

Dispersed Error Control based on Error Filter Design for Improving Halftone Image Quality

Sang-Chul Kim and Sung-Il Chien

Abstract—The error diffusion method generates worm artifacts, and weakens the edge of the halftone image when the continuous gray scale image is reproduced by a binary image. First, to enhance the edges, we propose the edge-enhancing filter by considering the quantization error information and gradient of the neighboring pixels. Furthermore, to remove worm artifacts often appearing in a halftone image, we add adaptively random noise into the weights of an error filter.

Keywords—Artifact suppression, Edge enhancement, Error diffusion method, Halftone image

I. INTRODUCTION

SOME image output devices such as e-paper, printer, and PDP use the limited number of gray-levels because of device characteristics and finite resources. In this case, degradation of the output image quality is expected, so these devices often employ the halftoning technique. As a halftoning technique, the error diffusion method takes neighborhood information into account to determine the output value. The error diffusion method produces relatively better image quality than other types of halftone methods[1]. Among them, Floyd-Steinberg error diffusion method is widely used because of its low computational complexity[2]. However, this method produces degradation of the edge quality and thus damages the vivid feeling of an image because comparatively much error is dispersed into the predetermined direction without regard to the location of edges. In addition, the worm artifacts which are the periodically repeating patterns of worm-like shape occur when the input values are uniform or slowly varying [3].

Many modified error diffusion methods have been developed to improve the halftone image quality. Jarvis proposes the use of a larger size error filter[4]. A larger error matrix can spread error over a wider region. In this case, the edge can be preserved because relatively small error is assigned to neighboring pixels. However, these methods generate many diagonal direction patterns because of fixed large error filter used. The edge directed error diffusion method[5] is redistributing weights of Floyd-Steinberg error filter according to the edge information of neighboring pixels to enhance edges. Nevertheless, this method could not preserve weak edges and jagged edges are also often observed in the neighborhood of strong edges. In addition, they did not make any efforts for minimizing worm artifacts.

Dispersing errors to neighboring pixels may change the gray-level of the original image. Consequently, edges of a halftone image can be damaged in certain areas and the worm artifacts occur in the uniform regions. For these reasons, quantization error of the current pixel and gradients of the neighboring pixels are important factors to be used for improving halftone image quality. Therefore, we first divide an edge and non-edge by calculating gradients between the current pixel and its neighboring pixels. In the edge pixels, an edge-enhancing filter is proposed to be used for avoiding edge damage instead of Floyd-Steinberg filter weights, controlling an amount of dispersed error to the neighboring pixels by using filter weights obtained from the gradient and error sign information. As for non-edge pixels, worm artifacts are often the main culprit to damage visual quality of a halftoned image. The blue noise mask(BNM)[6] can be used to introduce the random effect into worm artifact areas and reduce such artifacts, but it requires relatively complicate procedures to build a set of masks and large processing memories. Thus, we propose an artifact-suppressing filter in which filter weights are determined by mixing random values into Floyd-Steinberg filter weights. For appropriate randomness, the size of the random noise is adaptively controlled depending upon the magnitude of the gradient. We can successfully show that the proposed method can enhance the edge and minimize worm artifacts of the halftone image. Also, the size of the error filters are the same as that of the Floyd-Steinberg filter and all the procedure of the proposed method is the same as that of the typical error diffusion method except choosing the appropriate filter.

II. GRADIENT BASED ERROR FILTER DESIGN

A. Typical Error Diffusion Method

Generally, an error diffusion method consists of a feedback loop. It determines a halftone value by comparing an input value with a threshold, and quantization error is computed by subtracting the halftone value from the input value. The quantization error is distributed to the neighboring pixels by an error filter. The system block diagram for the typical error diffusion method is shown in Fig 1.

Usually, an error filter consists of its weights associated with the positions for the error distribution. The weights of a filter are used to determine how much error will be dispersed to the

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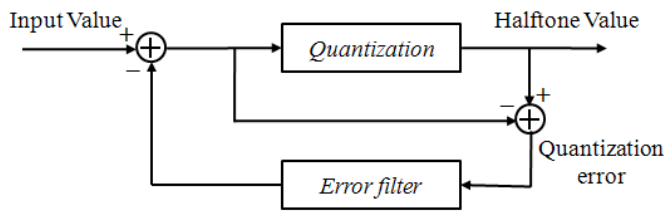


Fig. 1 System block diagram for typical error diffusion method

neighboring pixels. The weights of Floyd-Steinberg filter which is widely used are shown in Fig. 2. As shown in Fig. 2, X is the current processing pixel and the values of four neighboring pixels are weights of the filter at positions for error dispersion. For example, the value of 7/16 in Floyd-Steinberg filter means that 7/16 of quantization error is distributed to that position. The typical error diffusion methods generally use fixed weights.

