Dependence of Print Quality on Minimum Dot Size and Binarization Method

Shigeru Kitakubo and Yasushi Hoshino
Nippon Institute of Technology,
Miyashiro, Saitama, Japan

Abstract

In this paper we investigate the relation between the minimum dot size of a printer and print quality of binarized images based on 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. The smaller the minimum dot size of a printer becomes, the more dots can be used to express a value, brightness or density, of a pixel. We examine the relation between the minimum dot size and the quality of binarized images printed with that dot size. When we predict the higher resolution case, we consider the human visual system characteristics.

At 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 analize the results.

Two Binarization Methods

In the 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. We show the printed image of the original image, which was one of SHIPP (Satndard High Precision Picture data) copyright-protected by IIEEJ (The Institute of Image Electronics Engineers of Japan) and was halftoned to gray 256 continuous-tone, in Figure 1, and the binarized image by the error-diffusion method, each dot of which has a value of either 0 or 255, in Figure 2. The size of these images is 2048×2048 dots, and both are printed in 600 dpi.

Figure 1. Original image

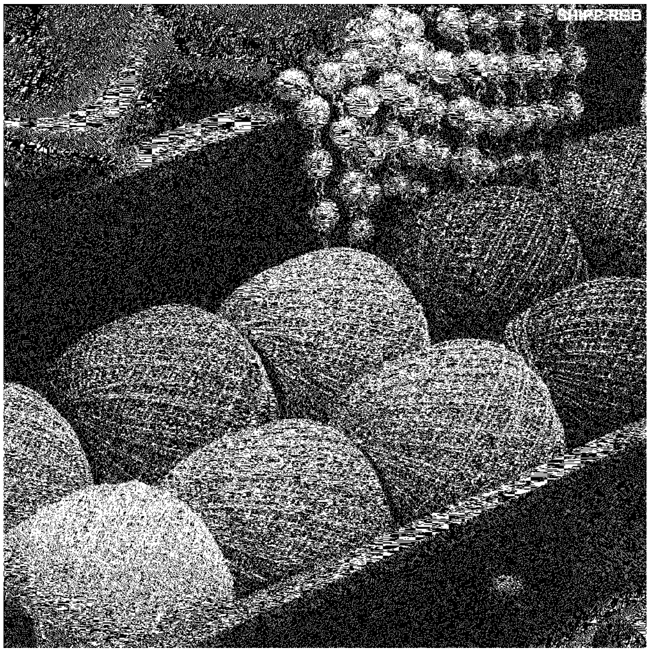

Figure 2. Error-diffusion

In the halftone screening method, a threshold matrix is used. A value of each dot is compared with the corresponding value of matrix for determining the output value. In the conventional halftone method, the value of the entries around the center are higher than the rest of the entries so that the output dots tend to cluster and form one big dot within the size of the threshold matrix. Figure 3 shows the binarized image by halftone screening method.

