Interpretation of Dot Area and Dot Shape of Inkjet Dots Based on Image Analysis

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Abstract

The dot fidelity of inkjet dots has been investigated for several different coated inkjet papers. Serafano and Pekarovicova have defined dot fidelity in terms of dot area and roundness. For inkjet printers, we can also define a nominal dot area and an "ideal" dot area, once the resolution of the printer is known. The nominal dot area is the area of the square pixel defined by the inverse of the resolution of the printer. The "ideal" dot area is defined as the area of the circle in which the square pixel can be inscribed. This is the smallest circular dot that will cover 100% of the area when all dot positions are printed. This pixel area is $\pi/2$ times the area of the square pixel. Thus, we can compare the actual printed dot size with both nominal and ideal dot sizes. This analysis provides a direct interpretation of dot gain, which can be compared with values obtained from densitometry. The dot areas observed in our laboratory varied between 1.25 and 13 times the ideal dot area, depending on the resolution of the printer and whether the coating was matte or glossy.

Introduction

Printed dot fidelity is an important component in image quality.[1] Image quality for a continuous tone grayscale image is determined by effective resolution of the image, the number of shades of gray that can be faithfully represented and the optical density of the darkest tone. The density of the darkest tone minus the density of the substrate determines the contrast of the image.[2] Color images consist of combinations of grayscale images of particular colors (Red, Green and Blue for displayed images and Cyan, Magenta, Yellow and Black for printed images).

For printed images, shades of gray are simulated by patterns of dots.[3] The dots may be of varying size on a rectangular grid as a conventional halftone[3-5] or a random, or stochastic, pattern.[3,4,6] Thus, once the contrast is characterized, the effective resolution is determined by the smallest dot that can be printed. The faithful reproduction of a large number of shades of gray depends on the ability to reproducibly print dots of the desired size and shape. Note that the effective resolution may be different from the stated (addressable) resolution of the device, since printed dots much larger than the spacing between addressed grid points preclude observation of fine detail on the scale of the grid.

Varying shapes of dots are employed in conventional halftones, including square, circular and elliptical.[7] However, for inkjet printers, the theoretical dot shape is circular, since the dots are obtained by impact with nucleated drops[8] that are spherical (in the absence of gravity) because of surface tension forces (even in the presence of gravity they must be circular in a cross-section perpendicular to gravity). Thus, the dot fidelity of ink jet dots can be measured by their nearness to circularity and how much their areas vary. In addition, we will see that it is insightful to compare the dot area with the nominal and ideal (defined in the next section) area determined by the printer's addressable resolution.

Theory

The digital representation of a continuous tone image consists of a rectangular array of square pixels. For printing, it is conventional to assign a resolution, in pixels per unit length, to the image. For example, a 4" by 3" image at 300 pixels per inch (ppi) is 1200 by 900 pixels. The area per pixel is just $1/ppl^2$, where ppl is the resolution. We call this the nominal area of a dot. For 300 ppi, the nominal, or pixel, area is 1.111 in^2 or 7168 $micron^2$ (μ^2).

Consider an image with exactly the nominal resolution of the printing device. If each square pixel in an image is 100% of the ink color, then the full image will be 100% of that color. Printing a circular dot with diameter less than the diagonal of the square pixel at every addressed point will necessarily leave some area uncovered. It is important for a solid area to be fully covered with ink to yield the darkest tone and hence the maximum contrast. The smallest area covering circular dot has a diameter equal to the diagonal of the square pixel (Figure 1). As seen in the Figure, it is just the circle into which the square can be inscribed. The radius of this sphere is

$$r = a/\sqrt{2} \tag{1}$$

where a = 1/ppl is the length of the side of the square. The corresponding area of the circular dot is

$$A = \pi r^2 = \pi a^2/2 \quad (2)$$

We define the ideal circular dot as one whose area is π/2 times that of the corresponding square pixel.

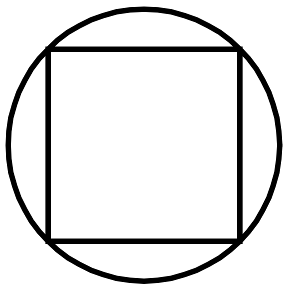

Figure 1. Illustration of ideal dot size showing a square pixel inscribed into a circle.

Results

The size and shape of inkjet dots depends significantly on the nature of the substrate, especially on the type of coating applied. Here, we present results of image analysis of dot fidelity for three different ink jet printers on two different matte coated papers. Results for glossy coated papers were presented elsewhere.[9] The printers used for the results reported here were a Hewlett Packard DeskJet 932C, an Epson Stylus Color 900 and a Canon S450. All are drop on demand[10] inkjet printers. The Hewlett Packard and Canon printers are Thermal inkjet printers and the Epson is a piezoelectric[10] inkjet printer. These printers are representative of desktop ink jet printers and samples printed on other printers by these manufacturers have yielded similar results in our studies.

Image analysis was aided by ImageXpert 9.1.4 from ImageXpert and Image Pro Plus 4.5 from Media Cybernetics. These consisted of microscopes and video cameras interfaced to computers with a framegrabber board. ImageXpert is Macintosh-based and Image Pro Plus is PC-based. We have generally found that the samples measured on either system give comparable results and software from each system can read and analyze images from the other system.

The results are summarized in Tables 1-6. The print pattern consisted of a square array of 36 x 36 dots on a 180 x 180 grid of pixels. With this spacing, dots seldom overlap, even though they may be much greater than the ideal size. The pattern was created with Adobe Photoshop and was printed for each of the four process colors, cyan, magenta, yellow and black. The pattern was printed at 300 dpi for all 3 printers and also at 600 dpi for the Hewlet Packard printer.

