Image analysis of ink-jet quality for multi use office paper

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ABSTRACT

A new image analysis procedure for the evaluation of ink-jet print quality uses a microscope, charge coupled device camera, video capture board, and image analysis software. Wicking, feathering, strike-through, print sharpness, and intensity determine ink-jet print quality. A print test target using various ink-jet printers combines text, graphics, and a photograph that measures sharpness for the text and color-to-color bleed for black into yellow. The test also evaluates the intensity of the strike-through and records optical densities of the color. This paper ranks the performance of 26 uncoated papers and one coated commercial ink-jet paper.

Application: *An image analysis method provides an objective means for measuring ink-jet print quality.*

INK JET PRINTERS ARE A RAPIDLY growing segment of computer printers. The low cost of the printers and the additional benefit of color printing have fostered their phenomenal growth. The aqueous nature of the inks has also generated many requirements for the papermaker. The paper must hold the ink near the surface to prevent bleed-through and control the vertical penetration to minimize wicking and feathering. Severe wicking or bleed-through is unacceptable to the customer even for a reasonably priced printer. Excessive hold out of the ink and dry time become issues. These competing factors are the parameters that affect ink-jet print quality.

A new method uses image analysis and optical density (OD) to evaluate ink-jet print quality. Wicking, feathering, strike-through, print sharpness, and intensity determine ink-jet print quality. These measurements and the ID of the primary colors—black, cyan, magenta, and yellow—are evaluated for 26 uncoated papers and one coated commercial ink-jet paper. The evaluation used Hewlett Packard DeskJet 560C, DeskJet 680C, and DeskJet 820 CXi; Canon BJC4000; and Epson Stylus Color and Color 500 ink-jet printers to generate prints.

Image analysis is a well-documented technique in the paper industry. Initial applications involved dirt speck analysis. These included the use of optical scanners and charge-coupled device (CCD) camera proposed by Rosenberger for the analysis of dirt specks *(1)*. The essence of this procedure became TAPPI Test Method T 563 pm 96. It uses image analysis to measure frequency, size, and intensity of dirt specks *(2)*. Similar requirements exist for image analysis systems whether for dirt specks, print quality, or formation. Parameters of interest include reproducibility, resolution, and calibration standards *(3)*. The method also requires an inherent practicality of the method to ensure its usefulness and acceptance by the operator.

Many examples of image analysis exist for the evaluation of print quality. These include all manners of printing such as offset, xerography, and ink-jet *(4-6)*. Lee et al. conducted an evaluation of ink-jet print quality on 41 commercial papers comparing image analysis with a panel response *(7)*. The most prominent references for ink-jet print quality were Hewlett Packard's Paper Acceptance Criteria: First Edition for the HP DeskJet 500C and the Second Edition for HP DeskJet 500C, 550C, and 560C Printers *(8,9)*. These manuals provided performance specifications for evaluating print quality on the Hewlett Packard ink-jet printers—text, color intensity, color-to-color bleed, light fastness, etc. Hewlett Packard also provided standardized test targets. The Hewlett Packard test targets became the industry standard for evaluating ink-jet print quality. Wasser et. al. used the test target in their image analysis study of the effects of sizing on ink-jet print quality *(10)*.

A partnership between Hewlett Packard and Stora Papyrus Nymolla AB in developing the first Hewlett Packard certified ink-jet paper details the impact of image analysis on print quality *(11)*.

The focus of the ink-jet printer manufacturers has shifted toward color and photographic quality images. The currently proposed method is a practical solution to evaluating ink-jet print quality. The method incorporates image analysis and OD for the objective measurement of ink-jet print quality on the latest ink-jet printer models from Hewlett-Packard, Canon, and Epson. Evaluating and ranking 27 commercial ink-jet papers demonstrates the efficacy of the method.

EXPERIMENTAL

Image analysis system

An image analysis system to analyze the print quality of printed material uses a stereo microscope, CCD camera, video capture board,

1. Image analysis workstation

2. Ink-jet print file

and image analysis software. The image analysis system is an imaging work station. This present study only concerns imaging for ink-jet print quality determination and concentrates on that segment of the system. Turnkey imaging systems are available for print quality, but they are one-dimensional in expansion and capabilities.

A stereo microscope, Olympus Research Stereo SZH10, mounted on a boom stand provided an unobstructed work area to magnify the printed images. The unit has a magnification range of 5x-70x. A fiber optic continuous ring illuminator with variable control calibrated using a SPER Scientific light meter is the light source. The camera model is the Sony DXC-960MD three-chip CCD color video camera. The camera has three video output formats—composite, RGB (red/green/blue), and Y/C [Luminance (Y)/Chrominance(C)]. The camera has a resolution of 786 horizontal by 494 vertical for image resolution of approximately 380,000 pixels. The camera couples to the microscope with a 10x C-clamp connector. The RGB format was used to capture the images.

The heart and soul of the imaging system are the video capture board and image software. The image analysis software is Sigma Scan Pro 2.0 Automated Image Analysis Software from Jandel Scientific software. The choice of imaging software determines the appropriate video capture boards for the stem. Choosing the Sigma Scan Pro provided a complete image analysis package that was simple to use with many standardized measurements. The choice of Sigma Scan Pro determined the video capture board to use. We chose the TARGA+ 16/32 from Truevision. This is a combination gray scale or color video capture board. Jandel Scientific recommends the TARGA+ capture boards for Sigma Scan applications. Using Sigma Scan Pro with a TWAIN compatible scanner is also possible. Using a two-monitor solution—a computer monitor and separate video monitor—maximized the flexibility of Sigma Scan Pro with the TARGA+ board. The video monitor is the Sony PVM-1353MD with two lines of input for RGB and composite video plus one input for Y/C video.

