

Error Diffusion of Clustered Dots

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Abstract

In this paper we show some experimental results on evaluating print quality of binarized images. We investigate how much the print quality is influenced by minimum dot size of a printer, binarization method, and human visual sensitivity. Especially, we propose an extended halftone screening algorithm. In this algorithm the total sum of errors in one block is distributed to the neighboring blocks.

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 which 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 which 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.

Through these results, we recognized the importance of halftone screening method, which is one of the most widely-used binarization methods in printing and publishing industry. In this paper 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.

First we describe above-mentioned two conventional binarization methods and show some sample images. Second we mention the stability of printed dots, which is one of the motivation of considering the clustered dots. Third we propose an extended halftone screening algorithm and show some processed images, which can help us evaluate on the relation between cluster size and print quality. Finally we discuss the results.

Two Binarization Methods

In error diffusion method, the error produced as a result of a dot binarization is distributed with a certain ratio. The error distributed to adjacent dot is summed with the current value of the dot for determining the output value. In the conventional error diffusion algorithm, the modified input value of a dot is calculated from the input value and the error of adjacent dots.

In halftone screening method, the original image is divided into some rectangular regions. An average value of all dots is calculated in each region, and one big dot, or a cluster, is to be output in the center of the region. The size of the cluster is determined depending upon the average value. In this study, we call this rectangular region a cell, and we use eight cells of different sizes, from 1 × 1 pixel to 8 × 8 pixels.

Figure 1(a). "Gradation", 256 continuous tone

Figure 1(b). "Balloons", 256 continuous tone

Sample Images

As input images, we use two 256-level grayscale images as in Figure1. We call them "gradation" and "balloons", respectively. The size of "gradation" is originally 4096 × 1024 pixels, and "balloons" is 640 × 480. In the "gradation" the vertical line at the left side consists of the dots of value 255. The value gradually decreases as the line goes to the right. The vertical line at the right side consists of the dots of value 0.

Figure 2 illustrates the output images of these two images binarized by the conventional Floyd and Steinberg error diffusion algorithm (threshold = 128).

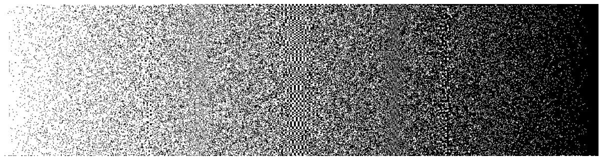

Figure 2(a). "Gradation", binarized by error diffusion

Figure 2(b). "Balloons", binarized by error diffusion

Stability of Dot Shapes

Generally, shape variation of dots printed by electro-photographic printers can not be ignored. Poor stability of dot reproduction leads to poor evaluation of print quality. It also causes unpredictable pattern, which can be objection-able. This is why we consider the stability of clustered dots.

Let us show some experimental results. Table 1 shows the variance of area of five kinds of clusters, each consists of 1, 4, 9, 16, and 25 dots, respectively. To calculate each variance, we observed ten sample images output by a 300 dpi laser printer. It is clear from this result that the bigger the cluster is, the stabler its printed image is.

Table 1. Average Area (AA), Standard Deviation (SD), and Coefficient of Variation (CV) of Clusters.

Cluster Size (Dots)	AA ($\times 2.69 um^2$)	SD	CV
1	1639	214	0.131
4	8255	531	0.064
9	19055	867	0.046
16	37935	1301	0.034
25	61080	1503	0.025

Figure 3 illustrates two micrographs. Figure 3(a) is a single dot and (b) is a cluster of 25 (= 5 × 5) dots. We can also see from these figures that the edge of the cluster in (b) is clearer than that of the dot in (a). As the resolution of printers has been getting higher, clustering is thought to be effective in getting stable printed images.

