QUANTITATIVELY RELATING INK JET PRINT QUALITY TO HUMAN PERCEPTION

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ABSTRACT

Using a combination of panel evaluation and quantitative printed image analysis, a direct relationship between visual perception and paper quality control has been made. A specifically designed print target is used to measure the effects of ink jet print on paper. The system produces objective measurements of bleed, wicking, raggedness, dot gain and other parameters that have been used to statistically correlate with human panel evaluations. The automated image analysis techniques employed measure comparatively, provide a high level of reproducibility and are objective, requiring no operator inputs.

INTRODUCTION

There are instruments available to measure discrete paper properties but prior to the development of this technique no measurements could completely define the subtle characteristics inherent in the human evaluation of a printed image. Prior techniques used for this purpose contained an element of subjectivity. Most called upon the operator to set a threshold of measurement or inspected an area too small to be significant in paper manufacturing quality control.

APPARATUS

The objective of this development was to design a fully automatic digital color image analysis instrument that would measure, classify, and report various elements of an ink jet printed image in a threshold-less environment. Ideally the system would be simple to use, be rapid, able to respond to a single command, and provide the paper process engineer and scientist timely information in one measurement step.

The hardware decided upon comprised a high speed desk top IBM compatible computer (PC) with 320 megabytes of memory, a graphic arts quality AGFA DuoScan 2000 flat bed scanner able to acquire full color images at 787 points per centimeter (2000 ppi), and a variety of ink jet printers. Various models of ink jet printers were tested and used, but the model remained the same for any series of tests.

Specimen Illumination – scanners

Flat bed scanner based systems are robust and are not fussy to setup and control. Unfortunately putting wet ink on light weight sheets will often cause cockle that can produce image shadows when using a single bulb scanner. The upper-end flat bed scanners, however, have dual bulbs that provide increased illumination, are arranged to be axially symmetric, and eliminate the shadows caused by protruding sheet fibers and cockle. These scanners are also available with resolutions exceeding 787 points per centimeter (2000 ppi) optical. At these high resolutions the full color images produced often will exceed 45 megabytes that subsequently demand large memory and high-speed image analysis computation in the supporting computer.

MEASURING POLYCHROMATIC IMAGE OBJECTS

Inside the 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 point before the image is filed away, displayed on screen, or transferred to the image analysis software.

In a sense, 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.

After extraction from the luminance vector as separate color bands, the digital luminance values (LV) of the picture points range from 0 LV to 255 LV in an 8 bit system (24 bit RGB), as shown in Fig. 3. There a several different imaging bit depth methods but the 24 bit (RGB) system is the most common and the easiest to implement. In it the lowest luminance value level, 0 LV, represents the lowest level of reflectivity, that level where the sensor detects no reflected light of that color and 255 LV the highest level of reflectivity for that color. If each of the three RGB sensors reports saturation , i.e. 255 LV, then the resulting display pixel shade is white. And the converse, when they all report no reflected light, i. e. 0 LV, the displayed pixel is black. Any other combination will show a recognizable color.

Introduction to image analysis - threshold

The customary method of determining what is part of an object of interest to be measured is to have the operator set a threshold level in the scale of luminance values for each color band. The threshold luminance value is that level below which the picture points are determined to be a part of the object of interest and above which they are considered to be part of the background.

Once the image analysis software has extracted or foregrounded those picture points that satisfy all threshold criteria it will then determine which of them are contiguous and begin to measure the properties of the contiguous points as a group. These may be area, perimeter, average luminance, luminance value variance, circularity, and other parameters relevant to the particular investigation. These properties are classified by specific type, size, shape, etc. and then stored in the system memory based on their image location coordinates so they may be retrieved for later analysis.

The comparative threshold – Hands free

Each of the print analysis measurements described in the following are "comparative" using internally generated thresholds based upon the contrasts within the printed image itself. The comparative thresholds are discussed more completely in "The Comparative Threshold" section below. They use no operator involvement beyond placement of the specimen on the image analysis scanner stage and pushing the start button. A specific pattern, especially designed to support this "hands free" method, is required.