The computer is essential for operation. Ours is a 90Mhz Pentium with two 1GB hard drives. A separate, recordable CD drive backs up the image files. Additional accessories of the imaging system include Hewlett Packard ScanJet IIcx desktop scanner, VCR, Olympus Research Microscope BH-2 Canon YH13 broadcasting zoom lens, and a Tripp Lite line conditioner. A pneumatic vibration isolation table stabilizes the microscopes. **Figure 1** shows the image analysis workstation.

This evaluation of ink-jet print quality used six ink-jet printers—Hewlett Packard Deskjet 560C, Deskjet 680C, and Deskjet 820Cxi; Canon BJC4000; and Epson Stylus Color and Stylus Color 500. The printers were in a room at TAPPI controlled temperature and humidity (CTH) conditions. All the commercial papers underwent aging

in the CTH room for at least 24 h before printing. The analysis used a minimum of three sheets per sample. **Figure 2** shows the test target used in the print quality evaluation. This target encompasses several features of the Hewlett-Packard Print Acceptance Criteria Second Edition—text passage, Es for visual wicking, waterfastness drip test, OD test, and the color-to-color bleed. This target varies from the Hewlett Packard target by the inclusion of savingthree sets of dots (8-point, 4-point, and 2-point) for print sharpness. There are four series of text. The sample used in the print quality measurements for the Canon and Epson printers is the first that is 12-point Times New Roman. The HP820Cxi printer used 12-point Courier New. Corel Draw v. 5.0 generated the test target for each printer with the specific printer drivers The bottom of the test target lists the printer model.

Calibration

Before the image analysis sessions, a calibration of the system is necessary. A calibration target is necessary for each magnification and light setting. A precision machinist ruler (metric) calibrates the system for distance, and a calibrated gray scale standard Macbeth Color Checker calibrates it for intensity. The chart contains six gray scale chips calibrated in OD from white (OD = 0.05) to black (OD = 1.50). The camera settings for calibrating the system and subsequent image analysis are the following: step gain 10 dB, color temperature 3200 K, white balance auto, CCD iris off, and shutter off. These settings assure uniform performance in capturing images. An 8 bit monochrome (256 gray scale) gives best results when imaging. The first step in generating the calibration target is to capture and save an image of the ruler as a bitmap file at the appropriate magnification. The next step is to capture images of each of the six gray scale chips from the Macbeth Color Checker at the appropriate magnification and illumination. Uniform segments of each gray scale chip are copied and pasted into the ruler image. The image is then calibrated for distance and area using a two-point calibration of the ruler. Gray scale chips perform a multiple point calibration. This image file is saved to serve as the calibration target for the image analysis procedure. All images captured while this file is active are calibrated for distance (mm) and intensity (OD). **Table I** lists magnification and illumination settings.

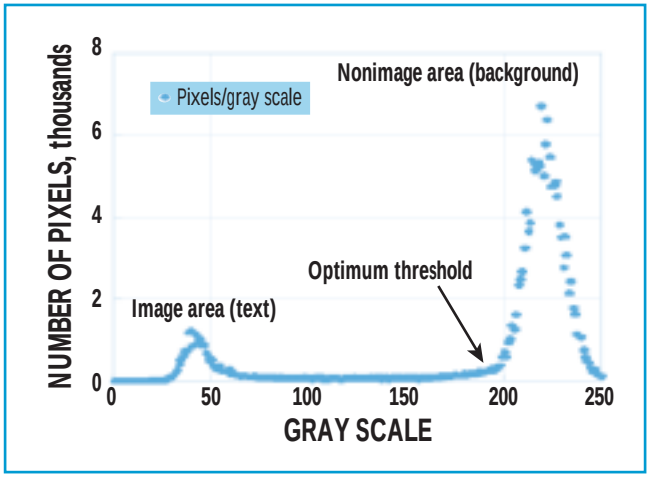
Image analysis procedure

After a calibration of the instrument, image analysis of the ink-jet prints can begin. With the appropriate calibration image on the system, the ink-jet print is positioned and secured with the area of interest centered in the field of view. For the text and dot measurements, the magnification is 10x, and the illumination is 3000 Lux at 15 cm from the light source. For analysis of the text, we chose the word "show" from the first passage. The image

Print test	Magnification	Light, lux
Text "show"	10x	3000 ± 20
Dots	10x	3000 ± 20
Color-to-color bleed	7.5x	3000 ± 20
Strike-through	5x	2500 ± 20

