Dependence of Print Quality on Minimum Dot Size and Binarization Method II

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Abstract

In this paper we show some experimental results about print quality of binarized images. We investigate how much it is influenced by minimum dot size of a printer, binarization method, and human visual sensitivity.

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 includes both AM and FM screening method in 1995, and discussed the relation between the resolution of printer and the quality of output image in 1996. We analyzed the error which will be caused by binarization process in 1997.

The resolution of printers has been getting higher and higher these days. Thus, we have been studying the relation between minimum dot size and quality of printed binarized images, since 1998. It is also significant to consider the human visual system characteristics in order to determine the optimal resolution.

First we define two binarization methods and show some sample images. Second we describe subjective evaluations on the relation between the minimum dot size and the print quality. Then 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 distributed error 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 clustered dots, is to be output in the center of the region. The size of the big dot is determined according as the average value. In this study, the size of each region is 8 dots by 8 dots, so that we can express 65 different values in each region.

Sample Images

We prepare two original images. Both have 3840×1440 dots. We call one of them the “gradation” and the other the “eyes”. In the “gradation” the vertical line at the left side consists of the dots of value 255. The value gradually decreases as it goes to the right. The vertical line at the right side consists of the dots of value 0. In the “eyes” we can see a close-up of an owl’s face. This owl is called “Blakiston’s fish owl”.

We binarize these two original images by using each one of the two binarization methods described above. We use 900 dpi printer, whose minimum dot size is about 28 μm, for output. We want to compare images with various minimum dot size. When we get the image with twice larger minimum dot size, we shrink the original image in half size, binarize it, and output it in 450 dpi, so that we can get the same size output image as the original one.

Figure 1(a). “Gradation”, Error-diffusion, 900 dpi

Figure 1(b). “Gradation”, Error-diffusion, 300 dpi

Figure 1(c). “Gradation”, Error-diffusion, 180 dpi

In this way we get sample output images with the resolution 900, 450, 300, 225, 180, and 150 dpi. The variety of "gradation" are shown in Figure 1 and 2, while the variety of "eyes" are shown in Figure 3 and 4. Those in Figure 1 and 3 are binarized by error-diffusion method, while those in Figure 2 and 4 are binarized by halftone screening method. In Figure 1-4, (a), (b), and (c) are the outputs with resolution 900, 300, and 180 dpi, respectively. Note that we modified these images for publication and so they might not look correctly.

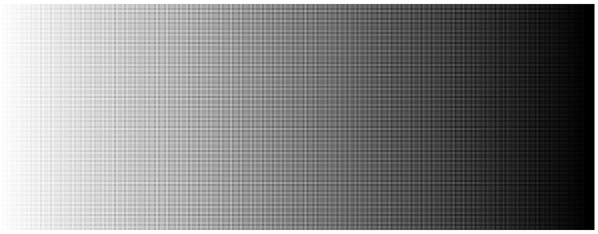

Figure 2(a). "Gradation", Halftone screening, 900 dpi

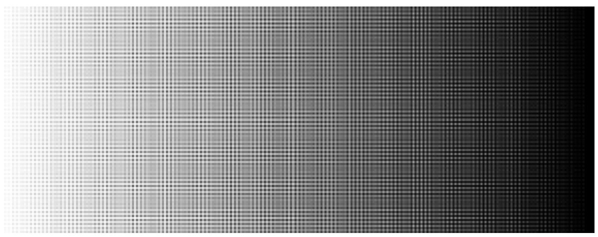

Figure 2(b). "Gradation", Halftone screening, 300 dpi

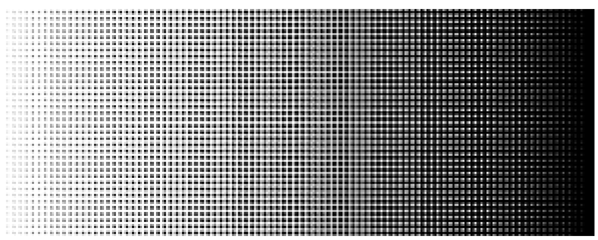

Figure 2(c). "Gradation", Halftone screening, 180 dpi

Opinion Tests

We prepare 24 sample images except the original ones, the number is calculated by 2×2×6 (two kinds of image, two binarization methods and six minimum dot size for output). We used the printer having high dot reproductivity, so we can assume the shape of each dot is almost a complete circle.

Figure 3(a). "Eyes", Error-diffusion, 900 dpi

Figure 3(b). "Eyes", Error-diffusion, 300 dpi

Figure 3(c). "Eyes", Error-diffusion, 180 dpi

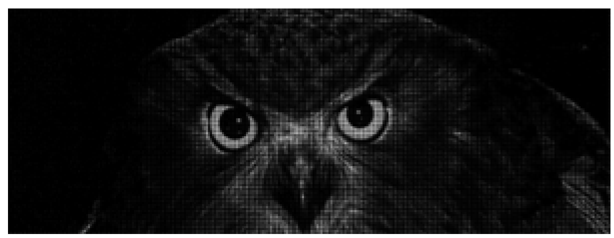

Figure 4(a). "Eyes", Halftone screening, 900 dpi

Figure 4(b). "Eyes", Halftone screening, 300 dpi

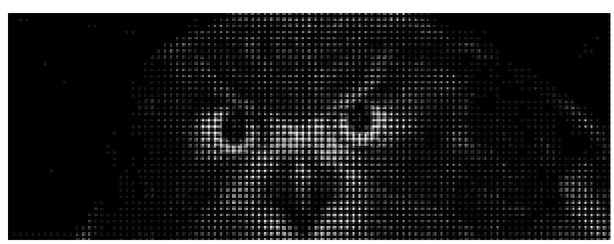

Figure 4(c). "Eyes", Halftone screening, 180 dpi

We asked several students to compare the original image with the binarized images. There were 4 items to be checked; print quality (total evaluation), sharpness, tone reproductivity, and objectionability of dots. One of the grades between 1 and 5 was assigned to every binarized image according as the following standard; 5: same as the original image, 4: almost the same, 3: difference can be perceived but good quality, 2: difference can be recognized, 1: obviously lower level. The results are shown in Table 1.

