Use of *Signature* Analysis to Discriminate Digital Printing Technologies

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Abstract

We describe the application of a machine-vision based (ImageXpert) print quality analyzer to derive and identify unique print quality "signatures". Test patterns generated by seven different state-of-the-art digital (ink jet and dry/liquid xerography) and impact (computer-to-plate offset lithography) printing technologies were quantitatively analyzed in terms of a statistically meaningful number of lines, half-tone dots and text features. In every case examined it is possible to resolve a unique print quality *signature* which enables differentiation of one printer technology/supplier from another. By this means we demonstrate the potential for definitive print analysis in the context of digital printing forensic document examination

Digital Printing Paradigm

Since Chester Carlson's discovery of xerography in 1938[1] and the subsequent introduction of the first commercial automated xerographic photocopier in 1960,[2] there has been a phenomenal growth in the development of non-impact printing technologies. Today, it is possible to purchase inexpensive colour ink jet and thermal dye diffusion transfer printers with amazingly high text and graphic print quality. Although of slightly lower resolution than impact printing technologies such as offset lithography, this gap is likely to narrow as relatively inexpensive, higher quality products become increasingly available to the general public. As an example Seiko Epson recently launched their next generation of piezoelectric ink jet printheads.[3] This latest commercial development centers around *variable-sized droplet technology* which enables ejection of three distinct ink drop volumes, viz., 3, 10 and 19 picoliters. In contrast mid-1980s commercial ink jet printers were based on droplet volumes of ~ 1000 picolitres. More recent developments in controlling the voltage waveform to drive a piezoelectric transducer[4] have disclosed the possibility of generating femtoliter drop volumes with current generation nozzle dimensions i.e. without imposing the practical constraints of designing even smaller nozzles.

These revolutionary improvements in relatively inexpensive printers have created burgeoning growth and improvements in print quality. Ready access to such technologies poses a serious challenge to many businesses and police forces because of the increasing likelihood of criminal actions such as removal of corporate intellectual property, fraud and counterfeiting.

In this paper we describe the results of a print quality assessment of several contemporary ink jet and xerographic printers. The potential for identifying a unique printer *signature*[*] and its use in digital printing forensics will be discussed.

Experimental

Printers

***Ink Jet Technology*:**

Bubble jet and piezotransducer-based printers used in this study included: HP Officejet Pro 1150C (360dpi print mode); Canon BJC-5100 (360dpi print mode); and Epson Stylus Color 740 (360dpi print mode). It should be emphasized that these ink jet printer models represent a random selection and that in the context of this study the results should not be interpreted as specifically endorsing one product over another.

Xerographic:

Printers selected for this study included dry toner based (Xerox DC40/600dpi, Xeikon DCP/32D/600dpi) and liquid toner based (Indigo E-print 1000/600dpi).

Offset Lithography (Computer-to-Plate):

For further comparison, test prints generated on a Heidelberg QuickmasterDI/>1016dpi were also included.

Print Quality Analysis:

Standard print test patterns were ink jet printed on Champion Ink Jet grade plain paper. For the other printers, a *standard* office bond paper recommended by the print manufacturer was used. Test patterns comprising line/dot/text/solids were evaluated with an ImageXpert print quality analyzer equipped with an automated motion-controlled x-y stage unit.[5] Selected ink jet print quality metrics[6] included: line width/raggedness and over-spray; dot roundness/perimeter and number of satellite drops. For the xerographic and lithographic printing technologies, image sharpness and image growth (positive versus negative prints) was used to discriminate subtle differences.

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[*] defined as distinguishing characteristic mark

Results and Discussion

Ink Jet Printing

Line Quality Evaluation:

Figure 1 shows a photomicrographic comparison of a 14pt character "i" for the selected ink jet printers. Distinguishable (left and right-handedness) features are clearly apparent.