THE INK JET PATTERN

The printed ink jet pattern, as shown in fig. 1, is specific to the test. It has unique characteristics designed to stress the paper in the presence of the ink, to facilitate the measurements, and to address the problems associated with digital printing and imaging.
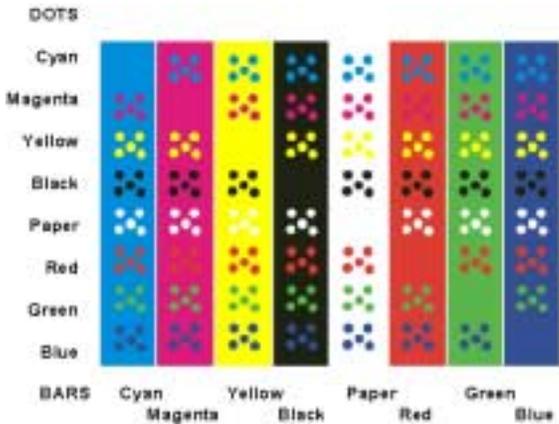

Fig. 1. This image of the ink jet pattern is in color that may not show in this reproduction. The side bar legends indicate the colors of the dots and bars.

Copyright: International Paper Corporation

Ink jet Pattern Characteristics:
- **Colors** – All primary and secondary colors, the substrate and black, are present.
- **Dots** - The dots in each color are commanded to be exactly 2.5 mm in diameter and are arranged in an asymmetric set of five (5). This arrangement of round dots overcomes the Moiré effect inherent in a digitally created ink jet print image optically imaged by a digital camera both having a rectilinear orientation. Each set of dots is printed in contrasting colors and matched in reversed color combinations to form a pair. Every color combination is paired including the substrate and black.
- **Empty Squares –** There are squares of color, having no dots in them, running from the upper left to the lower right, that are used by the measurement software to determine which color band will be used to examine the contrasting pairs of dots.
- **Size –** The pattern is 95 mm x 120 mm and occupies about 30% of a standard North American letter.

COMPARATIVE MEASUREMENTS

The comparative measurement is most significant aspect of this entire measurement system. It is why the system can function without a manually set threshold and deliver reproducible results.
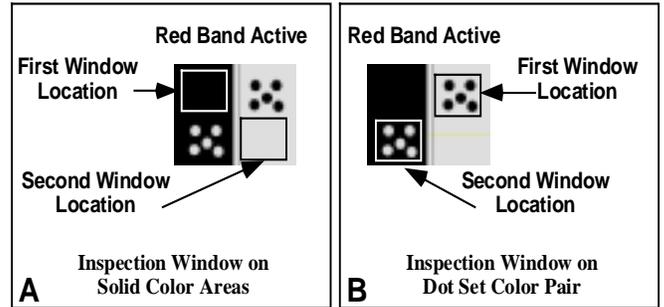

Fig. 2. A shows the position of an inspection window superimposed on the printed image. The window moves a total of eight (8) times down the image starting in the upper left and ending in the lower right measuring the solid area three color LV frequency distribution.

Fig. 2. B shows the window over one set of a pair of dot sets and then moved to the second set. The data obtained from these two sets are later compared before reporting.

The comparative measurement Window

The analysis is based upon a subdivision of the ink jet pattern into 64 discrete elements defined in size and shape by an inspection window. This small window moves with a high level of precision through the entire image in an order prescribed by the program logic. Fig. 2 shows the logic at work moving the window in its two modes, one to acquire the solid area data and the other to make the dot measurements using the solid area measurements to set the thresholds
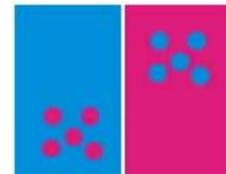

Fig. 3. A magnified view. The dots are arranged asymmetrically and commanded to be the same size. The bleed and wicking characteristics have caused the magenta dots to be smaller than the cyan dots.

An Example: Bleed – Color to color interaction. A small portion of the pattern is shown in Fig.3. All of the dots were commanded by the computer to be printed exactly the same size. Because the cyan has bled into the magenta the cyan dots have become larger and the magenta dots have become smaller. When the area and perimeter measurements are compared by subtraction or ratio, as shown in:

Bleed = Cyan Dot Area / Magenta Dot Area

This typical comparison becomes a measure of cyan to magenta bleed. The same comparisons are made for every color to color and paper to ink combination in the pattern.

THE COMPARATIVE THRESHOLD

In a color system it is necessary to determine the threshold luminance value three times, once for each of the color bands. Each color band criterion must be satisfied for a picture point to be identified as potentially being part of the object of interest. Figure 4 illustrates the multiple threshold criteria that can be present in a color image analysis system.
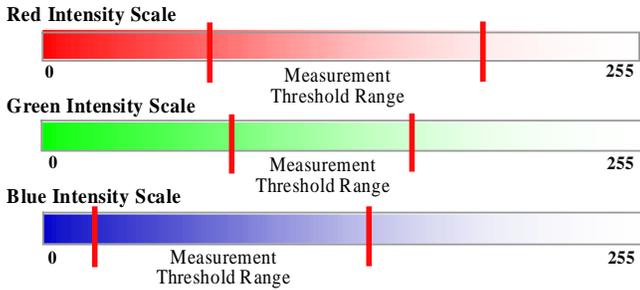

Fig. 4. The intensity scales present in each picture point in an image. Most image analysis systems can set two thresholds in each band that either include or exclude, for analysis, the intensities between them. A particular picture point must satisfy all three band's threshold criteria before being included in an object of interest.