Table 1. Subjective Evaluation of Image Quality.

Img/Bin. Methd.	dpi	Prt.	Shp.	Tone	Obj.
Gradation/ Error-Diffusion	900	4.6		4.6	4.4
	450	4.8		4.8	4.4
	300	3.6		4	3.4
	225	2.8		3	2.2
	180	2.2		2	1.4
	150	1.8		2	1.4
Gradation/ Halftone Screening	900	4		4	4
	450	3.2		3.4	3.2
	300	2.6		2.8	2
	225	1.6		2	1.4
	180	1.4		1.2	1
	150	1.2		1	1
Eyes/ Error-Diffusion	900	4.8	4.8	4.6	5
	450	4.2	4.4	4.4	4
	300	3.6	3.4	3.4	3
	225	2.6	2.4	2.4	1.8
	180	2	2	1.8	1.6
	150	1.6	1.4	1.4	1.4
Eyes/ Halftone Screening	900	4.8	4.4	4.6	4.8
	450	4.2	3.8	3.6	4
	300	3.4	2.8	2.8	2.6
	225	2	1.6	2.2	1.6
	180	1.2	1.2	1.2	1
	150	1	1	1.2	1

Img/Bin. Methd.: Image and binarization method.
dpi : Resolution (dpi).
Prt. : Print quality.
Shp. : Sharpness.
Tone : Tone reproductivity.
Obj. : Objectionability of dots.

Discussion

Images binarized by error-diffusion method was evaluated higher than those by halftone screening method in almost all the items. In the "gradation" binarized by error-diffusion method, the evaluation drops sharply between 450 dpi and 300 dpi. This is because there appears an irregular pattern at the center of each image of resolution less than 450 dpi. In halftone screening case, on the other hand, the evaluation drops gradually according as the resolution decreases. We can say from these results that we feel more uncomfortable about small unpredictable noise than about regular pattern of dots.

Compared among the images binarized by halftone screening method, the "eyes" gains higher evaluation than the "gradation". This means we tend to notice dots in smooth images like the "gradation", but in "eyes" our attention will be attracted more to the eyes themselves than the dots in the eyes. In other words, information from an image may hide the smaller components in it.

There are comments about the "eyes" binarized by error-diffusion method that the small dots in and on the outline of the eye are very objectionable. We did not predict this but we think this is because our preconception about the well-known object, an eye. We know an eye so well that we may expect the clear-cut image.

In any case when the resolution is 900 dpi, almost all the students gave the grade 5. We can say from this fact that the "certain value" in our conjecture; "The two binarization methods , error-diffusion and halftone screening yields the same output image quality when the resolution of the printers are higher than a certain value", will be about 1000 dpi.

To support the sentence above, let us consider human visual system characteristics. Generally, human visual sensitivity for spatial frequency decreases sharply when the spatial frequency exceeds 2 dots/mm. This means human visual system can not perceive the higher frequency part of images. Thus we examine the range of spatial frequency that human eyes can perceive the core part of the information. The FFT output curve of a continuous-tone image and the human visual sensitivity curve for spatial frequency are shown in Figure 5. The FFT output curves look almost the same in the part where frequency is less than 100 Hz when we analyze one of an continuous-tone image, a binarized image by error-diffusion method, and a binarized image by halftone screening method. By applying human visual sensitivity curves, a pattern which has this frequency can be recognized well when the minimum dot size is 40 μm. But it can hardly be perceived when the resolution is higher.

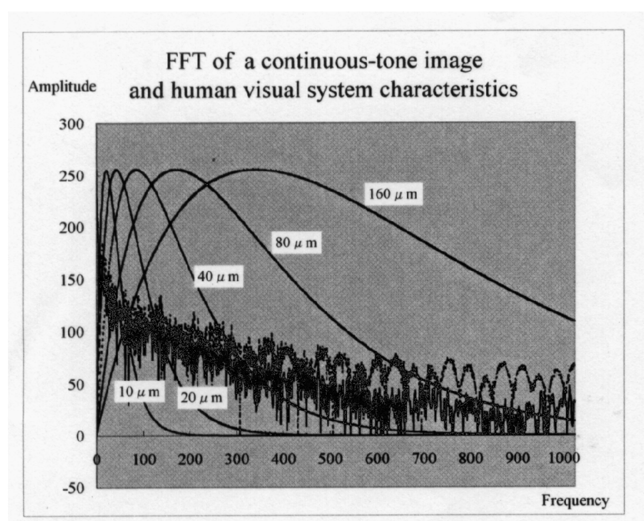

Figure 5. Spatial frequency of a continuous-tone image and visual system characteristics

As mentioned above, minimum dot size of a 900 dpi printer is about 28 μm, that is why we do not see a big difference between the two binarization methods.

Conclusion

By doing opinion tests, we could conjecture again that the two binarization methods , error-diffusion and halftone screening, yields the same output image quality when the resolution of the printers are higher than certain value. We also felt the meaning of an image will be transmitted from our eyes to the brain more strongly than information about the dots. It will be necessary to study human visual characteristics and the function of our brain system further.

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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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