I. Magnification setting and illumination at 15 cm for image analysis of ink-jet prints

3. Text from a 680C print of a certified ink-jet sheet

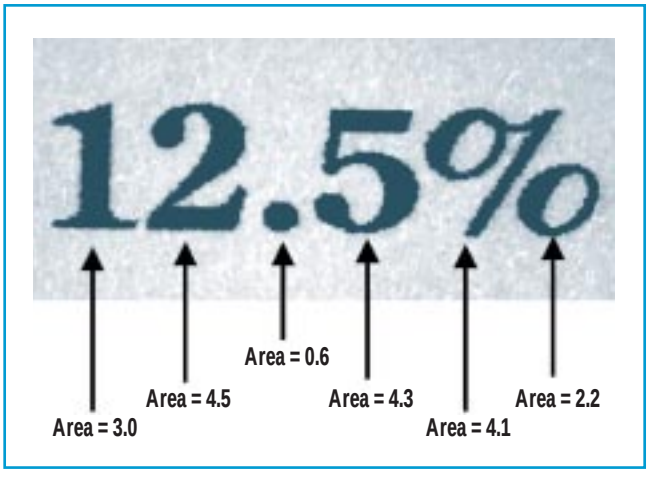


4. The frequency histogram for the text in Fig. 2 with the optimum threshold identified

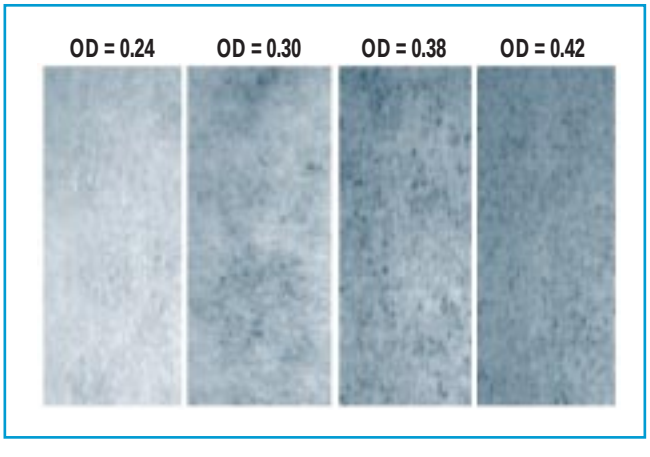
is focused and then captured. This image is calibrated for distance in mm and intensity (OD). **Figure 3** shows cropping the image to the area of interest—the word "show." Cropping is also important to remove video scan lines that result from interlaced video. The calibrated image is saved as a bitmap file.

The threshold is determined for each image and applied to the frequency histogram where the pixels associated with the background are observed. This is the point at which all pixels above area associated with the background (sheet) and all below are associated with the printed image (text, dots). By setting the threshold at this value, the measurements include all the pixels associated

5. Image analysis of text for two ink-jet prints with a threshold of 190. Sample A: area = 9.68 mm², perimeter = 65.6 mm, OD = 0.82. Sample B: area = 10.82 mm², perimeter = 68.8 mm, OD = 0.77.



6. Area measurements for the text items in the black-to-yellow color-to-color bleed



7. The strike-through images of four ink-jet prints and the OD measurements

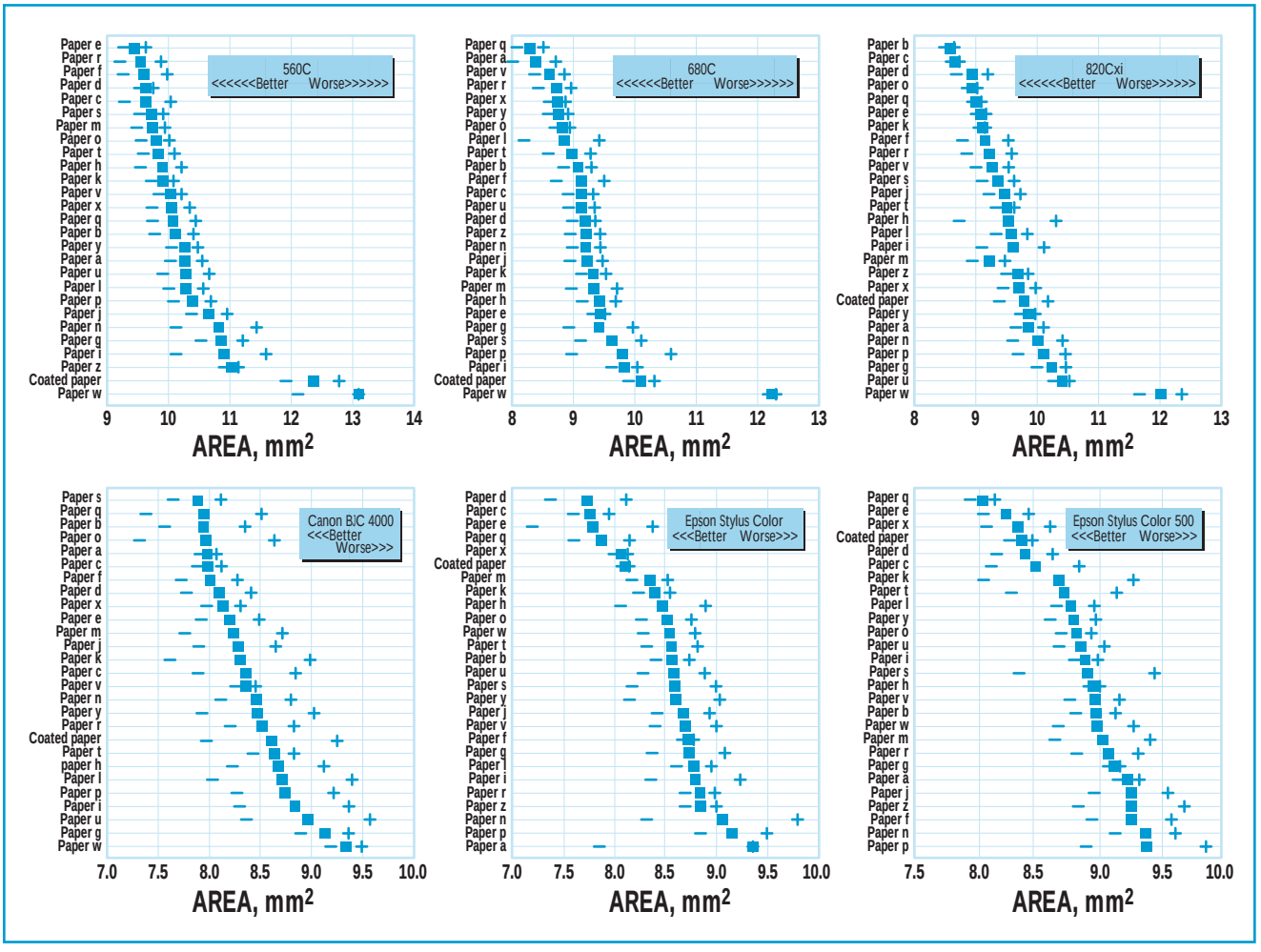
with the ink. **Figure 4** shows the frequency histogram—pixels/gray scale—for the word "show."