Using upper and lower thresholds to bracket or exclude a range of values in each color band allows the measurement system to define specific colors for measurement, for example a purple that ranges from a medium to dark intensity. In the analysis of print quality the lower threshold is always set to zero (0) thus including all picture points lower than the intensity of the upper threshold.
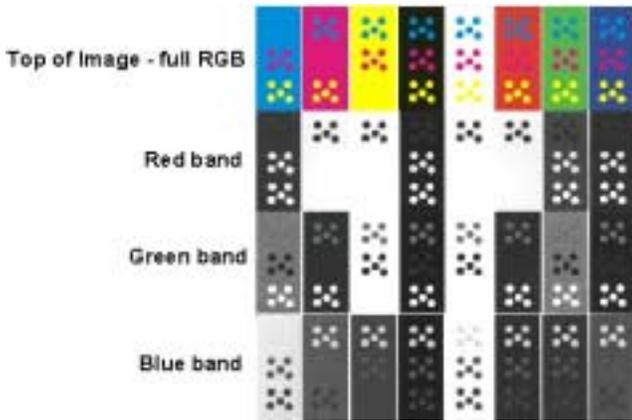

Fig.5. This full color image shows the effect of band separation. At the top is the full color image of the upper portion of the print pattern. Below it are the three bands, RGB, shown individually in gray scale.

Selecting the color band to be used

As shown in Fig. 5. each color sensor responds differently to the various printed colors. Consider the cyan and magenta set. The left most bar is cyan. (The reproduction may not show color.) Inspection of the cyan bar with the red band shows that the cyan bar has absorbed most of the red luminance, its intensity is very low and shows as a dark gray. The opposite is true of the magenta bar and, as a result, when evaluating the cyan/magenta pairs the analysis band will be red.

Automatic selection of the color band to be used in the analysis of dot set pairs is performed as the initial step in the print evaluation. Diagonally across the pattern shown in Fig. 1, from the upper left to lower right, are eight (8) empty squares containing all of the colors in the image. These empty squares are inspected individually and the picture point LV frequency distribution histogram for each color band is computed and stored in memory for later recall. A total of 24 histograms are stored.

The program then calculates the average intensity for the 24 histograms. The color band that demonstrates the highest contrast between average reflectance of the two colors present in the dot set pair under examination is selected and stored in memory.

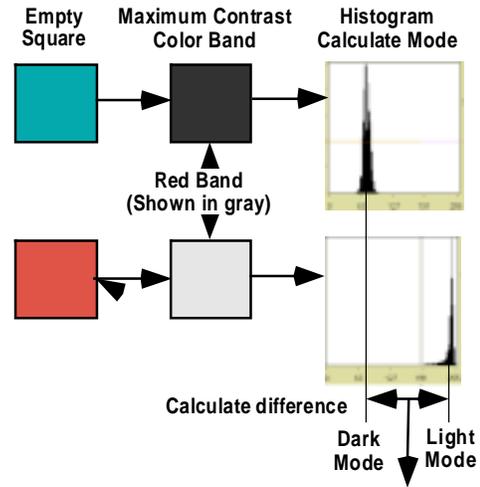**Threshold Value = 0.5 x Difference + Dark Mode**

Fig. 6. The histograms of each color band within the two solid color squares are compared to select the band that yields the highest difference in their statistical modes. The analysis of that pair of dot sets uses a threshold calculated from these statistical modes.

Calculating the comparative threshold

An example of the logic and math is shown in Figure 6 in which the Cyan & Magenta dot pair will use the red band for analysis. The program recalls the red band histogram for the Cyan empty square and does likewise for the Magenta empty square. The statistical mode for each histogram is calculated, which, in Figure 6 are called Dark mode and Light mode respectively. The mode is the most frequently occurring luminance value in the histogram. These two modes are subtracted and the difference added to the lower mode. This value is set as the threshold in the red band for the measurement of the dot area, perimeter, etc.