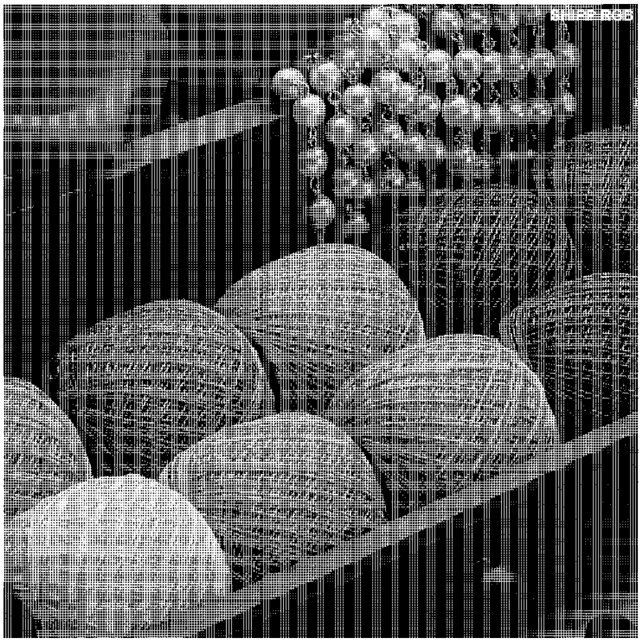

Figure 3. Halftone screening

Figure 4. Error-diffusion, 300 dpi

Subjective Evaluation of Image Quality

We evaluate the quality of those three images shown in Figure 1, 2, and 3. Our purpose in this section is to investigate the relation between the minimum dot size and the print quality. If an image is printed by a 600 dpi printer, the minimum dot size of this printed image is about 43 μm. First we show some sample images when the minimum dot size is bigger. We show an image with 1024×1024 dots binarized by error-diffusion method and printed by 300 dpi in Figure 4, halftone screening method in Figure 5, respectively. Moreover , images with 512×512 dots and printed by 150 dpi are shown in Figure 6 and 7.

When we evaluate an image quality printed in higher resolution, we must also take the reproductivity of the shape of dots into consideration. Whether the dots are in ideal shape, for example, complete circle, or not is quite a question. We want to leave this as a future task. To avoid this question, we observed the image on a computer display instead of evaluating printed images of several resolution. We virturally realized the variation of dot size by changing the distance from our eyes to the display.

We watched a 72 dpi image on the display from 30 cm, 1.5m, and 6 m away from it. These view corresponds to three images printed in 72 dpi, 360 dpi, and 1440 dpi, respectively with the distance of 30 cm from our eyes. We used three kinds of images: 256 continuous-tone, binarized by error-diffusion method, and binarized by halftone screening method. The results are shown in Table 1. Each number means the quality level compared with the grayscale image such as; 5: same level, 4: almost the same, 3: difference can be perceived but good quality level, 2: difference can be recognized, 1: obviously lower level. Note that in 30 cm – Error-diffusion case, image quality is between 3 and 4, that is , difference can hardly be perceived, but some objectionable pattern can be recognized in the image.

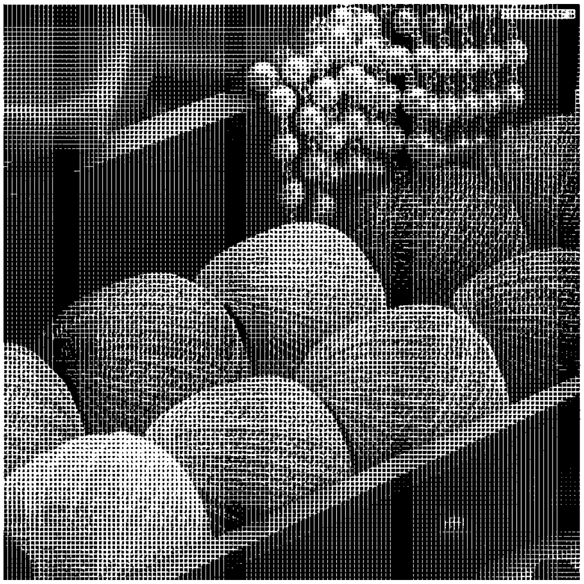

Figure 5. Halftone screening, 300dpi

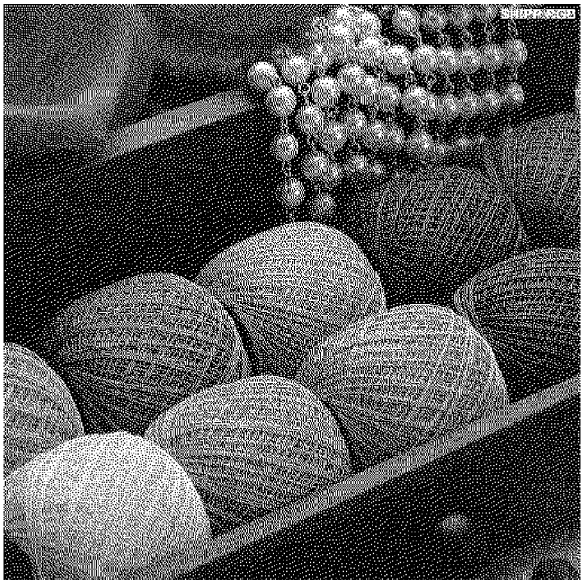

Figure 6. Error-diffusion, 150 dpi

Discussion

We can predict that the smaller the minimum dot size becomes, the less difference can be perceived among the images binarized by either one of these two methods.