The threshold is a grayscale value and is therefore limited to integers. A threshold overlay is applied to the image at the grayscale value of the inflection point from the frequency histogram. We have initially evaluated several techniques for mathematically determining the increase in area—objects—to incremental increases in grayscale. This determined that the inflection point is within one or two grayscale units of the optimum threshold.

After setting the threshold, the area, perimeter, and intensity are measured. The area measurement includes all areas associated with ink including over spray. This will lead to the number of objects measured ranging from 20 to 150 depending on the print for the word "show." Theoretically this is four objects. The additional objects do not significantly affect the area and represent less than 1% of the measured area. The small objects and over spray would greatly affect the perimeter and intensity. For these reasons, only the measurements associated with the text area considered for the perimeter and intensity. **Figure 5** gives examples of two prints with the image analysis measurements. The print quality for text and dots uses area, perimeter, and intensity. The area provides information on the sharpness of the print—smaller is better. The perimeter is a measure of the coastline of the text and provides valuable information on the degree of wicking and the uniformity of the text from one print to the next. The intensity provides the OD of the printed image.

The procedure for dots is identical to the method for text evaluation. There are three sets of dots: 8-point with 150 dots, 4-point with 182 dots, and 2-point with 364 dots. The image of the set of dots of interest is captured and cropped. The threshold is determined as described in the previous section and the image measurements are made for area, perimeter, and intensity. As a complement to the evaluation, the mean area and mean perimeter of the individual dots provide useful information on the uniformity of the ink-jet print.

The procedure for the evaluation of color-to-color bleed is similar. The black test, "12.5%," in the yellow field is used for the color-to-color bleed to maximize the contrast. A 256 gray scale image is captured and cropped. The threshold is set in a similar manner, but the background is the yellow field. The measurement is identical to the text measurement. The area measurement includes all areas associated with black ink including over spray. Only the measurements associated with the text items—theoretically six objects—are considered for the perimeter and intensity. The area, perimeter and intensity values per object are sorted and only the largest object—text



8. Area of the word "show" with variability shown by the plus and minus signs

items—are evaluated for average intensity and total perimeter.

The number of objects counted could be 4-6 depending on the degree of wicking. **Figure 6** shows an example of black-to-yellow color-to-color bleed with the area measurements for the text items. This image had a threshold of 170.

The next stage of the evaluation is strike-through or bleed-through. This is the degree of penetration of an ink through the sheet of paper. Strike-through is measured on the reverse side of the purple square at a magnification of 5x and an illumination of 2500 lux at 15 cm. The purple square of the test target is generated by 100% fill of the magenta and cyan inks. Initial evaluation of strike-through for the Hewlett Packard 500 series printers was of the composite black square. The procedure is similar in that a gray scale image of the reverse side of the purple square is captured and cropped. For strike-through, only the average intensity is measured. The threshold is set to 255 (256 gray scale = 0 to 255), and the intensity is measured that gives the average intensity of the image. **Figure 7** provides an example of strike-through of the purple square for four sheets.

The OD of the 100% fill areas for the cyan, magenta, yellow, and black squares are measured with a Macbeth Densitometer. For some printers such as the HP DeskJet 560, a composite black is generated for the color square segment. The composite black is a combination of cyan, magenta, and yellow. In these instances, the 100% black and composite black are evaluated. There are large differences between the black and composite black. One paper has an average black OD of 1.43 compared with an average composite black OD of 1.04. This lack of intensity is a reason for the diminished market for color printers offering a composite black despite being priced lower than the CMYK (cyan, magenta, yellow, and black) printers. The instrument is calibrated, and a minimum of four measurements per color are recorded. The print quality is defined by these 11 measurements or 12, if a composite black is generated. The measurements are area of text, perimeter of text, intensity of text, area of color-to-color bleed, perimeter of color-to-color bleed, intensity of text for color-to-color bleed, intensity of strike-through, OD

