Objective measurement of the ink wicking, surface topography (roughness), and "show through" properties of papers produced for ink jet print

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The image analysis technique (IA) described in this work uses an established statistical method (Standard Deviation) coupled with a standard IA visible object size measurement technique to capture the degree of ink movement along surface and sub-surface paper fibers. This wet ink movement occurs immediately after the wet low viscosity ink strikes the paper surface and before the ink vehicle solvents evaporate. Post deposit ink movement is the cause of visual image distortions often referred to as edge raggedness, feathering, and wicking.

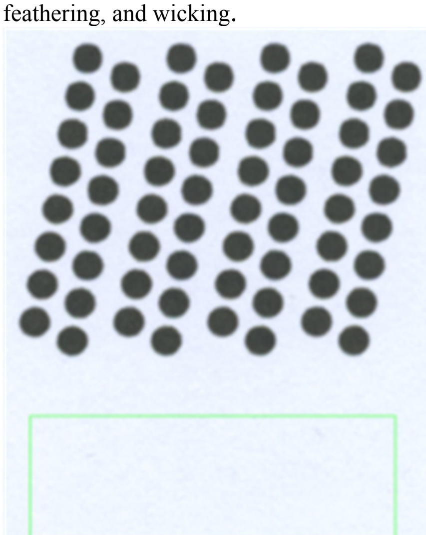


Figure 1 *This dot pattern arrangement assures the print engine jets are uniformly exercised. These dots are approximately 2 mm in diameter.*

The IA method employs a digital scanner to acquire full color (24 bit) high resolution images of a specifically designed printed pattern. Circular dots are used as the primary test pattern, contrary to common practice in which straight line and rectangular patterns are routinely employed. Using dots minimizes the possibility of the Moiré effect in the analysis: e. g. misalignment of the rectilinear printed line with the rectilinear scanner camera and the subsequent rectilinear image analysis. Dots are also the basis of printed half-tone images. Originally developed to analyze the quality offset/flexographic/gravure half-tone print dots, this method was later modified to analyze these non-contact inkjet dots. Practice has determined there is no difference between the perimeter wicking of a line and a dot. Dots offer many advantages to the image analyst using a high quality scanner: even at a low resolution of 600 ppi, dots cannot be misaligned. Experimentation has shown black ink is the best indicator of wicking.

Immediately below the dots shown in Fig.1 is an unprinted area shown outlined in green, in which the analysis system measures the paper reflectivity and surface topography (roughness) as measured by the Verity IA Stochastic Frequency Distribution Analysis (SFDA, Addendum I). As shown in Fig 2, the topography value is 743. The display also shows the actual topographic surface image of the paper.

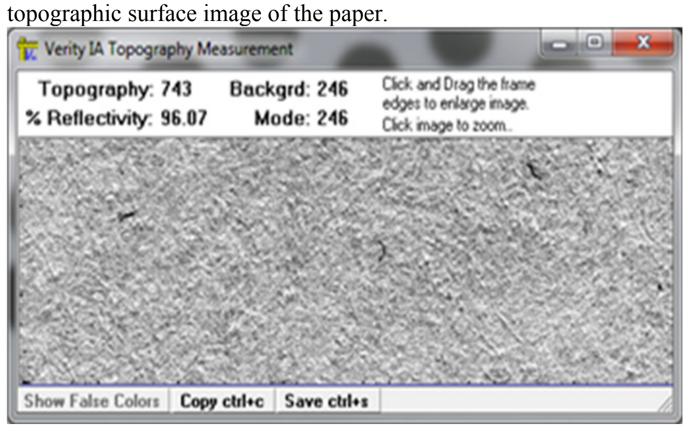
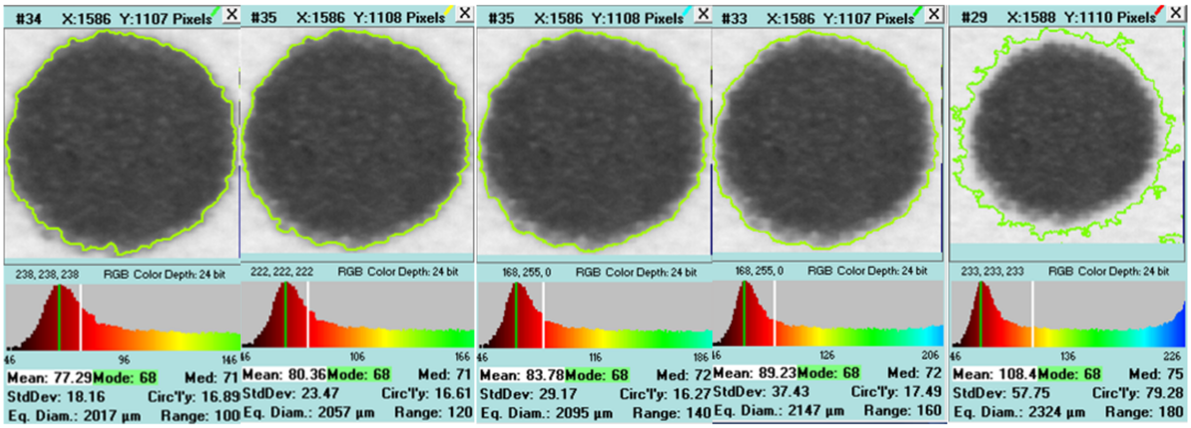


