absorbed color bands for the CMY inks (RGB) are inspected separately, there are at least four highly visible vertical streaks. Whereas on Fig. 9, Specimen 1 of Test 1, there are only three streaks, they are faint, only the yellow ink shows a streak clearly, and all the streaks are almost averaged out in the Average of All bands image. But the dominant distinction between the specimens is the black speckles. The mottle algorithm responds to the level of contrast in the image and as a result although the separate color images appear to be dominated by the stripes the pixel to pixel contrast is the mottle determinant. The cumulative effect of the stripes is averaged out in "Average of All" images, and thus correlation of the basic measurement of mottle in the "All" images to visible black gloss mottle.



Color Band Extracted (Absorbed by:)

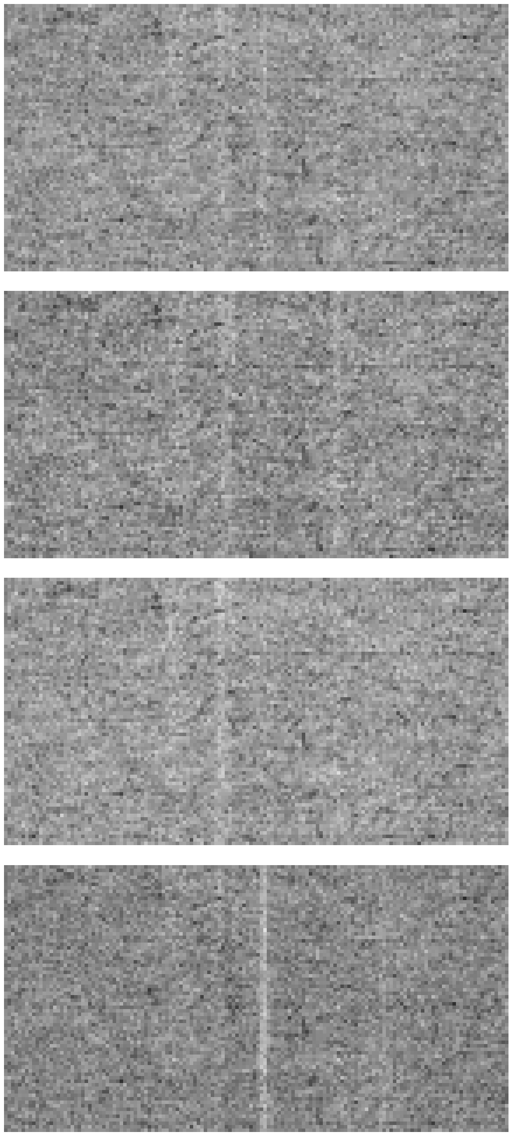
Average of All
Mottle: 34.87

Red (Cyan)
Mottle: 54.18

Green (Magenta)
Mottle: 50.69

Blue (Yellow)
Mottle: 74.04

Figure 9: The mottle source. A single image of Specimen #1 from Test 1 (Chart 2) split into its component color bands and enhanced. The original image (Average of All) used to make the mottle measurements, was enhanced using a brightness shift (+85) and then interpolated (12). Each of the color bands was extracted and similarly enhanced to examine the source of the cumulative variation in the base image. The printed reproduction should show a definite black speckle in all colors and the yellow image should show a high contrast mottle



Color Band Extracted (Absorbed by:)

Average of All
Mottle: 19.15

Red (Cyan)
Mottle: 44.25

Green (Magenta)
Mottle: 29.31

Blue (Yellow)
Mottle: 39.63

Figure 10: The mottle source. Specimen #1 from Test 2 (Chart 3) split into its component color bands and enhanced. The original image (Average of All) used to make the mottle measurements, was enhanced using a brightness shift (+85) and then interpolated (12). Each of the color bands was extracted and similarly enhanced to examine the source of the cumulative variation in the base image. Each of these extractions shows far fewer black speckles than Test 1

It was not the purpose of this study to pursue press diagnostics but it is apparent from Figures 9 and 10 that there is a definite striping introduced somewhere in the process that could also be influencing the mottle measurement.

