Shapes of Printed Dots and Image Quality

Shigeru Kitakubo, Yasushi Hoshino and Shi-Biao Xu
Nippon Institute of Technology
Miyashiro, Saitama, Japan

Abstract

In this paper, we compare electrophotographic printing and ink jet printing, observing the shape of printed dots or clusters of dots, and consider the factors which affect the uniformity of dot size. It is important to discuss the shape of printed dots because in the halftoning process, dispersed dots and clustered dots produce the mid-tone images. As the results of our experiment, it is clear that in the case of dots printed by electrophotographic method, the uniformity of the shape increases in proportion to the cluster size. On the other hand, in the ink jet printing method, the increase of uniformity is comparatively less obvious.

Introduction

Algorithms converting a continuous-tone image into a binary high quality image are important in non-impact printing field. A great number of digital halftoning algorithms have been presented. Recently, FM screening has been extensively studied. We proposed some new algorithms that include both AM and FM screening methods in 1995, and discussed the relation between the resolution of printer and the quality of printed image in 1996. We analyzed the error that could be produced by binarization process in 1997. In 1998 and 1999 we discussed the relationship between the minimum dot size and the print quality considering the human visual sensitivity. Last year we discuss the stability of the shape of minimum dots and the merits of clustered dots, and then propose a digital halftoning algorithm, which is a kind of combination of error diffusion and halftone screening.

In recent non-impact printing field, most printers print small dots to form each character or image. By arranging the location of dots, they can express every data such as characters, symbols, figures, and even continuous-tone pictures. We can say there are two groups of factors that affect print quality. One consists of the factors that have relation to printing software, for example, the algorithm of arranging the location of dots. The other consists of the factors that have relation to printing hardware, for example, dot size, accuracy of print position, and density of dots.

As mentioned above, two halftoning methods are widely used; one mainly uses dispersed dots, the other clustered dots. Each method has its own merit. When we discuss the application of these methods, dot size and its uniformity are important factor to be considered.

In the following, we describe the way to observe printed dots. Then we show the result of our experiment and discuss it. Finally we summarize the discussion.

Experimental

First we create some digital images of dots and then print them out. The digital images are created by an image-processing software. Seven different dot pattern images are made. They are an isolated dot, a cluster of two vertically adjacent dots, a cluster of two horizontally adjacent dots, a cluster of $2 \times 2 = 4$ dots, a cluster of $3 \times 3 = 9$ dots, a cluster of $4 \times 4 = 16$ dots, and a cluster of $5 \times 5 = 25$ dots. For each of these dot patterns, we make 100 different image data and print them out.

To print the digital data, we use two major printers and two major kinds of papers; a 300 dpi laser printer and plain papers, a 720 dpi ink jet printer and high quality papers for ink jet printers.

Each printed sample image is magnified optically and transferred as a digital image via a CCD camera into a computer. Then the shapes of dots are observed and size and brightness are measured. The optical recording devices are listed below:

Optical device:	TS-WH, optical microscope (c-mount) with a x5 object lens (Chuo Seiki).
Camera:	DFW-V300, CCD with IEEE 1394 interface (SONY).
Illumination:	HL-100E-LD, cold light with fiber (HOYA-SCOTT).

Cameras with IEEE 1394 interface can transfer uncompressed digital data of images with relatively less noise.

Results and Discussion

Pictures of printed dots by a laser printer and an ink jet printer are shown in Fig. 1 and Fig. 2, respectively. In Fig. 1(A) through (D), which are clusters of relatively small size, it can be seen that their edges or boundaries are vague. As the cluster size gets bigger, the shape of the cluster gets closer to its theoretical shape, which is rectangular. In Fig. 2, on the other hand, we can say the shapes of isolated dots are nearly rectangular, but they do not form a rectangular cluster if the cluster size gets bigger.

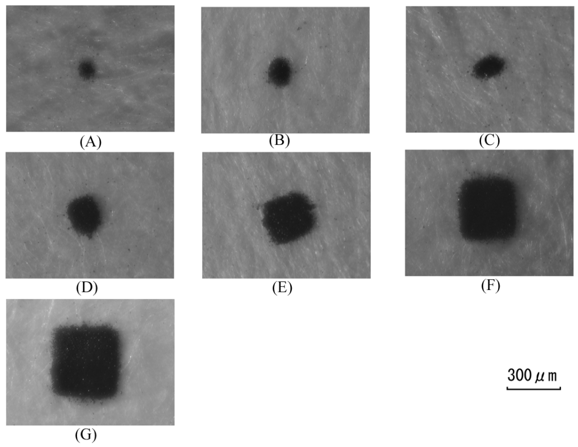

Figure 1. Magnified photos of dots printed by a laser printer. An isolated dot (A), two vertical dots (B), two horizontal dots (C), 2 × 2 dots (D), 3 × 3 dots (E), 4 × 4 dots (F), 5 × 5 dots (G)