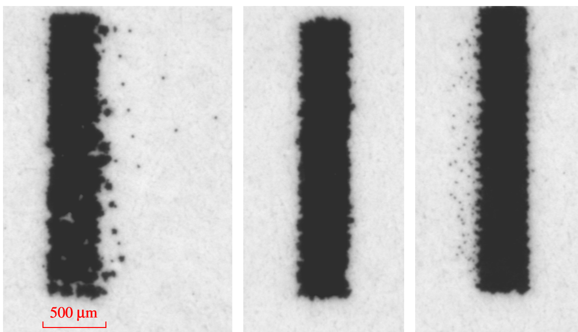

Figure 1. Photomicrographs of vertical line images printed on the same office paper with: a) Canon BJC-5100; b) Epson Stylus Color 740; and c) HP Office JetPro 1150C ink jet printers.

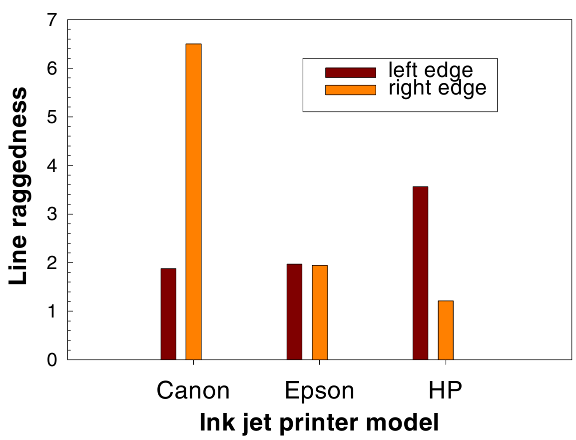

Figure 2. Variation in measured line raggedness (µm) vertical line (letter 'i') for different commercial ink jet printers.

Corresponding quantitative analysis of these images is shown in Figure 2 in terms of line raggedness. As far as discriminating *signatures* for the vertical 'i' line feature: 'HP' has the smoothest edge; (right-hand side); 'Canon' has the most ragged edge (right-hand side); and 'Epson' shows no difference between left- and right-hand edges. The origin for these differences is largely attributable to the degree of satellite drop generation, which provides the forensic scientist with a unique distinguishing *signature* feature to discriminate these printers.

A further discriminating line feature, image overspray/ smear, is defined in Figure 3. This measures the extraneous dots adjacent to the line, which, to the unaided eye, can contribute to an apparent image smear. Quantitative estimates of the extraneous dots in the adjacent regions (shown in Figure 3) are plotted in Figure 4. The results again show a clear distinction among the printers. Notably the Canon printer has the largest overspray population/extension whereas the Epson printer reveals no overspray beyond area 2.

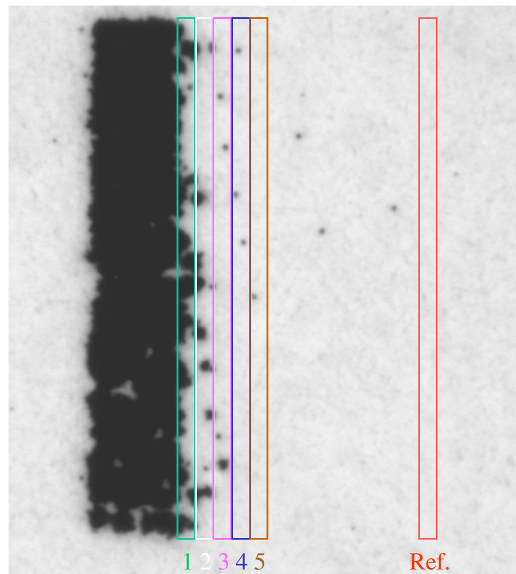

Figure 3. Definition of image overspray for a vertical line. The extraneous dots (overspray are measured in adjacent areas located at different distances from the line.