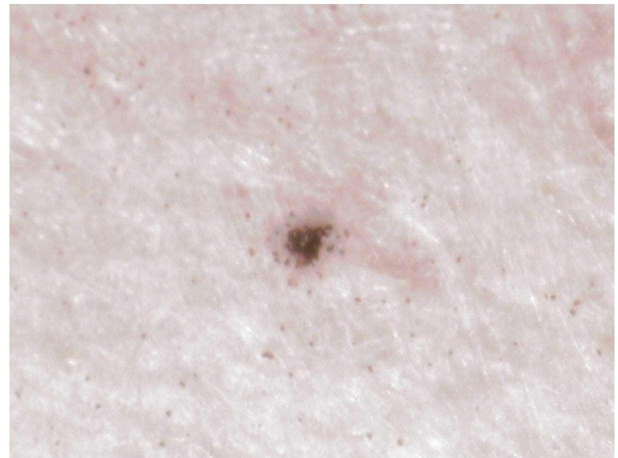

Figure 3(a). A single dot (×75)

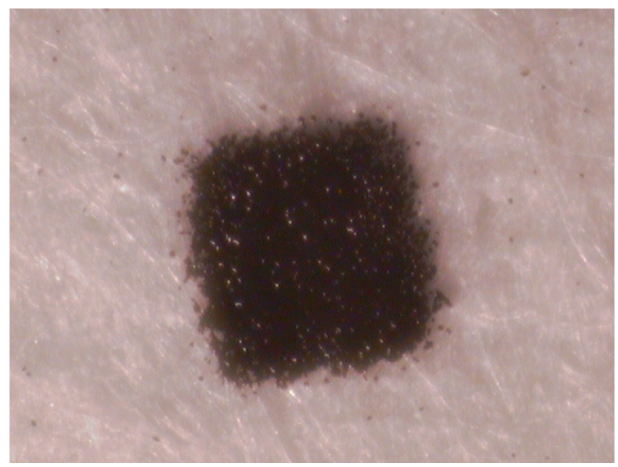

Figure 3(b). A cluster of 25 dots (×75)

Error Diffusion of Clusters

Here we describe how to distribute the error "cluster-wise". Suppose the size of cell used in halftone screening method is $n \times n$. First, binarize each pixel within the currently processed cell by applying halftone screening algorithm. Then the total sum of the $n \times n$ errors is to be distributed for a certain ratio to four neighboring cells, where the distribution ratio will be determined by the ratio of amount of errors which the current cell was given. Hence we can say this algorithm is the halftone screening with its error diffused.

Output images processed by this algorithm are shown in Figure 4(b), 5(b), and 9(b). For comparison, binarized images by the conventional halftone screening algorithm are shown in Figure 4(a), 5(a),.., 9(a). Note that our algorithm using 1 × 1 cell is almost the same as the conventional error diffusion algorithm.