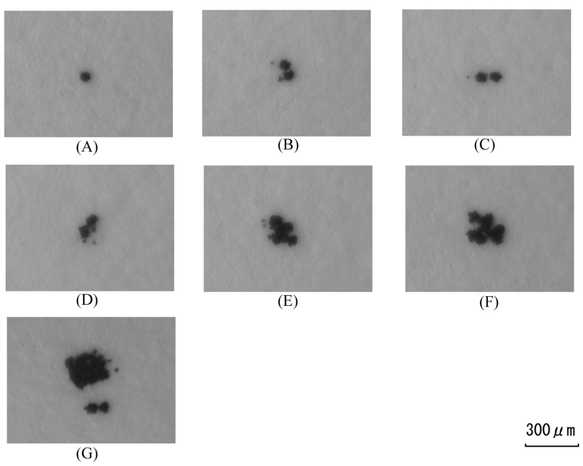

Figure 2. Magnified photos of dots printed by an ink jet printer. An isolated dot (A), two vertical dots (B), two horizontal dots (C), 2 × 2 dots (D), 3 × 3 dots (E), 4 × 4 dots (F), 5 × 5 dots (G).

Now we define the area of a cluster which will affects the printed image quality as follows:

When we look at the brightness histogram of pixels, we can tell the range of brightness values which corresponds to the cluster from the one that corresponds to the paper. Let [bc_0, bc_1] and [bp_0, bp_1] denote the ranges of brightness of pixels which correspond to the cluster and the paper, respectively, and bc_{max} and bp_{max} denote the brightness of highest frequency. We define the area of the cluster as the number of pixels which have brightness value lower than $(bc_{max} + bp_{max})/2$. Magnified images of an isolated dot and a cluster of 25 dots printed by a laser printer are shown in Fig. 3(A) and (B), respectively, and their brightness histograms in Fig. 3(C) and (D), respectively. We measured the sizes of 100 different images for each of two printing methods, laser and ink jet, and for each of the seven patterns, from an isolated dot through to a cluster of 25 dots.

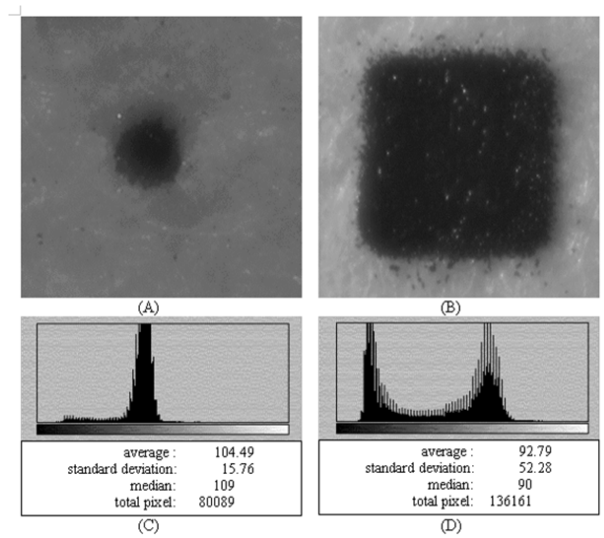

Figure 3. Magnified photos of dots printed by a laser printer and their brightness histograms. An isolated dot (A), and its brightness histogram (C), 5 × 5 dots (B), and its brightness histogram (D).

For each pattern, the average size μ and the variance σ^2 will be calculated as Eq. (1) and (2);

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i \quad , \qquad (1)$$

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N} (x_i - \mu) \quad , \qquad (2)$$

where N and x_i denotes the number of images and the cluster size of i-th image. The coefficient of variation V, which indicates relative uniformity of the cluster size, is calculated by

$$V = \frac{\sigma}{\mu} \quad . \qquad (3)$$

Values of average area μ, standard deviation σ, coefficient of variation V, maximum and minimum value of μ, and calculated and theoretical dot size are shown in Table 1, where $N = 100$.

Now we discuss the dependence of V on μ. When we look at Fig. 4(A), the case of the laser printer, V gets smaller as the cluster size gets bigger. In the case of the ink jet printer as in Fig. 4(B), the coefficients of variation are almost the same when the cluster consists of less than or equal to 3 × 3 = 9 dots. The value of V begins to decline when the cluster consists of more than 9 dots.

In the case of laser printer, it could be said from observations that the cluster size varies because the shape of edge is unstable. This may happen because the boundary of images in the development and transfer process inside printers tends to be affected by the noise from outside. Assume that the noise increases in proportion to the length of boundary of images. Then, for example, when a square cluster consists of $n \times n$ unit dots, the length of its boundary is $4n$, thus, as n increases, unstability of the shape of each dot will be weakened by the effect of clustering of dots and the coefficient of variation of cluster size will decrease.