Figure 2 *A typical surface topography (743) and reflectivity (96.07) display report. The surface of the paper is as shown as imaged by the Stochastic Frequency Distribution Analysis (SFDA) software.*

The surface reflectivity value (96.07) is computed and subsequently used to mathematically set the threshold values in Fig. 4, which are, in turn, used to measure the dot properties that are central to this measurement system.

Multiple Thresholding, The Measurement of Ink Wicking

To measure the dots the software uses a concept known as "Thresholding". In this measurement method the image in which the measurement will be made is an 8-bit derivative of the original full color 24- bit image acquired by the imaging device, usually a scanner. The derived 8-bit grayscale image is constructed from the pixel by pixel average of the three (Red, Green, Blue) channels in the original 24-bit color image. In an 8-bit image the pixel luminance (brightness) has a value between 0 (pure black) and 255 (pure white). To measure an object within the image, the pixels comprising the object of interest must contrast with the pixels immediately surrounding it. The IA program extracts or identifies the object of interest based upon the threshold value; those pixels having a value less (darker) than or equal to the threshold value are identified as being of interest. The IA program measurement



1 2 3 4 5

Figure 3 *Images extracted from the display reports showing, in green, the effects on the area (size) measurement of a single dot with the application of progressively sensitive threshold settings.*

Table 1 Calculated standard deviations for the measurements made in Figure 3. From these data it is apparent that the size measurement should be used to measure wicking. Equivalent diameter is a measurement used in the printing industry and is derived from the dot area measurement.

	1	2	3	4	5	Std Dev
Equiv. Diam (um)	2017	2057	2095	2147	2324	**119.6**
Mean Luminance	77.29	80.36	83.78	89.23	108.4	**12.3**
Range luminance	100	120	140	160	180	**31.6**

algorithm then associates the identified pixels to form the objects. The associated pixels forming the object of interest, in our case a dot image, are further analyzed to compute the size or area of the dot expressed as the equivalent diameter in the dot images in Figure 3.

Below each of the images are data and the pixel luminance histogram derived from the pixels found within the perimeter line (green). This line defines the dot size as measured by the program using the application of progressively higher thresholds (Fig 4).

These multiple thresholds are set using a rigid mathematic progression based upon the reflectivity measured in the unprinted area described above. These progressive thresholds measure the dot from its core or darkest value through to its fully wicked condition as shown in Fig. 3.5. It is the same dot in all the pictures taken from the IA system in an actual test using the thresholds set and shown in Fig. 4.

With the lowest threshold in Fig. 3, picture 1, the core or darkest portion of the dot is measured, as indicated by the equivalent diameter (Eq. Diam.) measurement of 2.017 mm. As the threshold is changed the measured equivalent diameter becomes larger and the other property measurements change as well. Table 1 illustrates the variation of these measured properties.

From this analysis and the computation of the measurement standard deviation, it appears all measured dot properties vary with change in threshold values. The size measurement standard deviation was chosen as the primary indicator of ink jet wicking.