B. Classification of the Edge and the Non-edge Pixels

The proposed method will decide to use one of different filters according to the edge and non-edge pixels. Then, we first divide the edge and non-edge by using the magnitude of a gradient. The gradients are calculated between current pixel and four pixels for errors to be dispersed. The gradient is defined as

$$\begin{aligned} d_1 &= I(x, y) - I(x + 1, y) \\ d_2 &= I(x, y) - I(x - 1, y + 1) \\ d_3 &= I(x, y) - I(x, y + 1) \end{aligned} \quad (1)$$

$$\begin{aligned} d_4 &= I(x, y) - I(x + 1, y + 1) \\ E_c &= \sum_{i=1}^4 d_i \end{aligned} \quad (2)$$

where $I(x, y)$ is the pixel value at position (x, y) . The d_1, d_2, d_3 and d_4 are the gradient of each direction and E_c is a sum of gradients. Next, we obtain absolute values of gradients, which will be used to determine the filter weights and to divide the edge and non-edge pixels.

$$D_1 = |d_1|, D_2 = |d_2|, D_3 = |d_3|, D_4 = |d_4| \quad (3)$$

$$D_T = \sum_{i=1}^4 D_i \quad (4)$$

$$Edge = \begin{cases} 1 & \text{if } D_T > T_E \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

In Eq. (5), T_E is a threshold to decide an edge, and D_T is a sum of the absolute gradients, called a total gradient.

C. Edge-enhancing Filter for Edge Pixels

The many conventional error diffusion method always distributes quantization error with the same fixed ratio to the neighboring pixels, which is represented by fixed weights of a filter. However, diffused error from the neighboring pixels can

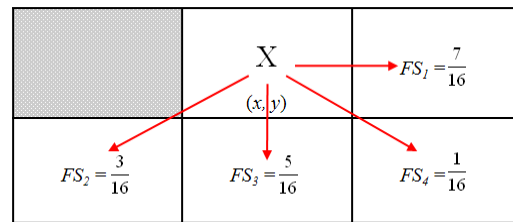


Fig. 2 Floyd-Steinberg filter weights and each position of weight

deteriorate the edge of a halftone image because the quantization result can be changed on the edge pixel. For enhancing the edges, we can think of using a sharpening filter first to accentuate edges and using a typical error diffusion method later. However, good edge enhancement by a sharpening filter is quite time-consuming and often needs a special processor for fast computation.

Instead, we change the filter weights adaptively by considering gradient and edge information, resulting in adjustment of error dispersion to neighboring pixels. It is found that two types of weights depending upon two conditions are needed for our edge-enhancing filters. The first condition is called an edge-boosting condition to which two cases are matched. The first case is that $E_c < 0$, which means the gray-level of the current pixel is probably the lowest and the quantization error $e(x, y) \geq 0$, which means that once error is transferred to the neighboring pixel, its gray-level becomes larger. In this case, the error diffusion helps to make an edge more noticeable, but compared to Floyd-Steinberg case, our method distributes more error to the neighboring pixels with higher gray-levels. In case that $E_c \geq 0$ and $e(x, y) < 0$, our method make the neighboring pixel with the smallest gray-level reduce the gray-level most severely. The second condition called edge preserving condition corresponds to the remaining two cases in which error dispersion tends to flatten gray-level difference. For retaining the edge profile, we make the weights of the filter be roughly inversely proportional to the magnitudes of the gradients. The weights of an edge-enhancing filter based on edge-boosting and edge-preserving conditions are determined as follows.

$$w_i = \begin{cases} \frac{D_i}{D_T} & \text{if } ((E_c < 0 \& e(x, y) \geq 0) \mid \\ & (E_c \geq 0 \& e(x, y) < 0)) \\ f\left(\frac{D_i}{D_T}\right) & \text{otherwise} \end{cases} \quad (6)$$

w_i is a weight of the edge-enhancing filter at the i th position. The f is a monotonic decreasing function to decide weights of an edge-enhancing filter based on an edge-preserving condition to reverse the magnitude of original weights. For simplicity, we use $f(x)$ defined by

$$f(x) = \frac{1}{3}(1 - x). \quad (7)$$

D. Artifact-suppressing Error Filter for Non-edge Pixels

Generally, the error diffusion method does generate some unwanted textures which looks very unnatural sometimes. One type is composed of wavy lines that occur in the highlights and shadows. Another artifact is a coarse noise pattern in the midtones, which is generated between two periodic patterns of the same average gray level[7]. These patterns are often called "worm artifacts".

