Relation Between Some Characteristics on Errors Caused by Binarizations and Print Quality

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Abstract

In this paper, errors produced by a binarization are analyzed by using the discrete Fourier transform. Some items such as binarization methods, resolutions, and human visual system characteristics are discussed in terms of the error.

Introduction

Halftoning, or converting a continuous-tone image into a binary image, has been studied in non-impact printing field. However, evaluating the quality of the binarized image objectively is still difficult because human visual system characteristics are too complicated.

There are many factors which will influence on the quality of binarized image. In this paper we consider the following three factors; 1) the kind of binarization methods, 2) resolutions of binarized images, 3) characteristics of the spatial frequency of errors produced by binarizations. We discuss the relation between 3) and 1), and between 3) and 2). We also consider human visual system characteristics. We define an error of a dot produced by a binarization as the difference of the output value of the dot from the input value throughout this paper.

Binarization Methods

We consider two well-known binarization methods, that is, the error-diffusion methods and the halftone 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 original image which has 256 continuous-tone value in Fig.1, and the binarized image by the error-diffusion method, each dot of which has a value of either 0 or 255, in Fig. 2. The size of these images is 128 × 128 dots, and both are printed in 72 dpi.

In the halftone 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. Fig. 3 shows the binarized image by halftone method.

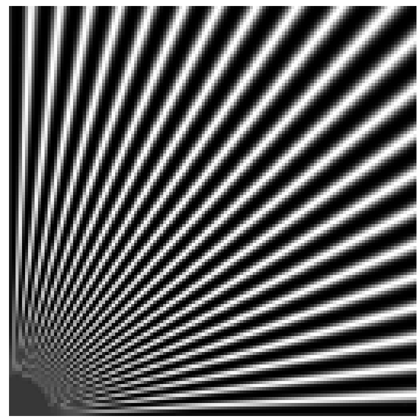

Figure 1. Original Image

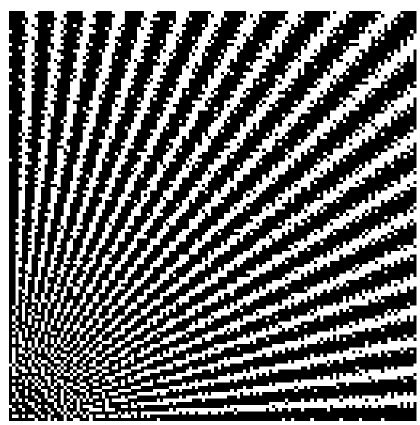

Figure 2. Error-Diffusion

Resolution of the Output

Let n be the ratio of the resolution of the ouput image for that of the input image. This means the value, or brightness, of each dot in input image is expressed by using $n \times n$ dots in the output image. Theoretically, the more dots are used to express one dot in the input image, the less the average error will be. To select an adequate resolution is important especially when the goal is to get a hard copy image printed by a printer. We select two resolutions, 288 dpi and 576 dpi, considering the resolution of laser printers generally used now. Fig.

4(a) shows the binarized image with 4 times higher resolution, 288 dpi, than the original image, 72 dpi. The binarization method used here is the error-diffusion method. Fig. 4(b) shows a part of Fig. 4(a) printed in 72 dpi. Both images cover same area, thus the part printed in Fig. 4(b) is one sixteenth of Fig. 4(a). Fig. 5(a) and Fig. 5(b) are the cases of 8 times higher than the original. Fig. 6 and Fig. 7 are the cases of halftone method corresponding to Fig. 4 and Fig. 5, respectively.

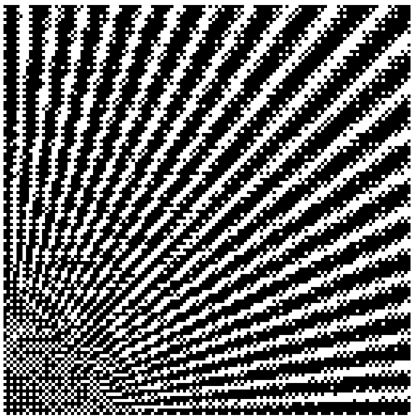

Figure 3. Halftone

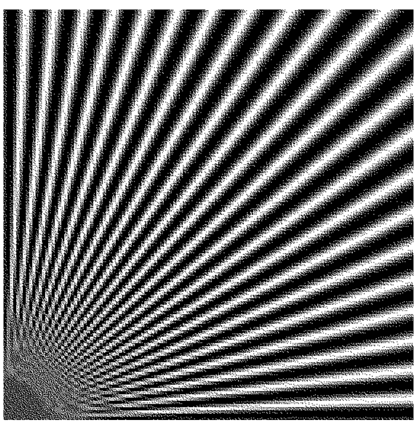

Figure 4(a). 288dpi, Error-Diffusion

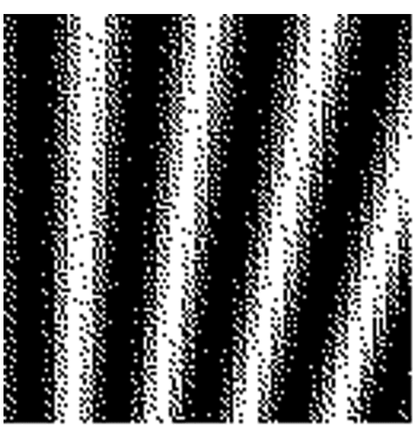

Figure 4(b). 72dpi, Upper-left part of Fig. 4(a).(×4)