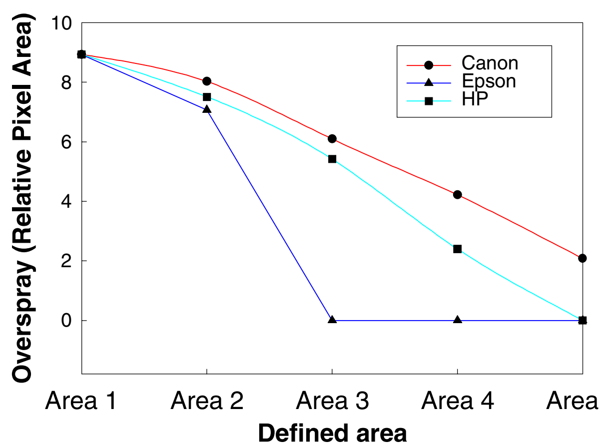

Figure 4. Variation in vertical line (image 'i') overspray for different commercial ink jet printers.

Dot Roundness:

Figure 5 shows comparative photomicrographs of ink dots for the three commercial ink jet printers. Quantitative analysis for these images is shown in Figures 6 and 7 for dot roundness and image background noise respectively. Among these ink jet printers, 'HP' reveals the highest dot roundness and lowest perimeter, whereas ‘Canon’ prints show the least round and most ragged dots. An additional discriminating image feature (which is apparent in Figure 5) is the image background noise caused by the presence of a uniform distribution of very small satellite ink droplets in the non-image area of a print. In Figure 7 this is quantified in terms of the number and average area of satellite drops adjacent to the image. Again, clear distinctions are apparent among the different images. The ‘Epson’ printer shows no drop satellites whereas the ‘Canon’ printer produces more, and larger, drop satellites than the ‘HP’ printer.

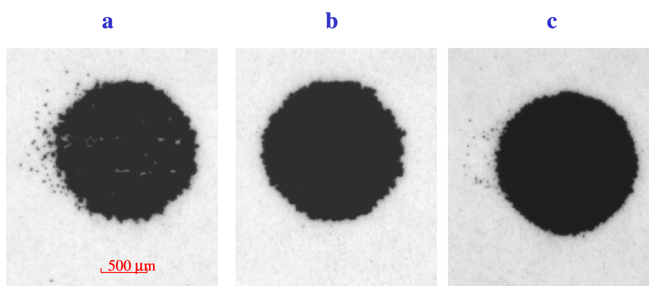

Figure 5. Photomicrographs showing text, dot of an “i” images, printed on the same office paper with: a) Canon BJC-5100; b) Epson Stylus Color 740; and c) HP Office JetPro 1150C ink jet printers.

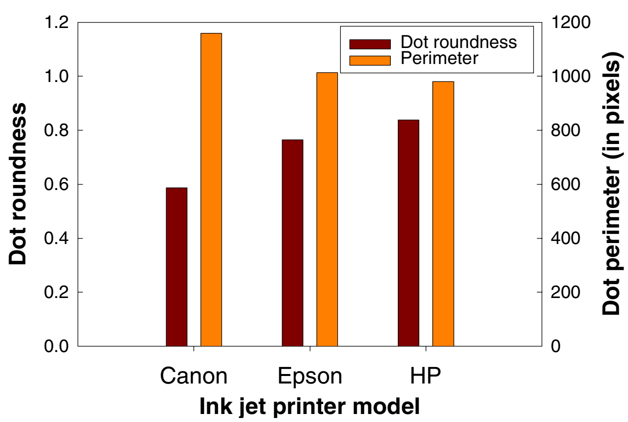

Figure 6. Variation in dot roundness and perimeter of the dot of an ‘i’ for commercial ink jet printers. Dot roundness is defined as the ratio of the perimeter of an equivalent circle (with its area equal to the area of the dot), to the perimeter of the actual dot.

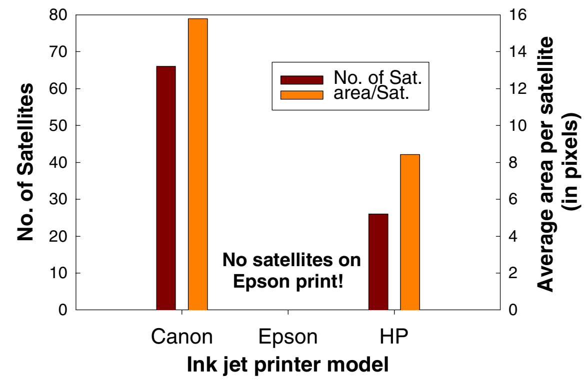

Figure 7. Variation in satellite drop population and area for the dot of an ‘i’ for different commercial ink jet printers.