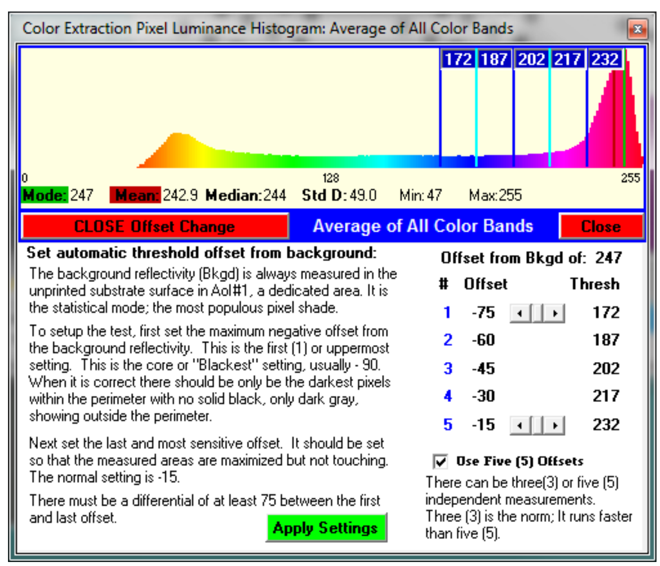


Figure 4 *Shown are the thresholds used to perform the measurements as shown in Figure 3. Once set, the analysis uses them each time the measurement is called.*

Wicking

Is the measurement truly sensitive to the subsurface movement of ink? The images in Fig.3 show the effects of applying thresholds ranging from 139 to 214. The dot images in Fig. 3 may be misleading because the picture dimensions are uniform and the visible dot physical dimensions are the same but the subsurface wicking is changing. The outer limits of the subsurface wicking are traced by the light green line as defined by the threshold.

The images in Figure 5 illustrate subsurface wicking by uniformly changing the image pixel luminance values so the sub-visible very light gray pixels associated with the subsurface wicking in the left image become visible as totally black in the right image. As shown in the histograms, the process is actually a mathematic interpolation of the histogram pixel luminance values combined with a shift in the pixel mean value and then applied to the image pixel luminance values.

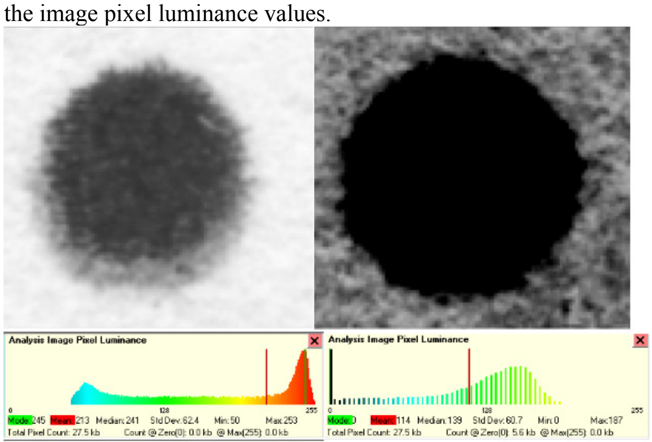


***Figure 5** The same dot shown as 8 bit grayscale before (left dot image) and after the application of image interpolation and mean shifting (right dot image).*

Figure 5 shows an 8 bit image of a dot in which the pixel luminance values range from 0 (black) to 255 (white). At a threshold of 139 the equivalent diameter is of the black dot core, the darkest part of the dot as noted in chart 1 having a mean luminance of 77.29. At the highest threshold the lightest gray pixels are included. These light grey pixels are not normally visible to the human observer unless the image is enhanced as shown in Fig 5.

Wicking Index

In practice the actual multiple thresholds computed size measurement standard deviation was found to be too small a number for easy recognition of change in the wicking characteristic. To improve recognition the "Wicking Index" was calculated as:

Where:

SDA = Standard Deviation of Dot Areas at Multiple Thresholds

$$\text{Wicking Index} = (SDA * 100) - 20 \qquad (1)$$

This number is prominently displayed by the analysis software instead of the actual multiple threshold dot area standard deviation.