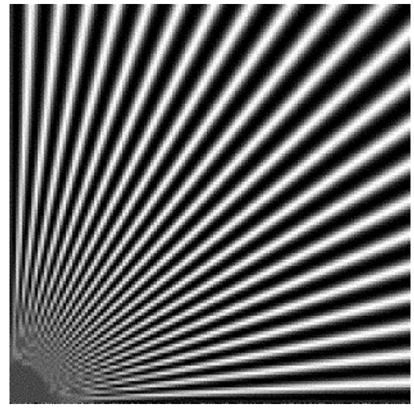

Figure 5(a).576dpi, Error-Diffusion

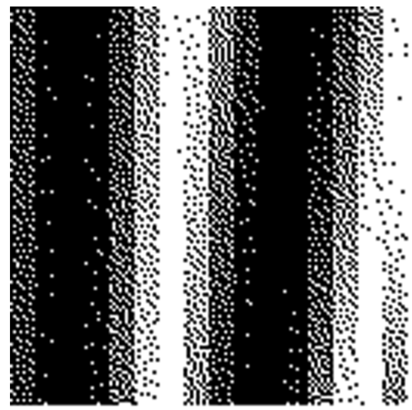

Figure 5(b). 72dpi, Upper-left part of Fig. 5(a).(×8)

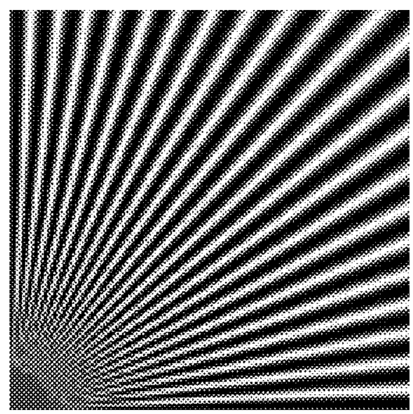

Figure 6(a). 288dpi, Halftone

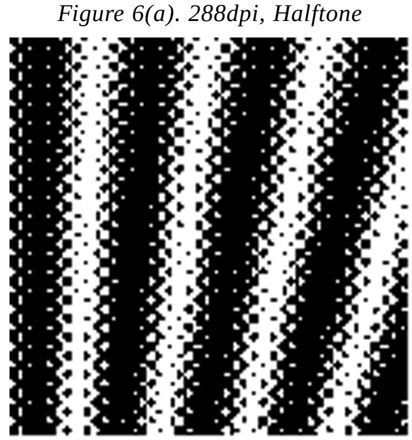

Figure 6(b). 72dpi, Upper-left part of Fig. 6(a).(×4)

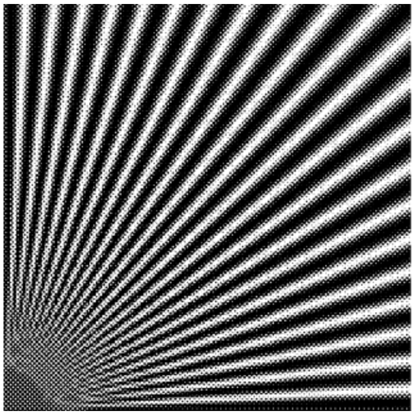

Figure 7(a). 576dpi, Halftone

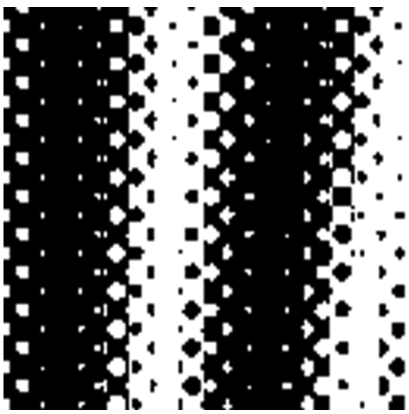

Figure 7(b). 72dpi, Upper-left part of Fig. 7(a).(×8)

Spatial Frequency

Let I, O, and E be dot value matrices of the input image, the output image, and errors, respectively. When the resolution of the output image is higher than that of the input image, the size of O is bigger than that of I. Therefore we define modified imput matix I' as follows:

$$I'(i',j') = I(i,j)$$
$$(0 \le i,j < N,\ i \le i' < (i+1)m,\ j \le j' < (j+1)m), \quad (1)$$

where N is the number of dots per line of I and $N*m$ is that of O. A sample case of m=2 is shown in Fig. 8

$$I = \begin{pmatrix} 160 & 80 & . & . \\ 150 & 110 & . & . \\ . & . & . & . \\ . & . & . & . \end{pmatrix} \rightarrow I' = \begin{pmatrix} 160 & 160 & 80 & 80 & . & . \\ 160 & 160 & 80 & 80 & . & . \\ 150 & 150 & 110 & 110 & . & . \\ 150 & 150 & 110 & 110 & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \end{pmatrix}$$

Figure 8. Modifying the original dot value matrix.

