Quasi-continuous Dot Position Error Diffusion

*Kazuhisa Yanaka, Hideo Kasuga and Yasushi Hoshino**
Kanagawa Institute of Technology, Shimo-ogino, Atsugi, Kanagawa, Japan
**Nippon Institute of Technology, Miyashiro, Saitama, Japan*

Abstract

Halftoning, which is a technology of printing continuous-tone images imitatively on bi-level printing devices such as ink jet printers and electrophotographic printers, has been studied extensively, and many techniques such as error diffusion have been proposed. The premise of them is that the size and pitch of each dot is equal. In the case of ink-jet printers however, the dot position can be controlled with a smaller unit than dot size by electrostatic deflection, etc, though the dot size is fixed because it is determined by the size of a drop of ink. Yanaka et al. have already proposed an algorithm in which the position of each black dot is completely continuous, and each black dot is regarded to be a charged particle. In this paper another solution has been proposed, in which the position of each black dot is digital, but can be controlled with a smaller unit than the dot size. The algorithm is an extension of conventional error diffusion. In order to get better halftone images, scalable error filter has been proposed, in which error filter of arbitrary size can be generated simply by giving a parameter.

Introduction

Halftoning is a technology to transform a continuous tone image into a dot structure suitable for ink-on-paper (bi-level) printing. Since it has tremendous practical value, various techniques have been invented and some of them have been practically used. Among them, error diffusion algorithm[1] was invented by Floyd and Steinberg in 1975, and is still considered one of the best. By the way, in many printing technologies, the position of center of dot can be controlled finer than the size of dot. For example, in ink-jet printing technologies, the path of charged drops can be controlled by electrostatic deflection as shown in Figure 1. From now on, we call the minimum pitch of dot position on a paper "dot pitch", or simply “pitch”. However, it is usually assumed that the size and the pitch of a dot is the same, but it is not always true. By making use of this fact, the quality of halftoning can be improved. Yanaka et al.[2] proposed a halftoning algorithm under the condition that the position of each black dot is completely continuous. This paper proposes a different algorithm, in which the position of the dot is not completely continuous but quasi-continuous. The algorithm is an extension of error diffusion.

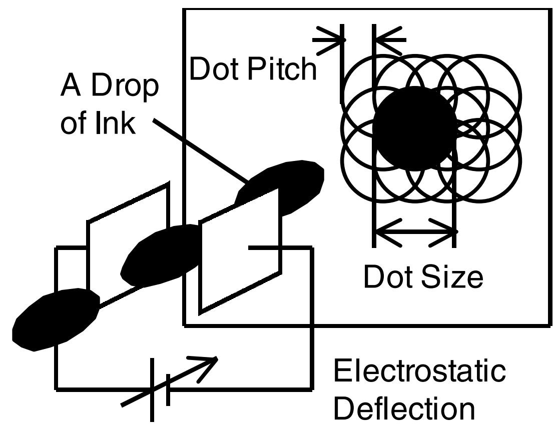

Figure 1. Fine Control of Dot Position

Principle of the Proposed System

In the case that black dots are formed on a white paper, possible position of each black dot shall be as fine as $1/m$ of the size of each black dot, where m is a positive integer. Figure 2 shows the case of m=4.

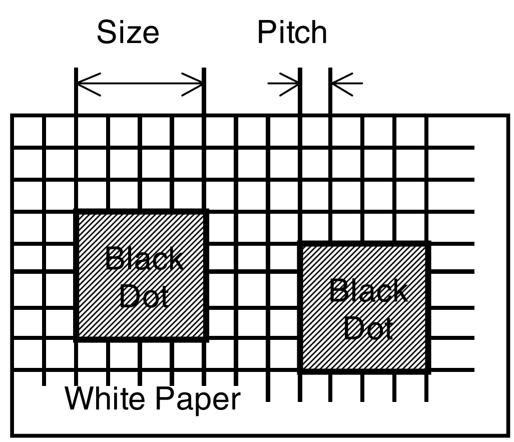

Figure 2. The Case of m = 4

So as to simplify the discussion, the original image is assumed to be square, and the number of pixels of a side is n. As shown in Figure 3, an original square image which consists of $n \times n$ picture elements is magnified m times both vertically and horizontally. The simplest way to do this is to copy the value of a pixel to $m \times m$ pixels. This process is called "resolution conversion". As the result, an image of $nm \times nm$ pixels is obtained. Of course, the purpose of this magnification is not to get a larger image, but to get more coordinate points, each of witch corresponds to "pitch".