Summary

The mottle algorithm described in the appendix works on black gloss mottle measurements. Based on the observations of specific image locations, it is possible the gloss speckle observed visually comes from the concentration of ink at the gloss location. The increased ink level causes both low incident visible gloss from increased resin and a much darker tone from a coincident pigment concentration. The mottle algorithm responds to the concentration of pigmentation as a variation in contrast.

By splitting the color images of the black print into its component red, green and blue bands and enhancing the images of these bands, reveals a possible cause of the measured mottle.

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.

Literature Cited

Rosenberger, R.R
2002 "A new Mottle Measurement Algorithm that Creates a Spatial Distribution Mottle Profile Responsive to Transitions within the Digital Image"
Proceedings, 11th International Printing and Graphic Arts Conf., ATIP, October 1-3, 2002, Bordeaux, France, vol 2, no. VIII-4

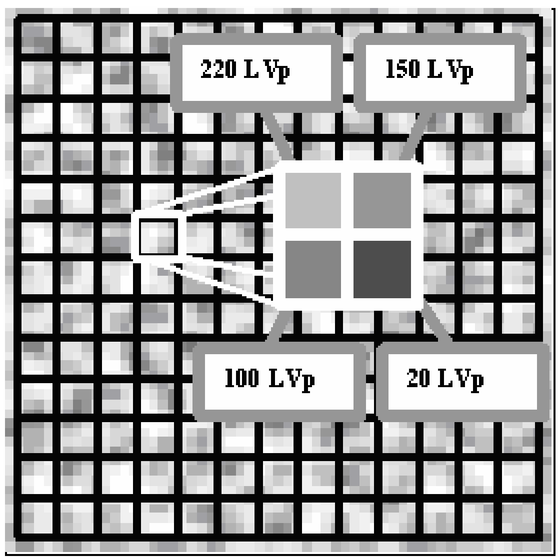
Appendix

A paper on a related subject written by the author (Rosenberger, RR, 2002) has been largely quoted or rephrased to fit this context.

Mottle Algorithm - Stochastic Frequency Distribution Analysis

The mottle method employs a series of different size tiles that follow a binary dimensional progression, i.e. 2, 4, 8, 16…1024. The dimensions are expressed as pixels. The pixel dimensions can be converted to physical dimensions using the image resolution, i.e. 300 pixels per inch (ppi).

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.

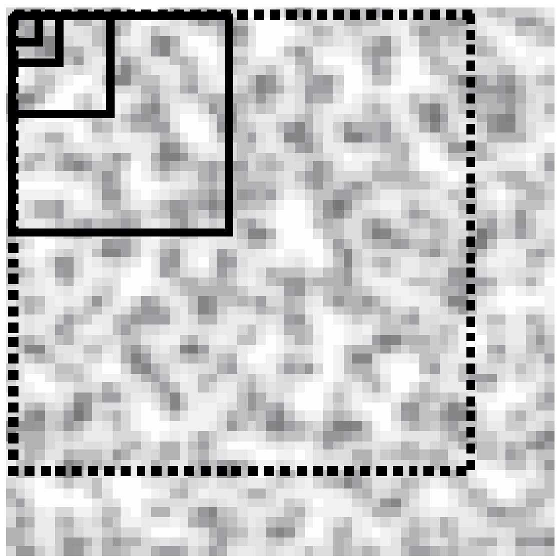


Appendix Figure 1: The basis for the method is the 2 pixel x 2 pixel contiguous tile pattern shown in black.. Shown in white is the extraction of a single tile with the contained pixel luminance values. (LVp).

As shown in Figure 1, 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 useful in detecting pits. Empirical data, however, suggest a resolution of 300 ppi (spi), or even lower (150 ppi), is sufficient for most visible mottle evaluations.