Comparison of Other Digital Printing Technologies

Figures 8 and 9 show photomicrographs of the same print features generated on different state-of-the-art digital printing presses. These are based on dry xerographic, liquid xerographic and computer-to-plate offset lithographic technologies. For the dry xerographic images (Figure 8), closer inspection of a seraph feature reveals differences in the degree of fusing of individual toner particles. However Figure 9 shows less physical distinction between the liquid xerographic and offset lithographic images. As revealed in Figure 10, this can be mitigated somewhat by measuring the image sharpness,[1] which represents the transition region between the solid print and unprinted background. It is determined by measuring the average number of pixels orthogonally in the transition from dark to light pixels. On this basis offset lithography reveals the highest rise time value indicating the most blurred edges.

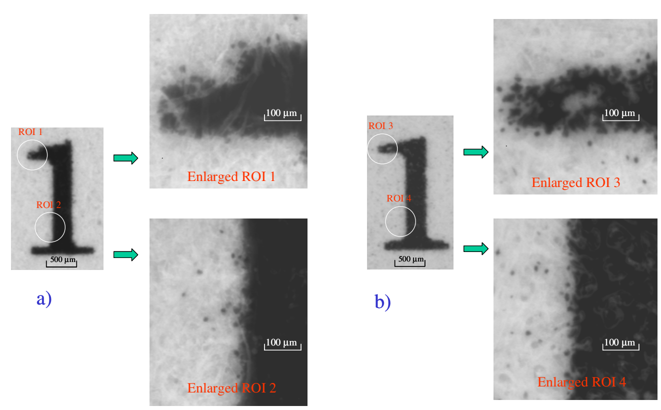

Figure 8. Comparison of dry xerographic print features for: a) Xeikon DCP/32D; and b) Xerox Docucolor 40.

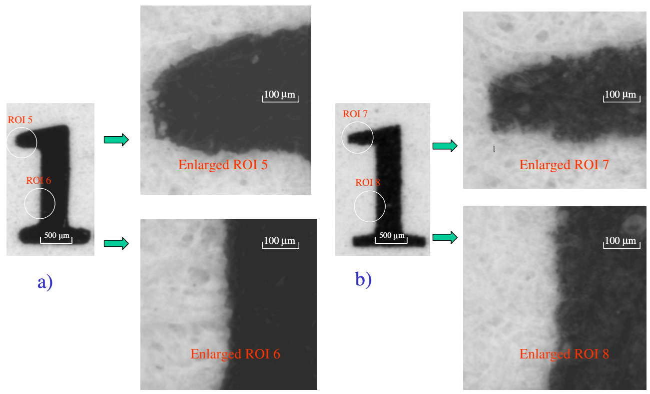

Figure 9. Comparison of digital print features: (a) liquid xerographic (Indigo E-print 1000); and b) computer-to-plate offset lithography (Heidelburg Quickmaster DI).

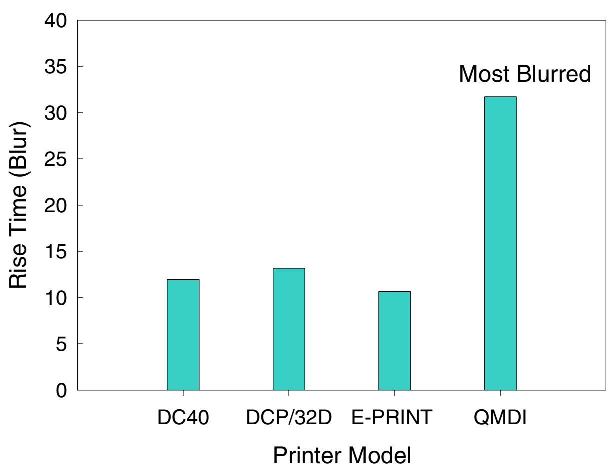

Figure 10. Variation in image sharpness for xerographic (dry and liquid) and offset lithographic printers.