Let us consider human visual system characteristics. Generally, human visual sensitivity for spacial 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 amount of information, the range of spacial frequency, that is necessary for human eyes to perceive the core part of the information.

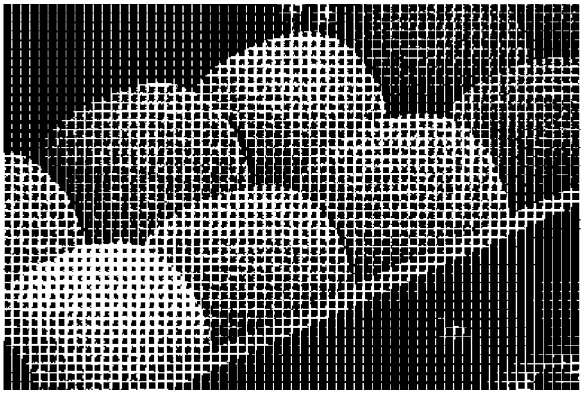

Figure 7. Halftone screening, 150 dpi

We analyze the spatial frequency of images by using the discrete Fourier transform. As a computer program, we used FFT (Fast Fourier transform). We add human visual sensitivity curve for spatial frequency over the FFT output. The FFT outputs of the three images, which were in Figure 1, 2, and 3, are shown in Figure 8, 9, and 10, respectively.

We can convert the value along the axis of frequency to the number of dots in the followin manner. In Figure 8, for example, a “80 µm” curve has its peak around 200 in frequency. Roughly, “frequency 200” in horizontal frequency part corresponds to the existence of lateral stripes whose width equal to about 5 (=1024/200) times miminum dot size. When the minimum dot size is 80 µm, human eyes recognizes a dot with diameter 5*80=400 µm. This value is equivalent to 2.5 dots/mm and is considered reasonable for the peak of human visual sensitivity. This curve is expressed by the equation:

$$Amplitude=255*5.05*EXP(-138*1.30903*f/2048)$$

$$*(1-EXP(-130.903*f/2048)) \qquad (1)$$

The shapes of FFT output curves in Figure 8, 9, and 10 seems almost the same in the part where frequency is less than 100 cycles per 2048 dots. By applying human visual sensitivity curves, a pattern in a image which has this frequency can be recognized well when the minimum dot size is 40 µm. As the resolution becomes higher, or minimum dot size becomes smaller, this pattern becomes hard to perceive by our eyes. Particularly, when the minimum dot size is 10 µm, high frequency part, higher than 100 cycles per 2048 dots, can hardly be perceived. This meets the result in Table 1 when the distance is 6 m (1440 dpi = 17.6 µm/dot), quality of three images seemed to have no difference.

Table 1. Subjective Evaluation of Image Quality.

Distance/ Image	30 cm (72 dpi)	1.5 m (360 dpi)	6 m (1440dpi)
Grayscale	--	--	--
Error-diffusion	3 - 4	≈ 4	≈5
Halftone screening	≈ 3	3 - 4	≈5

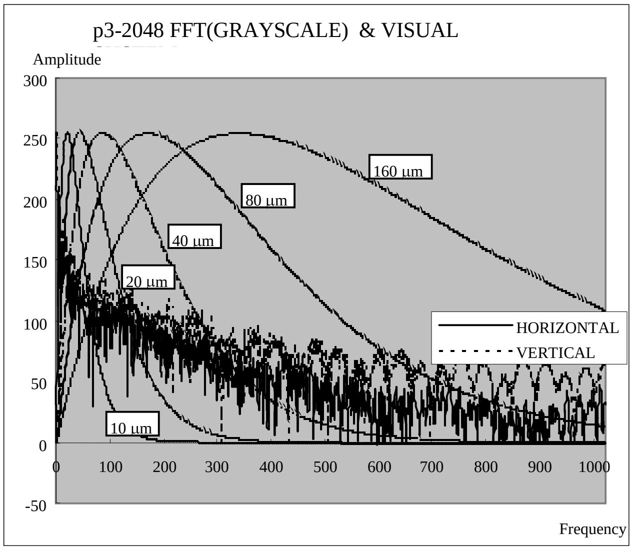

Figure 8. Spatial frequency (256 continuous tone) and visual system characteristics