Table 1. Observation results of several dot pattern; average area, standard deviation, coefficient of variation, maximum value of area, minimum value of area, and dot size (with theoretical value). Laser printer (A), and ink jet printer (B).

(A)

Dot Pattern	Average Area (pixels)	Standard Deviat'n (pixels)	Coeff. of Variat'n	Max. Value (pixels)
1	3435.5	354.5	0.103	4465
2(Vertical)	7742.7	572.6	0.074	8678
2(Horizontal)	7077.4	527.5	0.075	8510
2×2	14775.4	855.2	0.058	16798
3×3	28727.3	1467.9	0.051	32396
4×4	48260.2	1910.4	0.040	52599
5×5	70730.9	1387.7	0.020	73625

Dot Pattern	Min. Value (pixels)	Dot Size (μm×μm)	Dot Size Theoretical Value (μm×μm)
1	2566	90×90	85×85
2(Vertical)	6475	90×190	85×170
2(Horizontal)	6163	182×91	170×85
2×2	12861	186×186	169×169
3×3	24998	260×260	254×254
4×4	44654	337×337	339×339

(B)

Dot Pattern	Average Area (pixels)	Standard Deviat'n (pixels)	Coeff. of Variat'n	Max. Value (pixels)
1	1426.1	199.2	0.140	1856
2(Vertical)	2793.4	254.9	0.091	3275
2(Horizontal)	2247.4	432.1	0.192	3027
2×2	3738.3	575.6	0.154	4745
3×3	7061.0	879.3	0.125	8995
4×4	12547.6	892.5	0.071	14792
5×5	18942.8	1658.8	0.088	24365

Dot Pattern	Min. Value (pixels)	Dot Size (μm×μm)	Dot Size Theoretical Value (μm×μm)
1	1138	58×58	35×35
2(Vertical)	2269	57×115	35×70
2(Horizontal)	1623	103×51	70×35
2×2	2522	94×94	71×71
3×3	5686	129×129	106×106
4×4	10204	172×172	141×141

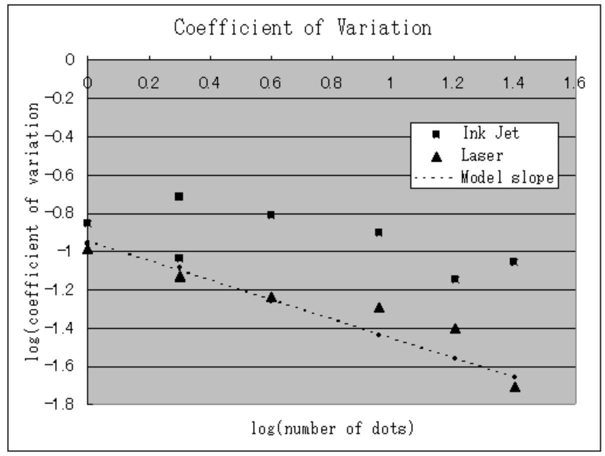

Figure 4. Comparison of the coefficient of variation of dot size; laser printer and ink jet printer. The model slope (---) indicates a model case in which the shape of a cluster is assumed to collapse only at its boundary.

In the case of ink jet printer, it could be said from observations that each isolated dot has high resolution and better tone reproductivity than that printed by a laser printer because the value of V is almost the same as that of an isolated dot printed by laser printer although the size is smaller. As the cluster size gets bigger, however, many of the dots are printed and overlapped at the unexpected location. This may happen because of the poor accuracy of print head handling process, of paper handling process, and of the unstability of ink ejecting direction. Assume that each dot is completely independent and no two dots have interaction. Then the standard deviation of dot size is in proportion to the square root of the number of dots, while the value of V, which is calculated by (standard deviation)/(number of dots), is in inverse proportion to the square root of the number of dots. From the observation, however, the decrease of V is relatively dull. This may happen because of the poor accuracy of some factors mentioned above in addition to the unstability of the dot shape that the dots themselves have.

Summary

Shapes and sizes of printed dots were observed from the viewpoint of investigating the variation of printed dots. A laser printer and an ink jet printer were used. As the result of our experiment it was clear that in the case of dots printed by electrophotographic method, the uniformity of the shape increased in proportion to the cluster size. On the other hand, in the ink jet printing method, the increase of the uniformity was comparatively less obvious. These results will supply some fundamental data to decide which halftoning method we should choose, dot clustering type or dot dispersing type. Moreover, it can be expected these data leads to the improvement of mage quality of printers.

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Biography

Kitakubo Shigeru is Assistant Professor of Nippon Institute of Technology. He gained Bs., Ms. and Dr. degrees from Tokyo Institute of Technology in 1986, 1988, and 1992, respectively. In 1993 he got a position at Nippon Institute of Technology. He participates in every NIP conferences since 1995. He is now interested in digital processing theory.