The worm artifacts are normally caused by spatial regularity when a fixed error filter is used continuously. This regularity can be suppressed by random noise. There are two different ways to introduce randomness in the error diffusion method. One approach is that random noise is applied to a threshold[7,8], and the other is to add random noise to the weights of the error diffusion filter[9]. Although random noise can effectively remove the regularity in non-edge pixels, thereby minimizing the worm artifacts, it disrupts the edge profile because formation of the edges requires spatial regularity. Therefore, we conclude that the random noise should be applied to only the non-edge pixels.

To apply randomness, we employ to add random noise to the filter weights. We can consider three parameters of an error filter to supply randomness: the number of weights, positions of weights, and values of weights. Among them, we change only the values of weights by considering constraints of hardware and complexity of implementation. The random noise is generated by a random number generator of uniform distribution and added to each weight of an error filter. The sum of all weights in the perturbed error filter should still be one at all cases. An artifact-suppressing filter is designed as following.

If the arbitrary filter weights are only produced by a uniform distribution random generator, we found that randomness introduced here is too large for our purpose. Therefore, we choose to mix random noise into Floyd-Steinberg's filter weights. For this, we introduce the mixing ratio which controls the balance between Floyd-Steinberg filter weight and a random value according to the magnitude of a gradient. The mixing ratio is determined as

$$r_m = \begin{cases} -0.05 D_T + 1.0 & \text{if } D_T < T_R \\ 0 & \text{otherwise,} \end{cases} \quad (8)$$

r_m is a mixing ratio and T_R selected as gray-level 20 in this paper is a threshold to introduce randomness. If D_T is larger than T_R , randomness is no longer useful and the artifact-suppressing error filter is equivalent to Floyd-Steinberg error filter.

Next, we generate random values by uniform random distribution over a range of [0,1] and random weights are obtained by normalizing random values. The random weights are defined as follows.

$$RW_i = \frac{RN_i}{\sum_{i=1}^4 RN_i} \quad (i = 1, \dots, 4) \quad (9)$$

RN_i and RW_i are random value and random weight at each filter position, respectively. Each random weight is mixed to the Floyd-Steinberg filter weight of the same position. Finally, the weights of an artifact-suppressing filter are determined as

$$w_i = r_m RW_i + (1 - r_m) FS_i \quad (i = 1, \dots, 4) \quad (10)$$

FS_i denotes a Floyd-Steinberg filter weight of i th position as shown in Fig. 2. We also note that

$$\sum_{i=1}^4 w_i = 1 \quad (11)$$

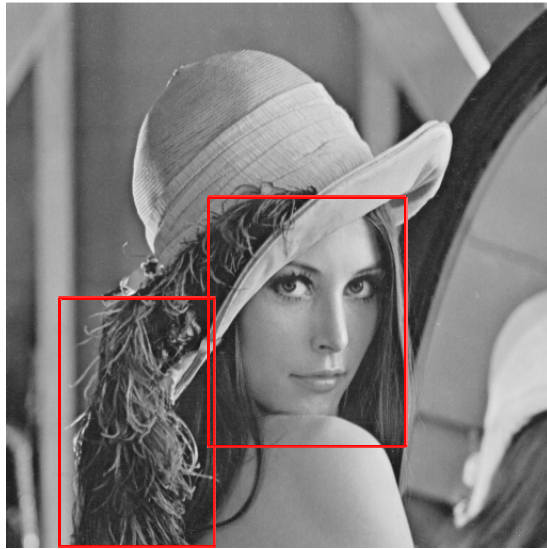
III. EXPERIMENT RESULTS

To evaluate the proposed method, image qualities of the conventional and proposed methods are compared. The halftone results for Lena image are shown in Figs. 3 and 4. Fig. 3(a) shows the original image. For better assessment of visual image qualities, two areas in the boxes are enlarged and included in Fig. 4, respectively. In Floyd-Steinberg method, many edges have deteriorated in the feather ornament, and much worm artifacts are observable in a background wall and some face region, which are shown in Figs. 3(b) and 4(b). Figs. 3(c) and 4(c) are results of Jarvis-Judice method. Compared with Floyd-Steinberg method, it seems that this method produces better vivid image because the larger error filter can spread error on the wider area. But many other types of artificial patterns occur in the most area. The edge-directed method is shown in Figs. 3(d) and 4(d), producing slightly better strong edges than Floyd-Steinberg method, but this method has failed to improve the weak edges. In contrast, as shown in Figs 3(e) and 4(e), the proposed method1 which uses only an edge-enhancing filter provides better expression of edges. Especially, the weak edge is much enhanced when compared with the previous methods. However, many worm artifacts are still occurring in the face and background areas. Figs. 3(f) and 4(f) show results of proposed method2, in which the edge-enhancing filter and artifact-suppressing filter are adaptively chosen according to the magnitude of the gradient. The proposed method 2 is successful not only in enhancing the edges but also in minimizing the worm artifacts.