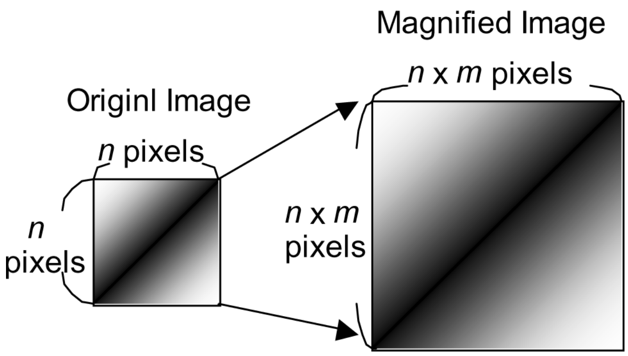

Figure 3. Resolution Conversion

If the magnified image is converted to a binary image by error diffusion, the number of black and white dots is increased in proportion to $m \times m$. Since the size of a black dot is $m \times m$ times larger than a pitch, and only black dots are formed by ink, it leads to a bad result that the resultant halftone image becomes dark. Therefore, in order to compensate this phenomenon, and keep the brightness level, "gray-scale conversion" is required in advance.

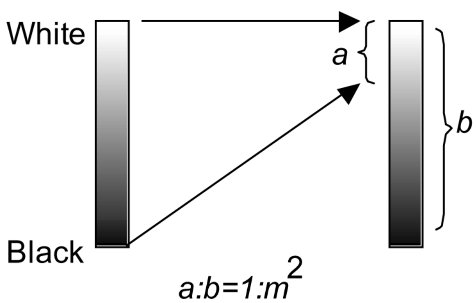

Figure 4. Gray-scale Conversion

The gray-scale conversion is a simple linear transform of the gray level of each pixel. All the gray-scale range from white to black is compressed to only $1/m^2$ portion of the total gray-scale near white. In other words, the image is whitened in advance so that less black dots are required.

The two conversions mentioned above can be executed in arbitrary order. As the result, a whitened and magnified version of the original image is obtained. Error diffusion is applied to the resultant image. The total flow of the process is shown in Figure 5.

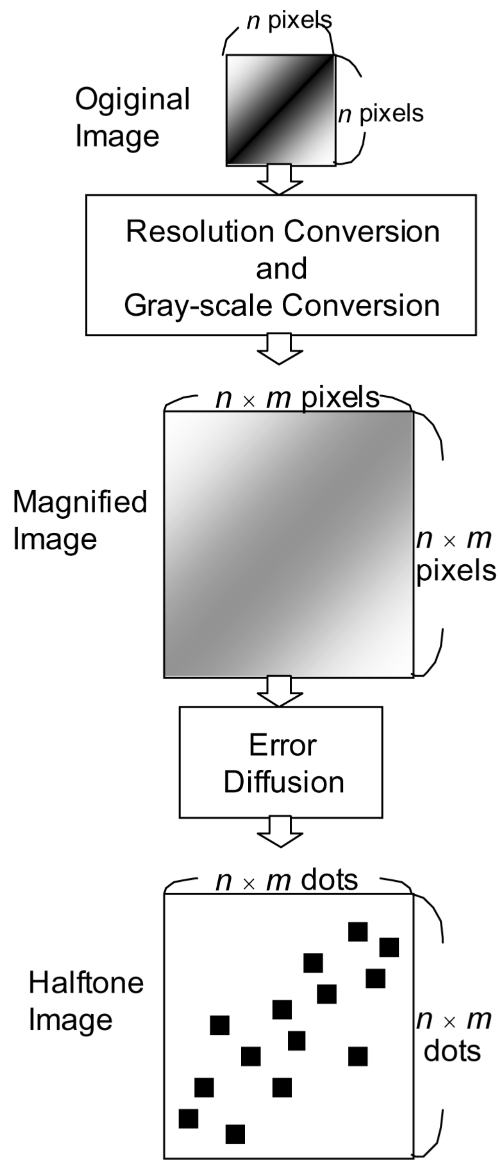

Figure 5. Block Diagram of the Proposed System

Scalable Error Filter

Error diffusion halftones are plagued by a "wormy" texture especially in highlights and shadows. This fact is very important, since almost all the areas in an image becomes highlights through above-mentioned conversion. Our conclusion is that the reason of the occurrence of such a texture especially in highlights is that the error filter size is too small. In these areas, the intervals among minority dots, in this case which are black dots, tend to become long, since the density of black dots is very low compared to those of white dots. The filter must be large enough to cover a sufficient number of neighboring minority dots. In other words, the area in which error is diffused should be expanded m times both vertically and horizontally. In addition, the error filter should satisfy the following conditions.