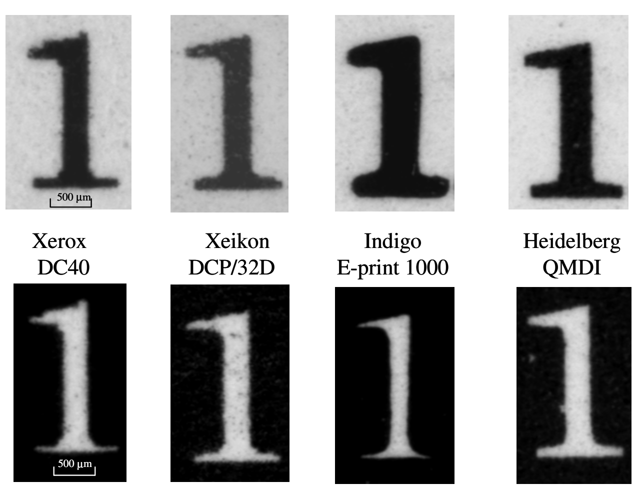

Figure 11. Comparison of positive (upper) and negative (lower) prints showing image growth in xerographic (dry and liquid) and offset lithographic images.

Finally, as illustrated in Figure 11 a more stressful test and discriminating measure for these printers is to compare image growth. The size of images developed on paper typically increases from its original size on the printing plate or photoreceptor. One means of measuring image growth is via area ratio, defined for the same font as, the area of the positive text image to the area of the negative text image. Corresponding results plotted in Figure 12 show that in this case the liquid xerographic image exhibits the most dot gain.

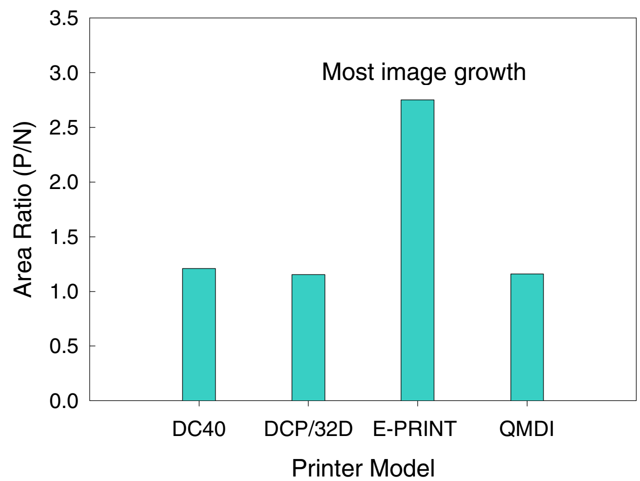

Figure 12. Variation in image growth expressed as the area ratio of positive (p) and negative (n) text images for xerographic (dry and liquid) and offset lithographic printers.

Conclusions

We have demonstrated that the ImageXpert® system, an automatic machine-vision based print quality analyzer, is a powerful means for document examiners and forensic scientists to differentiate one digital printing technology from another. Using a variety of image features and print quality metrics it is possible to identify distinctive, *signature* features, discriminating one ink jet printer model from another. Higher resolution xerographic and lithographic offset printers present more of a challenge for forensic examiners. However with judicious selection of appropriate metrics and print features it is possible to differentiate individual printers. If necessary, complementary analysis in paper, ink and toner chemistry can also provide supplemental evidence for the examiner.

Acknowledgements

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Biography

John Oliver received his PhD in Physical Chemistry (McGill University) in 1976, BSc Chemistry (Surrey University, UK) in 1968, and holds an adjunct professorship at the University of Alberta. He has published over 40 technical articles in his field and has co-authored 20 patents relating to specialty papers and inks for ink jet printing and xerography.

He joined the Alberta Research Council in 1997 as a Senior Research Officer prior to which he worked at Xerox Research Centre of Canada, studying ink-paper interaction fundamentals in ink jet and xerographic printing processes and development of specialty paper grades and novel inks.