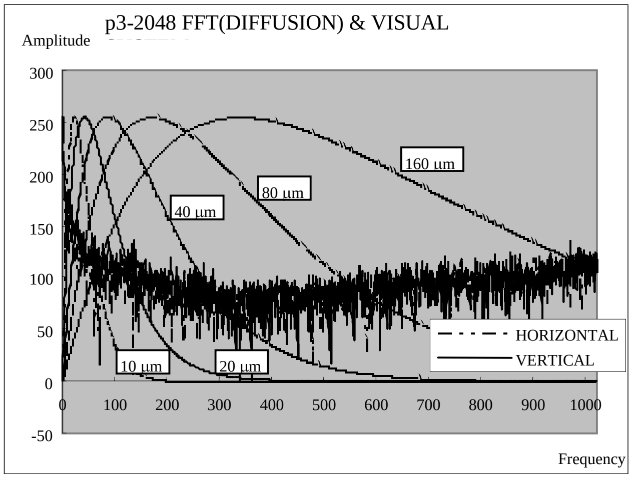

Figure 9. Spatial frequency (Error-diffusion) and visual system characteristics

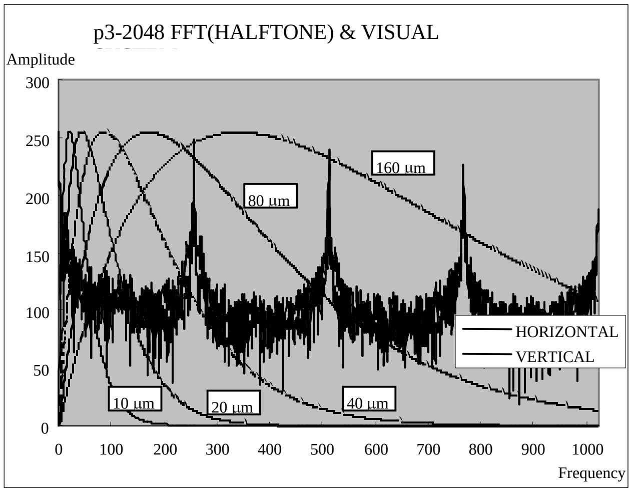

Figure 10. Spatial frequency (Halftone screening) and visual system characteristics

Considering the sampling theory, a half of the range of frequency that can be perceived is enough as information for us to perceive the core part of an image. Thus, when we use a 1440 dpi printer, we can perceive the core part of the original image if the image data has the same frequency part of less than 50-100 cycles per 2048 dots as the original one. In case of our sample image, either of two conventional binarization methods preserves sufficient information for the original image data.

Human brain system has, however, some kind of function to adjust the spatial frequency sensitivity of images perceived through the eyes. We seem to perceive the automatically corrected images. This is to be left as a future problem.

Conclusion

We made several images having several resolution, and evaluated the quality subjectively. Then we discussed the result of evaluation from the viewpoint of frequency analysis. As a summary, we conjecture that the two binarization methods, errror-diffusion and halftone screening, yields the same output image quality when the resolution of the printers are higher than a certain value.

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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

Hoshino Yasushi is Professor of Nippon Institute of Technology. He gained Bs., Ms. and Dr. degrees from University of Tokyo, 1970, 1972, and 1984 respectively. After he gained Ms. degree, he joined Electrical Communication Laboratories of NTT and developed LED printer firstly, high speed laser printer, color laser printer by using ultra elliptical laser beam scanning, photo-induced tonning technology and ion flow printing. He moved to Nippon Institute of Technology on 1994. He published more than 20 papers and several papers also in IS&T's Journal. He attended almost NIP congresses. E-mail: hoshino@nit.ac.jp