Now we can define the (i, j)th entry of the $Nm \times Nm$ error matrix E as follows:

$$E(i, j) = O(i, j) - I'(i, j) \quad (0 \le i, j < Nm) \qquad (2)$$

Spatial frequency of an error is obtained by the discrete Fourier transform. We use FFT to analyze the errors. The outputs are shown in Fig.9-12. Fig. 9, 10, 11, and 12 indicates spatial frequency of the errors of Fig. 4(a), 5(a), 6(a), and 7(a), respectively. Note that Fig. 12 shows only a relatively lower frequency part of Fig. 7(a).

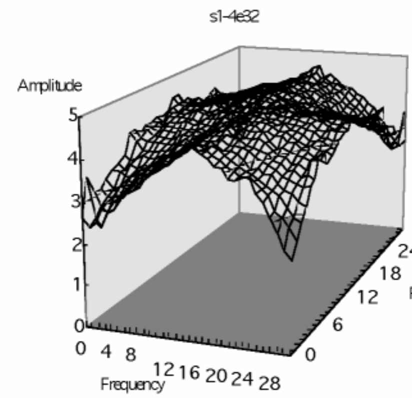

Figure 9. Frequency-Amplitude of Errors of Fig. 4(a).

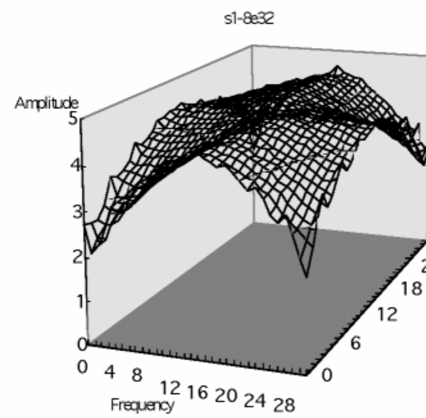

Figure 10. Frequency-Amplitude of Errors of Fig. 5(a).

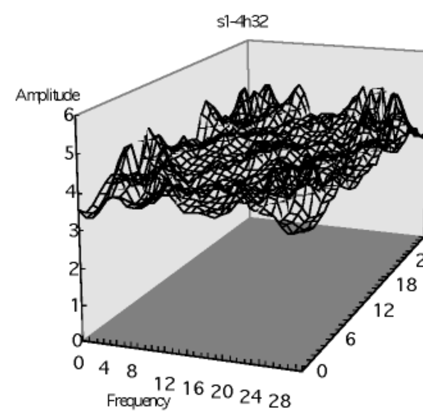

Figure 11. Frequency-Amplitude of Errors of Fig. 6(a).

Discussion

The error-diffusion method produces less error than the halftone method does theoretically, that means the amplitude around the origin (0,0) should be relatively small. This is true when we compare Fig. 9 with Fig. 10, or Fig. 11 with Fig. 12. The halftone method yields several clusters, or clustered dots, and we can see in Fig. 10 and Fig. 12 several peaks, each corresponds to the frequency of one of the clusters.

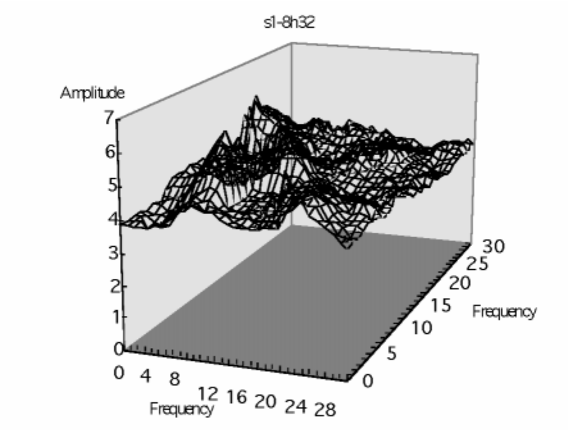

Figure 12. Frequency-Amplitude of Errors of Fig. 7(a).

Generally, it is known that human visual sensitivity for spatial frequency decreases sharply when the spatial frequency exceeds 2 dots/mm, and it goes alomst zero when the spatial frequency is more than 10 dots/mm. This means we need to check the part of lower frequency in Fig. 9-12. Moreover, we must consider the minimum size of a printed dot, that is determined by the resolution. Note that 72 dpi is about 2.83 dots/mm, and 400 dpi is about 15.7 dots/mm.

Conclusions

We can recognize there are correlations between a spatial frequency of errors and a binarized method, also between a spatial frequency of errors and a resolution of the output image. Considering these experimental results and human visual system characteristics, we may possibly construct a basic theory of optimal halftoning algorithm.

Reference

1. H. Kotera, Image Processing and Printing Methods, *IS&T's Eleventh International Congress on Advances in Non-Impact Printing Technologies*, pp. 12–15 (1995).

❋ Previously published in *IS&T NIP13*, pp. 550–553, 1997.