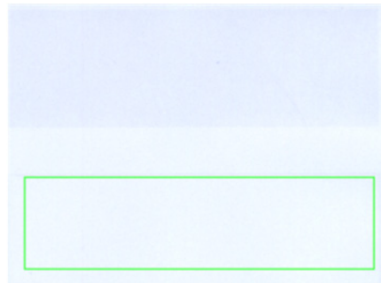


***Figure 6** The reverse side of a paper sheet printed with a solid black area above an unprinted area (shown here with a green perimeter). As measured, the reflectivity of the unprinted area is 96.87 and the reflectivity of the black print area is 94.5, the arithmetic difference between them yields a "show through" value of 2.37.*

Show Through – Paper Porosity

Ink Jet requires the vehicle to be evaporated or absorbed into the paper. When absorbed the vehicle carries fine pigments and dyes with it, the degree to which this penetration is visible can be measured on the the reverse side of a paper with a solid area printed on its front. Figure 6 illustrates this measurement.

Wicking, Show Through, Surface Topography, - Experimental Data

Table 2 demonstrates how this analysis technique works in practice. Several different commercially available papers were tested with this method. The papers are all 20 lb. chosen based upon the manufacturers claimed ink jet print performance characteristics, and the widest possible price per sheet. One of the papers, number MFG4 "Treeless" Copy, is composed of sugarcane husk and bamboo and was very slightly gray. All the rest were conventional wood fiber pulp and very bright white with one being a "Premium" grade.

The data presented in Table 2 show the performance of the test papers. With the exception of MFG1 Standard Bright, price does indicate performance. It is interesting to note the "Treeless" paper, MFG4, has a comparatively rough surface on both sides but the back is twice as rough as any other sheet tested. The MFG3 Premium Multi-purpose is both the most expensive of the "wood pulp" sheets and outperforms all the other wood pulp sheets (Non-treeless).

Table2 The results for each paper tested are shown ranked by the wicking index. The best performers have the lowest Wicking Index and the lowest percent "Show Through".

	Wicking		Show Through		Topography		%	Price/
	Index	Rank	Index	Rank	Front	Back	Reflectance	Sheet
MFG3 Premium	4.8	1	6.02	2	761	724	91.2	$0.013
MFG4 Treeless Copy	5.3	2	5.97	1	1471	2549	84.1	$0.014

MFG2 Multi-Purpose	7.2	3	7.41	6	942	958	89.62	$0.010
MFG1 Basic Copy	7.6	4	6.84	3	1163	1265	89.89	$0.007
MFG1 Standard Bright	7.9	5	7.03	4	1235	1104	89.54	$0.011
MFG1 Multi-Purpose	8.3	6	7.2	5	1256	1163	89.09	$0.007

Addendum I

Stochastic Frequency Distribution Analysis

The Stochastic Frequency Distribution Analysis (SFDA) is usually employed in the measurement of surface patterns such as, topography, visible solid tone print mottle, half-tone print mottle and paper formation. SFDA is a digital algorithm that operates only on digital images that can be acquired by any means. The original image may be poly-chromatic but must be processed to produce a mono-chromatic image for analysis. Its pixel (picture elements) luminance values (PLV) must vary from zero (0) for black to any number equal to or greater than 255 for white. The image content must be intended to be spatially uniform as the algorithm will measure the degree of spatial dispersion within the image PLV on a scale where zero (0) represents a perfectly smooth or uniformly dispersed subject matter lacking any features or texture in which case the PLV all have the same value.

SFDA employs square targets (Often referred to as tiles) that can be a range of different sizes, to measure the uniformity of a random pattern's PLV spatial distribution. When measuring visible phenomenon such as print mottle, the targets, if they were actual, would usually visible at normal viewing distance. When measuring sub-visible features such as topography and half-tone mottle, the SFDA targets would not visible under normal viewing conditions.

Image Resolution

The resolution of the original image to be analyzed must be high enough to record the features of the mottle or pattern to be measured. With visible print mottle this is the texture or minute disturbances reproduced only with resolutions equal to or greater than 236 pixels per centimeter (ppc), or 600 pixels per inch (ppi). Because the eye detects but averages together sub-visible feature luminance, higher resolution than normally expected is required to resolve print mottle.