Every ink jet printer model will have a unique print engine and inks to which the substrate will respond differently. These differences show up in the printed image as a variation in color intensity that can change the automatic selection of the active color band. As a result, at times, in certain evaluations, it is necessary to inhibit the automatic band selection and substitute a fixed color band selection for each pair of dot sets. The program can be set either to automatically calculate the

color band to be used or to refer to a manually created look-up table held in memory.

MEASUREMENTS

All measurements are made upon contrasting pairs of color dot sets. Using as an example the cyan and magenta set in the first two columns as shown in figures 1, 2, & 3, prior to performing a measurement on one of the pair sets, only one of the three color bands (RGB) is activated.

- **Non-Uniformity** is the measure of the picture point luminance value (LV) variation within an image; a measure of the tendency toward a bimodal image pixel LV frequency distribution. A rising non-uniformity number indicates a tendency toward a black (Half at 0) and white (Half at 255) bimodal LV distribution while a falling non-uniformity number indicates a trend toward a uniform image having a single mode picture point LV distribution.
- **Area (Gain) -** The size of the dots in sq mm is measured based on a computed threshold discussed in " The Comparative Threshold".
- **Perimeter -** The perimeter (P) of each dot is measured at the same time as its area (A).
- **Circularity (Raggedness)** Circularity (C) computed from the perimeter (P) and area (A) of each dot as:
  $$C = P^2/A$$
  For a perfect circle "C" is always 4*Pi or 12.57 thus "C" is proportional to the degree of raggedness.
- **Count of Dots –** The number of dots in each measured set is counted. Bleed and wicking can merge dots so the set count will not equal five. In this case the software posts a warning in addition to the count being recorded.

The Ink Jet Pattern Measurement Steps
The program logic performs these steps in order.
1. Orient the pattern and the measurement rectilinearly.
2. Measure the solid areas and store RGB histograms.
3. Measure the characteristics of the dots as color pairs.
4. Display the dot gain and raggedness for:
   Black: ink on ink and ink on paper
   Colors: ink on ink and ink on paper.
5. Report and record all 196 measured data points.

RUNNING A TEST

A single sheet printed with the pattern shown in Fig. 1is placed on the scanner with a flat 200 mm x 200 mm, 2.2 Kg, white faced specimen weight placed upon it and the test initiated. The computation automatically proceeds after the scan is made. A total of 196 separate measurements are reported and recorded. From these 196 the following overall evaluations are extracted and also reported as the common control parameters used in the mill test laboratory.

- **Ink to Paper:** All of the dots printed directly on the paper or are paper within a colored field
- **Ink to Ink:** Dots that are printed within a colored field
- **Gain:** % growth, computed as the absolute sum of the difference in measured areas of the color and paper dot set pairs divided by the commanded area of the dots.

- **Raggedness:** % growth, computed as the average of all the relevant circularity measurements divided by 4Pi (the circularity of a perfect circle).
- **Black:** Only the black dots and paper dots when in a black field.
- **Color:** Only the non-black dots and paper dots when in a colored field.

REPEATABILITY

25 tests were conducted in five (5) groups. Each group of tests was separated by time and the scan conditions were varied in some cases. TAPPI 1206 method was employed. Tests were not run in a temperature and humidity controlled environment.

The range of % repeatability:
- Ink to Paper: Black gain : 0.31 to 0.88
  Colors gain: 0.26 to 1.17
  Black raggedness: 2.01 to 15.19
  Colors raggedness: 1.95 to 4.07
- Ink to Ink : Black gain : 0.28 to 0.38
  Colors gain: 0.76 to 1.53
  Black raggedness:1.97 to 2.88
  Colors raggedness: 1.32 to 2.86

Results indicated a high level of precision for all but the black raggedness. The raggedness or circularity is not a comparative measurement and is also derived from two variables; the square of the perimeter divided by the area. The black raggedness seems to improve as the specimen continued to dry and stabilize on the warm scanner.

PANEL TESTING AND CORRELATION

There are 196 measurements within the ink jet print pattern:
- **28 Non-Uniformity**: For all dot set pairs.
- **56 Area**: For each dot set in the pattern.
- **56 Circularity**: For each dot set in the pattern.
- **56 Perimeter**: For each dot set in the pattern.

These data have successfully been used with data obtained from blind panel tests in a multiple regression analysis. The coefficients derived have been used to create equations that describe the relationship between the Ink Jet Pattern tests and Text, Landscape, Portrait, and Illustrations printed on the same papers.

CONCLUSIONS

Repeatability studies show excellent results and demonstrate that this completely objective test is available to correlate with human evaluation. Users have developed proprietary correlation between the numeric data reported by the method and panel tests. This method of determining the performance of ink jet papers provides the mill quality control lab and research scientist an automated test.

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