Appendix Figure 2: 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

Figure 2 shows the mottle 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

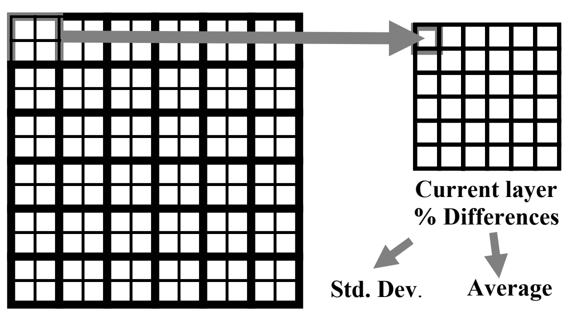
The binary progression in tile sizes is used to determine the spatial variation component of mottle, fine to coarse. As explained above, the sizes are set using a binary progression starting with a 2 x 2 pixel tile and ending with the largest the image will accommodate. Each successive tile size is based 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 2 & 3.

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.

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

Figures 3 and 4 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.



Appendix Figure 3: 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 (1) among the pixel luminance values (LVp) within each tile pixel size based upon a 256 luminance value scale.

$$PctDiff = 100 \times \Sigma(Abs(Diff_{P1\ to\ P4}))/ (6 \times 256) \quad (1)$$

Where: $Diff_{P1\ to\ P4}$ 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 3, 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.

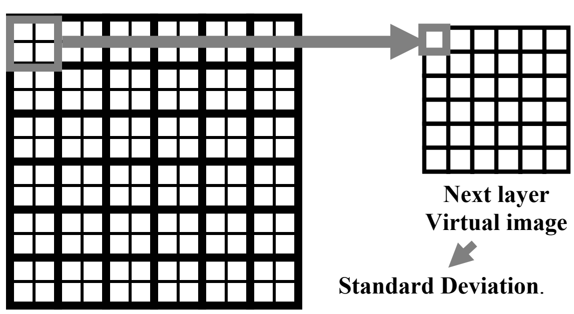
Data Base 2. Average of the Pixel LV

Then, as a second function, the average (2) of all the pixel luminance values is calculated and stored in the database location for that tile.

$$AveLV = \Sigma_{1\ \tau o\ 4}(LVp)/ 4 \quad (2)$$

Where LVp is the pixel luminance value

Data base 2 serves two purposes: First, as shown in Fig. 3, it is used in the mottle calculation for the tile pixel size under current evaluation and, second, as shown in Fig. 4 it is used as the basis to create a virtual image or data base for the next layer or tile size.

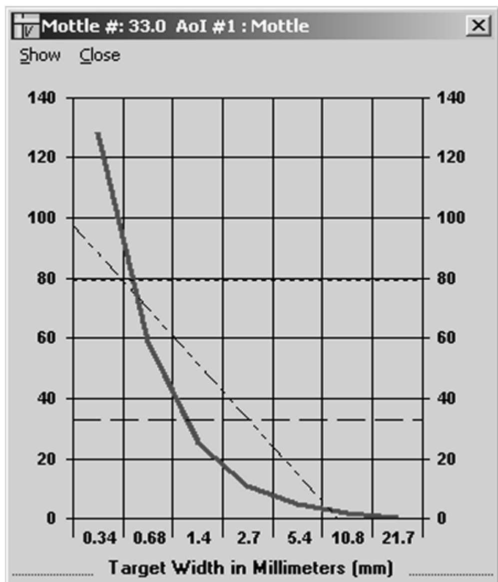


Appendix Figure 4: From the averages of the 2 element x 2 element previous layer create a new virtual image to be used as the basis for the next layer measurements. Each element of the subsequent layer is composed of the average of a 2 element x 2 element average of the previous layer. The standard deviation of the data in this layer is a term in the mottle calculation.

These two data bases are then used to calculate the mottle number for the layer (3). Each layer is dedicated to a specific physical tile size.

$$\text{Layer Mottle\#} = SD_{Diff} \times AVE_{Diff} \times SD_{Averages} \quad (3)$$

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



Appendix 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.

The final mottle number is the arithmetic average (4) of the individual tile size mottle numbers as calculated above.

$$\text{Mottle} = (\Sigma_{1 \text{ to } N} (\text{ Layer Mottle \#}))/N \quad (4)$$

Where:
N = the number of layers or physical tile sizes

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 tiles in the image is 21.4 mm square and the smallest target is 340 micrometers square.