Care must be taken to choose settings in the printer driver so as to print single dots of pure color. Printing with pure black is especially problematic, since all of the printers tend to use a "4 color black" when black ink is specified, mixing dots of cyan, magenta, yellow and black when only black is specified. In order to "force" the printers to print with black ink only, the image was specified as a binary black and white image and specified to only use black ink. This was successful for the Canon and Epson printers, but not for the Hewlet Packard.

The dot roundness reported for the different cases is defined as

$$\text{roundness} = 4\pi A/p^2 \quad (3)$$

where A is the area of the dot and p is the perimeter or the dot. The roundness is equal to one for a circle and is less than one for any other closed figure. The closer to one the roundness, the better the quality of the dot.

Table 1. Dot Fidelity Data for the Canon Printer on Paper A.

Color	Dot Area (μ^2)	Area Standard Deviation (μ^2)	Roundness	Roundness standard deviation
Black	14700	4904	.516	.116
Cyan	14866	2455	.540	.138
Magenta	15797	1870	.557	.115
Yellow	15159	2290	.556	.072
Average	15131	3152	.539	.114

Table 2. Dot Fidelity Data for the Canon Printer on Paper C.

Color	Dot Area (μ^2)	Area Standard Deviation (μ^2)	Roundness	Roundness standard deviation
Black	14994	1596	.629	.075
Cyan	14702	2221	.616	.090
Magenta	14787	1457	.589	.073
Yellow	15494	1109	.689	.053
Average	14994	1684	.631	.085

Table 3. Dot Fidelity Data for the Epson Printer on Paper A.

Color	Dot Area (μ^2)	Area Standard Deviation (μ^2)	Roundness	Roundness standard deviation
Black	16135	2131	.509	.143
Cyan	13332	2591	.500	.132
Magenta	11437	2833	.492	.107
Yellow	12423	2808	.499	.147
Average	13332	3299	.500	.133

Table 4. Dot Fidelity Data for the Canon Printer on Paper C.

Dot Area (μ^2)	Area Standard Deviation (μ^2)	Roundness	Roundness standard deviation	Color
14677	1631	.627	.114	Black
11207	2039	.558	.121	Cyan
9174	2211	.495	.126	Magenta
9770	2274	.568	.120	Yellow
11207	3209	.562	.132	Average

Table 5. Dot Fidelity Data for the Hewlett Packard Printer on Paper A.

Color	Dot Area (μ^2)	Area Standard Deviation (μ^2)	Roundness	Roundness standard deviation
300dpi				
Cyan	13361	3040	.600	.117
Magenta	15504	1664	.749	.076
Yellow	18634	2087	.695	.133
Average	15833	3534	.681	.135
600dpi				
Cyan	4071	1068	.589	.168
Magenta	5256	1020	.564	.120
Yellow	5997	1061	.667	.124
Average	5108	1430	.607	.149

Table 6. Dot Fidelity Data for the Hewlett Packard Printer on Paper C.

Color	Dot Area (μ^2)	Area Standard Deviation (μ^2)	Roundness	Roundness standard deviation
300dpi				
Cyan	12165	2126	.675	.150
Magenta	13976	1307	.683	.104
Yellow	15789	1954	.820	.059
Average	13977	2575	.726	.138
600dpi				
Cyan	3720	876	.709	.105
Magenta	4543	769	.617	.130
Yellow	5291	860	.827	.090
Average	4518	1148	.718	.164

Paper C showed significantly better performance for all of the printers. The dots were smaller, rounder and with less variation than with paper A. In all cases, the dots were significantly larger than the ideal dot size of 11260μ^2 for 300 dpi and 2815μ^2 for 600 dpi. The average 300-dpi dots were 25% larger than the ideal size, while the 600-dpi dots were 71% larger than the ideal size. This trend holds for many more samples observed in our laboratory than reported here. The smaller the target dot size, the larger the size relative to the ideal size. The larger than ideal dot size reduces the effective resolution. Thus, the effective resolution is 268 dpi for the 300-dpi prints, while the effective resolution is 459 dpi for the 600-dpi prints, based the resolution for which the actual dot size is the ideal size.

As stated earlier, the dot behavior is highly dependant on the paper coating. Here we have discussed only (2) matte coated samples. Generally, glossy coated samples yield printed dots both rounder and larger than reported here. We previously reported roundness values on glossy coated papers as high as .93 [9] and have seen some unreported samples with roundness greater than .98, nearly perfect circles. However, the average dot area in our previous report for glossy papers was about 3 times the ideal dot area for 300 dpi and more than 13 times larger for 760 dpi.

Discussion and Conclusions

We have presented a discussion of dot fidelity for ink jet printer dots. We have introduced the concept of an ideal dot size based on the smallest area covering circular dot. Our analyses and interpretation are applicable to any printing process where the image quality is governed by the smallest printable dot. The methods reported here form the basis for evaluation of image quality for both coatings and printers in our laboratories.

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Biography

Dr Paul D. "Dan" Fleming III is Associate Professor in the Department of Paper and Printing Science and Engineering at Western Michigan University. He has a Ph.D. degree in Chemical Physics from Harvard University. His current research interests are in digital printing and imaging, color management and interactions of ink with substrates. He has over 100 publications and presentations and one US patent. He has over 32 years experience in industry and academia.