Paper	HP560C Area	HP560C Rank	HP680C Area	HP680C Rank	HP820Cxi Area	HP820Cxi Rank	Canon BJC 4000 Area	Canon BJC 4000 Rank	Epson Stylus Color Area	Epson Stylus Color Rank	Epson Stylus Color 500 Area	Epson Stylus Color 500 Rank
Sample a	10.29	32	8.37	2	6.49	23	7.99	7	9.37	27	9.24	22
Sample b	10.11	25	9.05	10	5.44	1	7.95	5	8.57	13	8.96	17
Sample c	9.64	6	9.12	12	5.51	2	7.99	8	7.76	2	8.47	6
Sample d	9.63	5	9.15	14	5.73	3	8.09	10	7.73	1	8.38	5
Sample e	9.42	2	9.42	22	5.84	7	8.21	12	7.78	3	8.24	2
Sample f	9.59	4	9.10	11	5.91	9	8.01	9	8.73	19	9.27	25
Sample g	10.89	44	9.45	23	6.79	27	9.13	28	8.74	20	9.12	21
Sample h	9.89	16	9.41	21	6.21	15	8.67	23	8.48	9	8.95	15
Sample i	10.92	45	9.83	27	6.28	17	8.83	26	8.80	22	8.89	13
Sample j	10.68	42	9.21	18	6.17	13	8.28	14	8.68	17	9.26	23
Coated	12.37	50	10.13	29	6.43	21	8.61	21	8.11	6	8.36	4
Sample k	9.90	18	9.32	19	5.88	8	8.30	15	8.40	8	8.66	7
Sample l	l0.31	34	8.82	8	6.27	16	8.71	24	8.79	21	8.75	9
Sample m	9.71	8	9.33	20	6.28	18	8.24	13	8.34	7	9.03	19
Sample n	10.83	43	9.18	16	6.61	25	8.45	18	9.06	25	9.39	26
Sample o	9.79	14	8.81	7	5.75	4	7.97	6	8.51	10	8.81	11
Sample p	10.42	38	9.78	26	6.68	26	8.75	25	9.18	26	9.40	27
Sample q	10.09	24	8.27	1	5.80	6	7.94	4	7.87	4	8.04	1
Sample r	9.52	3	8.70	4	5.97	10	8.52	20	8.85	23	9.07	20
Sample s	9.71	9	9.61	24	6.07	12	7.89	3	8.58	15	8.89	14
Sample t	9.82	15	8.94	9	6.18	14	8.63	22	8.57	12	8.71	8
Sample u	10.31	33	9.12	13	6.92	29	8.97	27	8.58	14	8.84	12
Sample v	10.03	21	8.59	3	6.00	11	8.36	16	8.71	18	8.95	16
Sample w	13.13	51	12.24	30	8.21	31	9.33	29	8.54	11	8.97	18
Sample x	10.04	23	8.73	6	6.36	20	8.15	11	8.06	5	8.33	3
Sample y	10.28	31	8.73	5	6.48	22	8.47	19	8.59	16	8.78	10
Sample z	11.05	48	9.18	15	6.35	19	8.36	17	8.85	24	9.27	24

II. The text measurements for the word "show" in mm² and the sheet ranking for the six ink-jet printers including over 50 sheets for the HP560C and 27-30 sheets for the other printers

of cyan, OD of magenta, OD of yellow, OD of black, and OD of composite black when applicable. Future evaluations will include image analysis (area, perimeter; and intensity) of the dots.

RESULTS AND DISCUSSION

The image analysis procedure described is the culmination of a two-year effort to characterize ink-jet print quality. Adjustments to this image analysis procedure occurred during the study. Most notable is the elimination of the composite black and the implementation of our own test target. These changes were a response to manufacturer's changes in inks and printers. The paper requirements for ink-jet printers have also changed. The parameters that affect print quality may vary from one printer manufacturer to another. We have also seen variation in paper requirements from one model to another for one printer manufacturer. This ever-changing world of the ink-jet printers presents the papermaker with a moving target for quality ink-jet performance. This paper provides a practical means to determine ink-jet quality.

This study evaluated 27 commercial papers comprising commodity and premium papers labeled specifically for ink-jet or as multi purpose including ink-jet. Evaluation of the 27 papers used six printers. An initial evaluation on the Hewlett Packard DeskJet 560C included more than 50 papers. Better understanding of the ink-jet requirements resulted in elimination of several multi use papers. A second aspect of this study has been an upgrade of the test target. For the Hewlett Packard DeskJet 560C and DeskJet 680C, the Hewlett Packard Target from the Hewlett Packard Paper Acceptance Criteria Second Edition for DeskJet 500C, 550C, and 560C printers was used in the evaluation *(9)*. The Hewlett Packard DeskJet 820Cxi and Canon or Epson printers do not support this print file. Figure 1 is therefore a test target that would be universal for all printers. The HP820Cxi text analysis used the second text passage for the evaluation—Courier New. Paper rankings for performance include each parameter. The six image analysis rankings are averaged for a total image analysis ranking, and the five or six OD (includes strike-through) rankings are averaged for a total value. The 27 papers evaluated are commodity (17 sheets), premium (9 sheets), or coated (1 sheet).

The diversity in printer performance is obvious in the variation in text measurements from the DeskJet 560C to the DeskJet 680C and