(1) It should be scalable, so that even very large filters can be easily generated by simply changing a parameter, as shown in Figure 6.

(2) It should be isotropic to all the directions. In other words, the shape of the filter must be circular, the center of which is a pixel being processed.

(3) It should be sharp, in order not to lose the detail information included in original images.

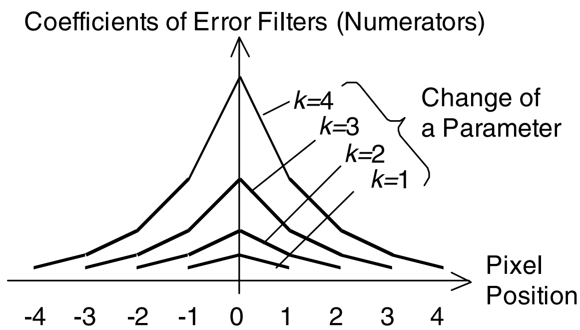

Figure 6. Scalability of Error Filters

$\left[\frac{1}{16}\right]$

	*	7
3	5	1

(a)Floyd and Steinberg(1975)

$\left[\frac{1}{48}\right]$

		*	7	5
3	5	7	5	3
1	3	5	3	1

(b)Jarvis, Judice and Ninke(1976)

$\left[\frac{1}{42}\right]$

		*	8	4
2	4	8	4	2
1	2	4	2	1

(c)Stucki(1981)

$\left[\frac{1}{768}\right]$ (k=7)

							*	64	32	16	8	4	2	1
1	2	4	7	14	27	48	64	48	27	14	7	4	2	1
1	2	3	6	11	18	27	32	27	18	11	6	3	2	1
1	1	2	4	7	11	14	16	14	11	7	4	2	1	1
0	1	2	3	4	6	7	8	7	6	4	3	2	1	0
0	1	1	2	2	3	4	4	4	3	2	2	1	1	0
0	0	1	1	1	2	2	2	2	2	1	1	1	0	0
0	0	0	0	1	1	1	1	1	1	1	0	0	0	0

(d)Scalable Error Filter Proposed in This Paper(k=7)

Figure 7. Error Filters

Until now, error filters for error diffusion seem to have been designed with trial and error. For decades, various error filters[3] have been proposed by many researchers as shown in Figure 7. However, the sizes of their filters are too small for the proposed system. Thus we propose the following scalable error filter shown in Figure 7(d).

The scalable error filter shown in Figure 7(d) can be described in more generalized form, shown in Figure 8.

$$\left[\frac{1}{\Sigma f_{i,j}}\right] \begin{matrix} & & & & f_{0,0} & f_{0,1} & f_{0,2} & f_{0,3} & \dots \\ \dots & f_{1,-3} & f_{1,-2} & f_{1,-1} & f_{1,0} & f_{1,1} & f_{1,2} & f_{1,3} & \dots \end{matrix}$$

Figure 8. Generalized Description of the Scalable Error Filter

where $f_{0,0}$ is the pixel being processed now. In this case, each filter coefficient $f_{i,j}$ is expressed by the following formula.

$$f_{i,j} = \left\lfloor 2^{k-\sqrt{i^2+j^2}} \right\rfloor \tag{1}$$

where the floor function, which gives the largest integer less than or equal to a real number, is used. The reason why Figure 7 shows the case of k=7 is nothing more than to simplify the illustration. If it is possible to choose the larger value of k, for example k=15, better halftone images can be obtained

Experiments

As a test image we used an image called "Portrait", which is included as "N1A" in ISO/JIS SCID: Standard Color Image Data.

Figure 9. Original Image (Portrait, 128× 128 pixels)

Although the SCID image is a high-resolution full-color image, we cut down the central portion of the image, down-sampled it, and removed the color information to get a monochrome image. Therefore, the size of the original image, shown in Figure 8, is 128 × 128. The result in case m=4 is shown in Figure 10. The improvement of the picture quality was observed in comparison with conventional error diffusion shown in Figure 11.