Figure 4(a). "Gradation", conventional, 1 × 1 screen

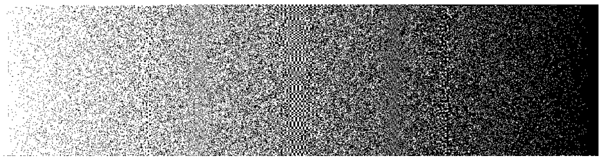

Figure 4(b). "Gradation", our alogorithm , 1 × 1 screen

Figure 5(a). "Balloons" , conventional, 1 × 1 screen

Figure 5(b). "Balloons" , our alogorithm , 1 × 1 screen

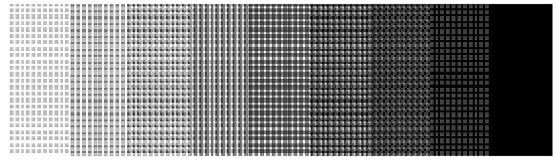

Figure 6(a). "Gradation", conventional, 3 × 3 screen

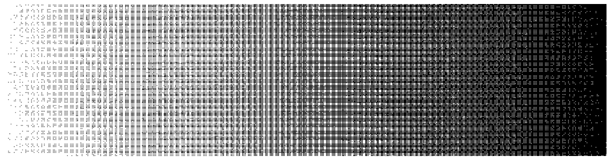

Figure 6(b). "Gradation", our alogorithm , 3 × 3 screen

Figure 7(a). "Balloons" conventional, 3 × 3 screen

Figure 7(b). "Balloons", our alogorithm , 3 × 3 screen

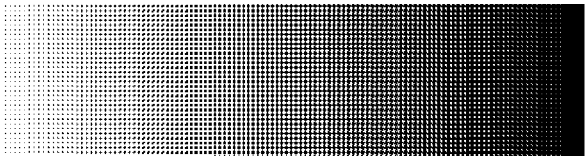

Figure 8(a). "Gradation", conventional, 5 × 5 screen

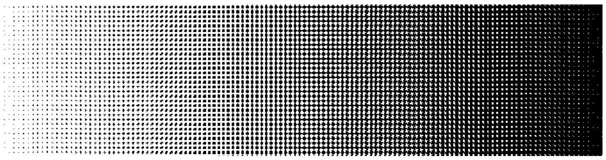

Figure 8(b). "Gradation", our alogorithm , 5 × 5 screen

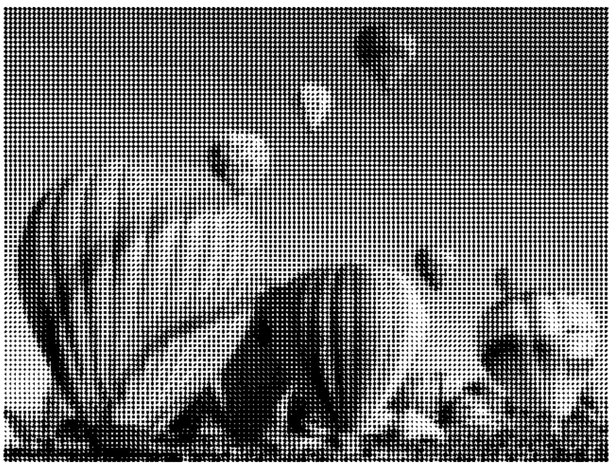

Figure 9(a). "Balloons" conventional, 5 × 5 screen

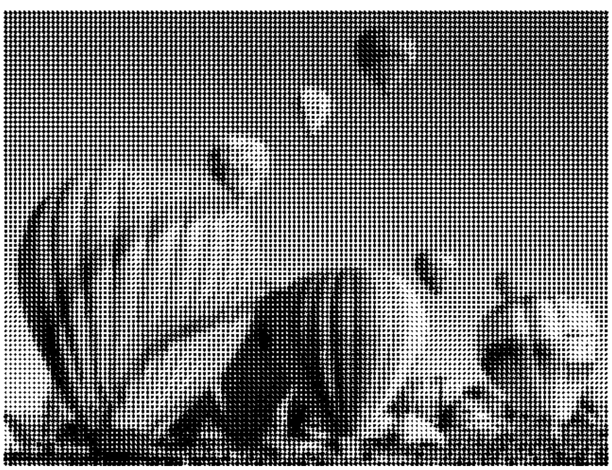

Figure 9(b). "Balloons", our alogorithm , 5 × 5 screen

Discussion

When we compare the quality of images in Figure 4 to 9, it is obvious that our algorithm inherits the merits of error diffusion. Particularly in the image in Figure 9(b), compared with the ones in Figure 2(b) and Figure 9(a), false contours in the sky part are diminished. We have suggested that the larger cluster can be printed more stably, and so we can expect the image in Figure 9(b) does not tend to have objectionable pattern even when it is printed many times.

We have given some opinion tests on these images about print quality, sharpness, tone reproductivity, and so on, but we still need to try our algorithm on other kind of images. We also need to investigate the ratio with which the errors are distributed.

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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 is now interested in digital processing theory. E-mail: kitakubo@nit.ac.jp

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