Paper	HP560C Cyan OD	HP560C Rank	HP680C Cyan OD	HP680C Rank	HP820Cxi Cyan OD	HP820Cxi Rank	Canon BJC 4000 Cyan OD	Canon BJC 4000 Rank	Epson Stylus Color Cyan OD	Epson Stylus Color Rank	Epson Stylus Color 500 Cyan OD	Epson Stylus Color 500 Rank
Sample a	1.28	7	1.20	4	1.24	5	1.13	12	1.05	4	1.16	4
Sample b	1.12	48	1.08	23	1.11	26	1.07	26	1.07	26	1.08	21
Sample c	1.12	47	1.05	28	1.10	28	1.11	19	0.92	22	1.07	22
Sample d	1.07	54	1.07	25	1.10	30	1.09	24	0.92	23	1.04	24
Sample e	1.16	30	1.01	31	1.09	31	1.04	27	0.88	26	0.98	26
Sample f	1.17	29	1.12	15	1.17	17	1.14	10	0.98	16	1.14	7
Sample g	1.25	11	1.14	9	1.24	7	1.16	6	0.97	19	1.11	16
Sample h	1.14	39	1.13	12	1.18	16	1.13	13	1.00	11	1.12	11
Sample i	1.17	27	1.16	6	1.19	12	1.12	15	1.00	8	1.12	10
Sample j	1.15	34	1.13	13	1.19	13	1.14	9	0.99	12	1.13	8
Coated	1.60	1	1.49	2	1.64	1	1.45	1	1.26	1	1.45	1
Sample k	1.15	36	1.14	8	1.16	23	1.10	21	0.97	17	1.12	12
Sample l	1.13	43	1.11	17	1.16	22	1.15	7	0.98	15	1.11	17
Sample m	1.22	13	1.11	20	1.16	21	1.10	20	0.96	20	1.09	20
Sample n	1.26	10	1.23	3	1.26	3	1.16	5	1.07	2	1.20	2
Sample o	1.13	41	1.09	22	1.17	18	1.14	8	0.96	21	1.10	19
Sample p	1.16	31	1.16	7	1.26	4	1.20	3	1.05	3	1.19	3
Sample q	1.19	25	1.02	29	1.10	29	1.01	29	0.85	27	0.97	27
Sample r	1.04	55	1.06	27	1.11	27	1.11	18	0.91	24	1.05	23
Sample s	1.15	35	1.12	16	1.18	15	1.08	25	0.99	14	1.11	15
Sample t	1.14	40	1.11	21	1.17	19	1.11	16	1.00	9	1.10	18
Sample u	1.09	51	1.11	19	1.17	20	1.14	11	1.00	10	1.12	13
Sample v	1.17	28	1.12	14	1.19	14	1.09	23	1.02	6	1.15	6
Sample w	1.09	50	1.11	18	1.16	24	1.13	14	0.99	13	1.12	14
Sample x	1.20	19	1.01	30	1.11	25	1.03	28	0.90	25	1.03	25
Sample y	1.13	42	1.17	5	1.22	9	1.16	4	1.03	5	1.15	5
Sample z	1.27	9	1.14	10	1.24	6	1.11	17	1.10	7	1.13	9

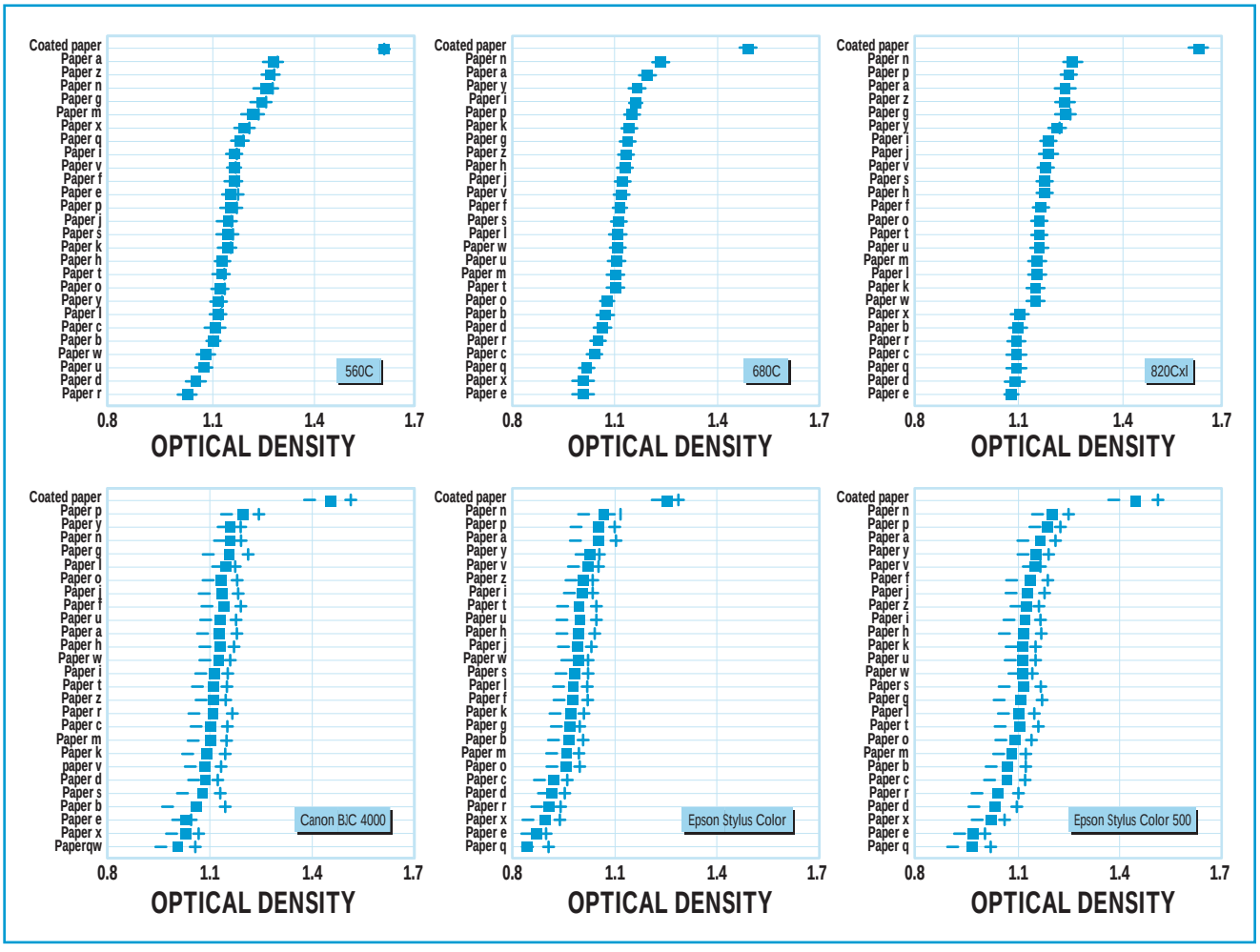
III. The OD measurements for the cyan blocks and the sheet ranking for the six ink-jet printers including over 50 sheets for the HP560C and 27-30 sheets for the other printers