Paper formation does not have visible texture as such, but does have wire marks that can obscure the formation measurement. In this case low resolution will minimize the impact of wire marks. The 60 ppc (150 ppi) is the recommended resolution for formation measurement. When measuring the sub-visible features in optical surface topography and the dots that make up half-tone print mottle, SFDA measurements require image resolutions of at least 472 ppc (1200 ppi).

Targets: Movement & Size

The SFDA measurement employs square targets. These square targets are moved through the entire image following a regular traversing pattern. Typically starting at the upper right corner of the image, the target is moved one half its width to the right, stops, makes a measurement and then moves another half width, measures and moves, repeating the move-measure pattern until the edge of the image is reached. Another line of measurements is begun that is one half its height below the first or preceding line. This movement pattern continues until the bottom of the image is reached.

Like the resolution, the size of the target depends upon the pattern to be analyzed; usually multiple target sizes are employed depending upon the surface being analyzed. When a series of sizes is employed the first target size used determines the progression of target sizes that will be used. The target physical dimensions follow a binary progression, i.e. 2, 4, 8,…1024 (maximum), as multiples on the first target. When only one target is used there is no size progression.

The target physical size progression used for print mottle measurement in an image with a resolution of 236 ppc (600 ppi) includes the target widths: 0.677 mm, 1.355 mm and 2.709 mm. Similarly, formation measurements use a resolution of 59 ppc (150 ppi) and target widths of 1.355 mm and 2.709 mm. In these two examples the targets of 0.677 mm and 1.355 are visible; the observed pattern is visible.

Topography is sub-visible; its features cannot be seen with the naked eye. When measuring topography a resolution of 472 ppc (1200 ppi) is required and the range of targets used in the evaluation starts with 0.338 mm which is below the visible limit.

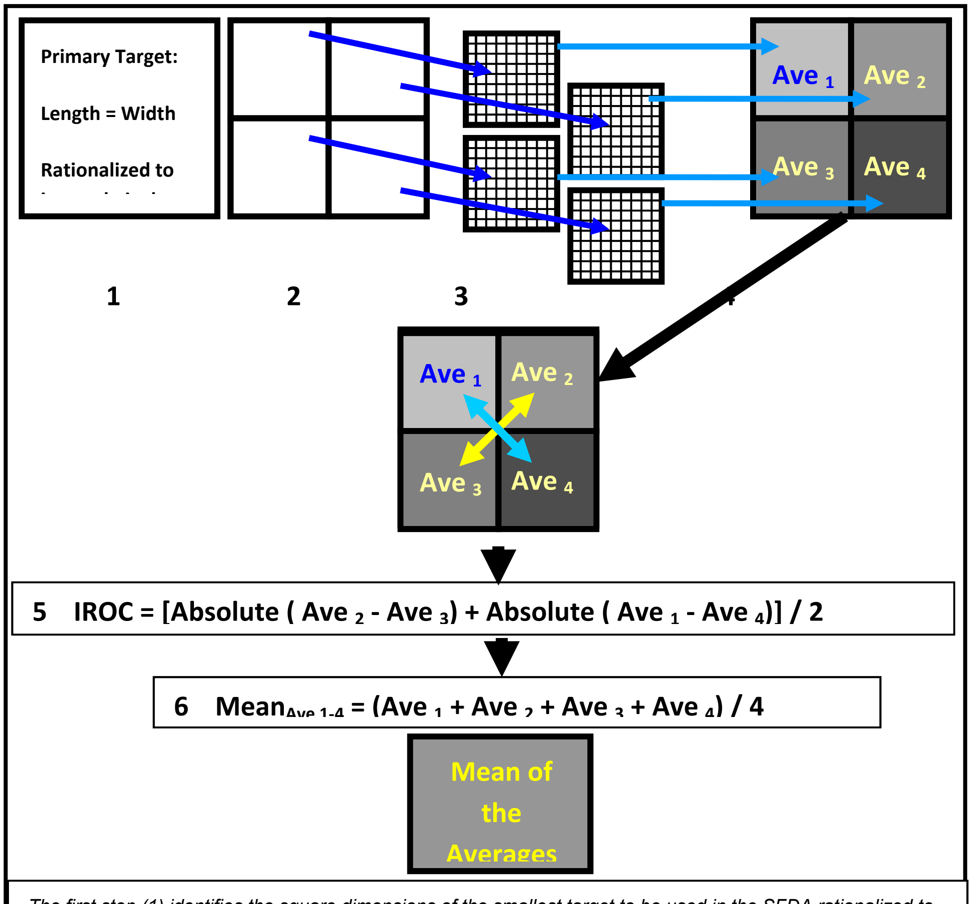
Internal Rate of Change (IROC) within the primary target area:

Up to this point the SFDA measurement resembles others that measure the variation spatial distribution but there is a difference: In addition to the variation in spatial distribution, SFDA measures the Internal Rate of Change (IROC) within the image.

In the analysis, the target used is always a square, dimensioned 2 elements x 2 elements as shown in the flow chart below. As described above, the target dimensions are determined by the measurement to be made, e.g. visible print mottle, topography, roughness, formation, etc. At the initiation of a SFDA measurement, the physical size (length and width) of this primary target square and the four (4) equal contiguous squares elements within it (See flow chart below) are rationalized to the resolution of the image to be analyzed. The primary target length and width measurements are always in integral pixels dimensions.

After the primary square physical dimensions are rationalized, the individual Pixel Luminance Values of the Pixels (PLV) within each smaller square are averaged. The average is recorded in a two dimensional data base at a location corresponding to the physical location of the smaller square. The new data base elements will be the equivalent of a new image containing the average of the PLVs in the smaller squares within the primary target.

The question might be asked: "Would using a lower resolution to acquire the original image suffice instead of this



The first step (1) identifies the square dimensions of the smallest target to be used in the SFDA rationalized to integral pixel physical dimensions. This target is then sub-divided into four equal and contiguous squares (2). The pixel luminance values underlying these smaller squares are then averaged (3). These averages are then used to create another image (4) that is then used to calculate the absolute Internal Rate of Change (IROC) within the original target area (5). At the completion of the IROC calculation data for the final calculation of the standard deviation and the mean IROC are accumulated. At step six (6) the mean of the four smaller squares average luminance values is calculated and data is accumulated for the final calculation of the standard deviation of these means.

averaging technique?" Empiric testing has shown that the human eye discerns the small variations that are sub-visible and, although the image may appear correct, the digital camera, when asked to operate a lower resolution, does not reproduce important details necessary to do a good analysis.

After the creation of this new image data base containing the PLV averages within the smaller square elements, the primary target is now moved one data base element horizontally. When the traverse is complete, the target is indexed down one target element and traversed one element at a time through the entire data base. This is the equivalent of moving through the original image one half (½) its physical width horizontally and one half (½) its physical height vertically throughout the entire image.

Calculations: SFDA

At each stop in the element by element traverse of the data base, the SFDA algorithm calculates:

1. The Internal Rate of Change (IROC) as the cross absolute differences in average luminance within the small squares in the primary target as shown in step five (5) in Figure 1. With this individual IROC, the algorithm updates the variables necessary to calculate:
   The Standard Deviation (σ_{IROC})
   The Mean (M_{IROC})
2. The mean luminance value ($\mathbf{Mean}_{Ave\ 1\text{-}4}$) of the small squares average luminance values. With this individual mean value, the algorithm updates the variables necessary to calculate:

   The Standard Deviation (σ_{Mean})
3. The SFDA Number is calculated at the completion of the data base traverse:

   SFDA Number =
   $$\textbf{Constant} \times \sigma_{IROC} \times M_{IROC} \times \sigma_{Mean}$$

The measurement with a range of target sizes

The results of the SFDA measurement in each target size within the pre-set range are averaged together for the final SFDA number. An image with a SFDA Number of "0" is the ideal, which occurs when no pattern or texture is exists in the image.

The SFDA measurement results from each size target are simply averaged:

Final SFDA Number =Constant ($\sum_{1\ to\ N}$ SFDA / N)

Where N is the number of Target Sizes used in the analysis.