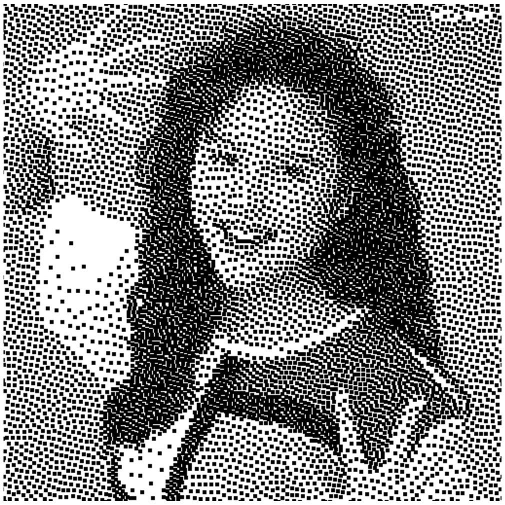

Figure 10. Halftone Image by the Proposed system

Figure 11. Conventional Error Diffusion

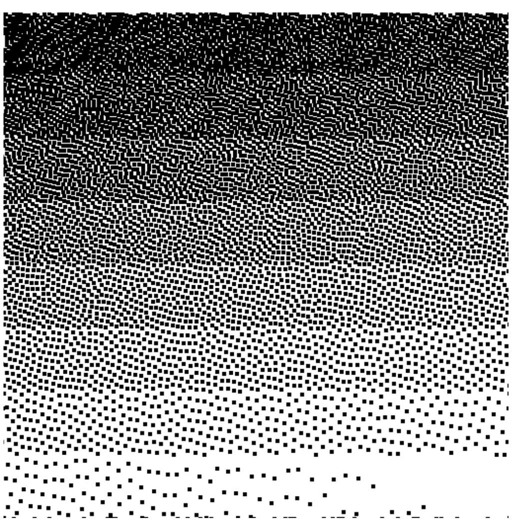

Figure 12.Halftone Image by the Proposed System (Grayscale)

In spite of the fact that the two halftone images consist of the black dots of almost the same number, the quality of Figure 10 seems to be considerably superior to that of Figure 11. Figure 12 is a halftone image of a grayscale, which is an artificially generated image.

Conclusion

A new halftoning algorithm has been proposed in which the position of each black dot can be controlled m times finer than the size of each black dot. The algorithm improves halftoned image quality although the size of minimum dot is not changed. Our system can also be applied to LED printers, in which dot position is variable only vertically, and laser beam printers, in which dot position is variable only horizontally. The error filter for error diffusion proposed in this report has a scalable function and can also be applied to conventional error diffusion algorithm.

References

1. Floyd,R.W.,and L.Steinberg,"Adaptive Algorithm for Spatial Gray Scale," SID Int. Sym. pp.36-37, 1975.
2. Kazuhisa Yanaka, Hideo Kasuga and Yasushi Hoshino, "Digital Halftoning Based on a Repulsive Potential Model," IS&T's NIP17, pp.784-788, 2001.
3. R.Ulichney, "Digital halftoning," MIT Press, 1996.
4. H.R.Kang,"Digital Color Halftoning," IEEE Press & SPIE Press, 1999.
5. Reiner Eschbach, "Recent Progress in Digital Halftoning II,"IS&T,1999.
6. Robert Ulichney, "A Review of Halftoning Techniques," IS&T/SPIE Conference on Color Imaging: Device-Independent Color, Color Hardcopy, and Graphics Arts V, San Jose, California, pp.378-391, January 2000
7. J.F.Jarvis, C.N.Judice, and W.H.Ninke,"A Survey of techniques for the display of continuous-tone pictures on bilevel displays",Comp.Graph.Imag.Proc., Vol.5, pp.13-40, 1976.

Biography

Kazuhisa Yanaka is a professor of Kanagawa Institute of Technology, Japan. He gained BE, ME and Dr.Eng. degrees from the University of Tokyo, in 1977, 1979, and 1982 respectively. He joined Electrical Communication Laboratories of NTT in 1982 and developed videotex terminals, teleconferencing systems, and image coding algorithms. He moved to Kanagawa Institute of Technology in 1997.

Hideo Kasuga is a research associate of Kanagawa Institute of Technology, Japan. He gained BE, ME and Dr.Eng. degrees from Shinshu University in 1995, 1997, and 2000 respectively. He worked at the university as a research associate for months, and he moved to Kanagawa Institute of Technology in 2000. His main research field is image processing.

Yasushi Hoshino is a professor of Nippon Institute of Technology, Japan. He gained BE, ME and Dr.Eng. degrees from the University of Tokyo, in 1970, 1972, and 1984 respectively. After he gained ME degree, he joined Electrical Communication Laboratories of NTT and developed LED printers, laser printers, and ion flow printers. He moved to Nippon Institute of Technology in 1994. He published more than 20 papers, including several papers in IS&T's journal. He attended almost all NIP conferences.