820Cxi. The 500 series printers use a black ink based on dye. The 600 and 800 series printers use a pigmented black ink. There are drastic differences in the wicking and intensity of these two types of ink. For the 560C printer, the range of values obtained for the text area is 9.52-13.13 mm^2. This compares with 8.37-12.24 mm^2 for the HP680C. Smaller area gives sharper text. A large area indicates excessive wicking. While the spread of the values is similar, the total area is less for the pigmented ink.

The grouping of the data is more narrow for the pigmented ink. **Figure 8** gives graphs of the text area for the word "show" for the 560C, 680C, 820Cxi, Canon BJC4000, Epson Stylus Color, and Epson Stylus Color 500. **Table II** gives the ranking and area measurements of the text "show" for the six printers. Note that the 560C and 680C use the same font and print file. The 820Cxi uses a separate font, and the two Epsons and Canon use the same font and print file.

Space limitation prevents us from providing all the image analysis data and rankings of the 27 commercial papers on the six ink-jet printers. The data presented are some measurements to compare good and poor prints. Note also the variation in ranking from one printer to another. From the data in Table II, sample e has a text area of 9.42 mm^2 for a ranking of 2 in 51 sheets for the 560C printer. Sample e has a text area of 9.42 mm^2 with a ranking of 22 in 30 sheets for the 680C printer. Such variation also occurs when comparing performance in text quality to color intensity (OD). Sample b ranks 1 in text area and 3 in text perimeter area in 31 papers for the 820Cxi printer. The rankings for the OD of the black, cyan, magenta, and yellow squares are 26, 26, 29, and 29, respectively, in the 31 papers for the 820Cxi printer. This is a vexing situation because parameters that provide good text quality do not guarantee color performance. In addition, the ranking of ink-jet quality is difficult when the data fuses. From the data in Table II, the Epson Stylus Color printer has seven papers with average text areas of 8.51-8.59 mm^2.

The OD provides insight into color performance. Higher OD gives higher color intensity. **Table III** contains the OD measurements of the cyan blocks for the commercial sheets. **Figure 9** contains graphs of the cyan OD for the six printers. The variation in performance from one printer to another in the text measurements also occurred in the OD measurements. From the data in Table III, sample x has an average OD of 1.20 with a ranking of 19 in 51



9. Cyan OD values

sheets for the 560C printer. Sample x has an average OD of 1.01 and a ranking of 30 in 31 sheets for the 680C printer. The variation from one printer model to another is obvious in viewing OD. For the Epson Stylus Color printer, only the coated sheet had a cyan OD greater than 1.20. The average for the uncoated sheets is 0.98 density units. Compare this with the 820Cxi with six papers having cyan OD greater than 1.20 and an uncoated average of 1.17 density units. The black, cyan, and magenta squares provide the best differentiation in performance. The OD of the yellow square has a narrow range. The yellow OD range is only 0.17 density units for the 820Cxi printer (0.84-1.01) for the uncoated sheets with 16 of the sheets having OD of 0.86-0.92. There is a problem having a narrow range of data. The sheets ranked from 11 to 27 for yellow OD on the 820Cxi may be statistically equal within experimental error.

The total image analysis and OD rankings listed in **Table IV** demonstrate the difficulty in evaluating for ink-jet print quality. The image analysis ranking is the numerical average of the rankings for text area, text perimeter, text intensity, color-to-color bleed area, color-to-color bleed perimeter, and color-to-color bleed text intensity. The image analysis rankings for the Cannon and Epson printers also include dot area, dot perimeter, and dot intensity. The OD ranking is the numerical average of the OD rankings of the primary colors plus the strike-through measurement. A composite black ranking is included where applicable. A lower value of the overall ranking indicates a better total ink-jet print quality. From Table IV, it is apparent that clusters of papers have similar rankings. A second point from Table IV is the variation in performance of the papers in the two phases of the evaluation. For the 820Cxi printer, sample a ranks near the bottom in performance for image analysis but near the top in OD. Sample x, a premium paper, ranks near the bottom in performance for both image analysis and OD on the 820Cxi. Sample s, a commodity paper, ranks higher in OD performance than several premium papers for the 820Cxi printer.

CONCLUSIONS

Despite some clustering of data, the image analysis method described in this paper provides an objective

Paper	Type	HP560C IA	HP560C OD	HP680C IA	HP680C OD	HP820Cxi IA	HP820Cxi OD	Canon BJC 4000 IA	Canon BJC 4000 OD	Epson Stylus Color IA	Epson Stylus Color OD	Epson Stylus 500 Color IA	Epson Stylus 500 Color OD
Sample a	C	43.0	11.5	13.2	9.4	25.7	9.6	17.6	12.4	21.8	6.6	21.7	8.2
Sample b	C	34.0	34.0	17.8	25.4	17.0	27.2	11.0	22.6	9.6	20.8	11.2	22.6
Sample c	C	31.3	41.8	17.5	22.2	12.2	23.4	9.8	20.8	5.2	20.2	8.8	20.6
Sample d	C	27.8	48.8	8.2	16.8	12.7	22.4	14.8	22.0	11.3	20.2	12.3	19.8
Sample e	P	11.8	26.0	17.0	20.8	13.2	20.0	17.4	21.8	15.1	22.0	12.2	22.0
Sample f	P	19.0	31.8	10.0	18.2	14.0	19.0	8.3	11.6	17.9	14.6	15.0	12.8
Sample g	C	30.5	21.2	17.7	14.0	16.7	12.8	20.1	10.6	15.1	17.0	19.7	16.4
Sample h	C	27.8	29.3	18.8	12.0	18.5	17.2	20.3	14.0	14.1	14.0	15.3	13.2
Sample i	P	32.7	28.0	20.2	12.2	13.7	16.6	18.2	17.6	11.9	8.8	9.7	9.8
Sample j	C	32.3	38.3	15.7	19.4	12.7	18.2	18.6	13.2	12.8	15.0	16.9	14.8
Coated		25.5	2.7	13.8	6.0	16.7	2.8	8.6	1.8	1.9	1.0	1.7	1.6
Sample k	C	28.2	26.2	15.8	16.2	14.5	21.6	10.2	19.4	11.0	18.8	10.9	16.6
Sample l	P	31.8	37.5	13.0	18.4	16.8	16.0	14.2	11.8	17.2	15.0	10.9	12.4
Sample m	P	26.3	10.7	19.2	14.0	20.3	11.8	19.7	14.6	17.8	14.6	19.9	14.0
Sample n	C	40.3	18.8	21.0	13.0	21.8	8.8	15.7	9.8	18.2	7.2	17.4	7.4
Sample o	P	27.3	25.5	12.5	20.4	1.8	20.6	7.0	7.8	12.2	16.8	12.9	14.0
Sample p	C	40.2	29.2	26.5	13.8	20.0	8.0	20.8	7.0	21.9	7.2	24.4	6.6
Sample q	P	31.2	16.2	3.3	20.8	11.2	22.6	11.2	22.8	12.4	24.4	9.0	24.6
Sample r	P	22.5	49.0	14.5	22.4	11.7	23.4	15.2	18.2	18.0	19.4	17.4	19.4
Sample s	C	11.8	35.3	19.2	16.4	14.0	13.8	11.0	16.6	16.3	12.4	14.4	13.2
Sample t	C	23.3	33.7	13.7	18.0	11.8	18.0	15.8	19.8	10.0	12.6	8.0	14.8
Sample u	C	36.3	43.3	21.2	15.6	24.2	20.8	22.2	17.0	15.2	11.8	15.9	14.0
Sample v	C	32.7	26.5	7.5	15.4	15.7	15.4	18.8	17.8	13.2	9.2	13.8	9.8
Sample w	C	44.7	46.3	25.2	22.4	27.2	24.4	24.0	18.8	15.0	12.0	16.3	11.6
Sample x	P	27.0	24.5	11.3	23.0	21.3	18.8	17.8	19.8	13.4	21.2	13.4	19.6
Sample y	C	25.8	34.7	12.5	13.0	19.7	14.8	13.3	12.4	10.6	8.2	7.4	9.0
Sample z	C	38.8	13.3	12.2	10.8	14.3	7.6	22.1	14.2	18.8	7.0	21.3	9.2

IV. Total image analysis (IA) and OD rankings for the commercial papers on the six printers showing type of sheet as commodity (C) or premium (P). Smaller rankings equate to better print quality.

means for measure ink-jet print quality. The methods and ranking system allow analysis of prints from all ink-jet printers. This method like the printers is evolving. Ink-jet printers, inks, and papers are undergoing constant change. From the inception of this project, we understood that we were facing a moving target. The following statements highlight the flexibility of this method:

- The printer driver generates the print file used as a test target so that adding a new printer to the data base is as simple as obtaining the printer.
- The addition of new printers insures that the method is current. Maintaining older printer models means no neglect for the base installation of printers.
- By evaluating ink-jet performance on Epson, Canon, and Hewlett Packard printers, we have targeted more than 90% of the ink-jet printer market.
- The image analysis procedures provide a practical and simple means for objective determination of ink-jet print quality.
- The component design of the system allows for easy expansion.
- The ranking system provides a comparison of paper performance between brands of papers and between brands of printers.

As with any analytical technique, knowledge of the limitations of a method is essential for obtaining significant results. The finest uncoated paper will show variation in physical and performance properties throughout a ream or a case. For this reason, controls—paper of tight tolerances—require evaluation with every group of papers. Variation is also present in the printers and ink. Variation exists in print-head deterioration. A key advantage of image analysis is the identification of variations in paper performance over time. This would be difficult without the aid of computerized measurements.

This image analysis procedure is a current snapshot of a program that began more than two years ago. The initial emphasis was on meeting the print quality requirements established by Hewlett Packard. As the emphasis shifted to include other printers and color performance, the focus of our procedure also changed. We propose this image analysis procedure and performance ranking system as a practical method for the evaluation of ink-jet print quality. Future efforts will include applying the method to evaluating coated sheets. We may also examine the

parameters for their impact on performance. For example, strikethrough will be negligible on a coated sheet. Another factor under consideration is sheet brightness. In addition, we are still undecided about the best use of the photograph. It provides excellent differentiation between prints that the consumer can readily see. We will address these items. This procedure is practical and flexible and ready for the next generation of super inks or perfect paper. TJ

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Received for review April 23, 1997. Accepted Oct. 27, 1997.

Presented at the Delaware Valley TAPPI Full Day Conference.

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