Fig. 5 shows the simulation result of Buddha status image. Figs 5(c) to 5(g) show the enlarged halftone images for two boxes in Fig. 5(a). Like the case of Lena image, the conventional methods generate still above-mentioned problems. Especially, many worm artifacts appear in the background walls and a part of the leg of the status. As expected, the proposed method 2 effectively reduces the worm artifacts, while enhancing edges in some reliefs and boundaries of bricks.

IV. CONCLUSION

The error diffusion method is widely used to produce a halftone image, but it tends to weaken the edge and produce unpleasant patterns such as worm artifacts. In order to solve the



(a)



(b)



(c)



(d)



(e)



(f)

Fig. 3 Results of various error diffusion methods for Lena image : (a) original image, (b) Floyd-Steinberg method, (c) Jarvis- Judice method, (d) edge-directed method, (e) proposed method 1, and (f) proposed method 2

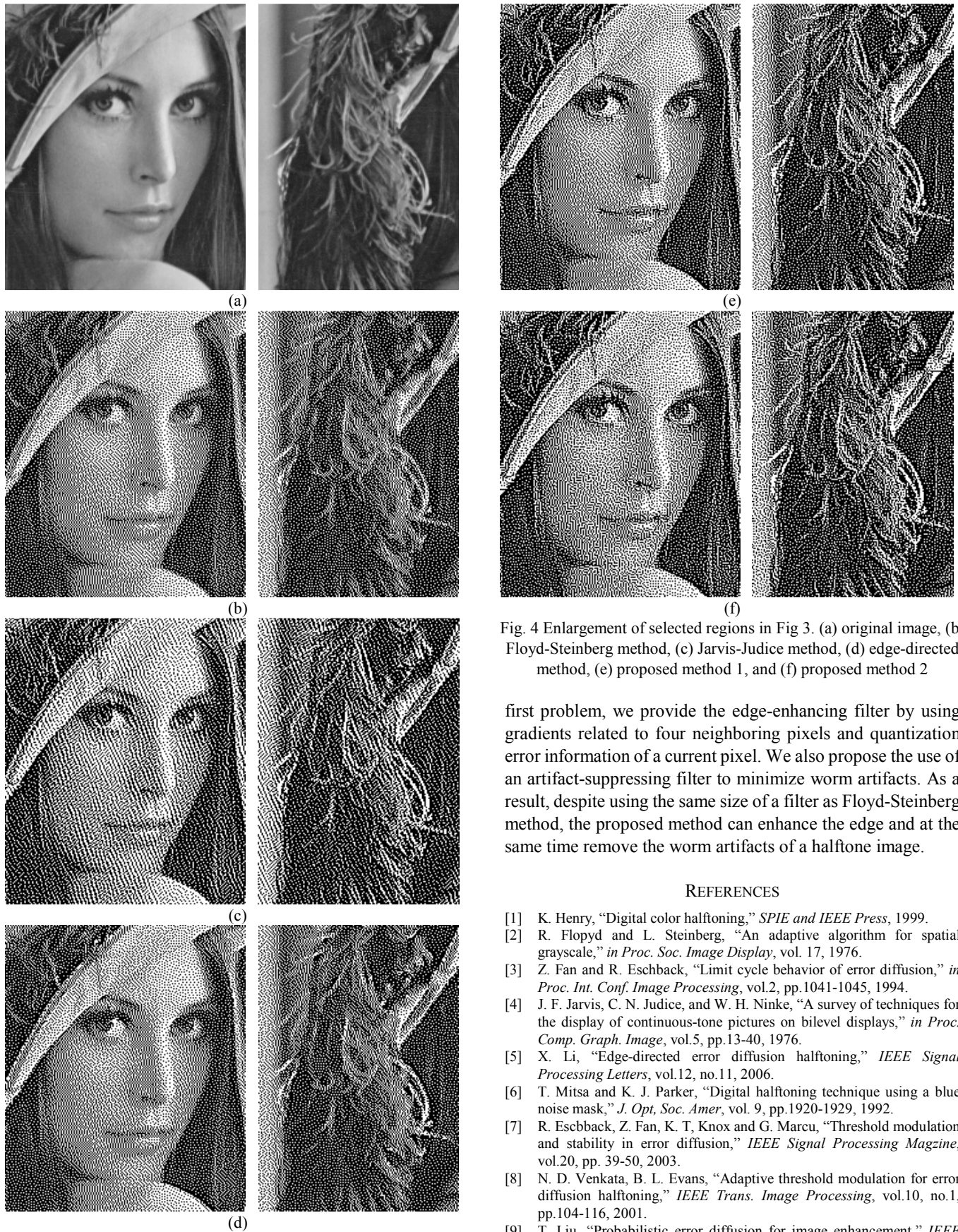
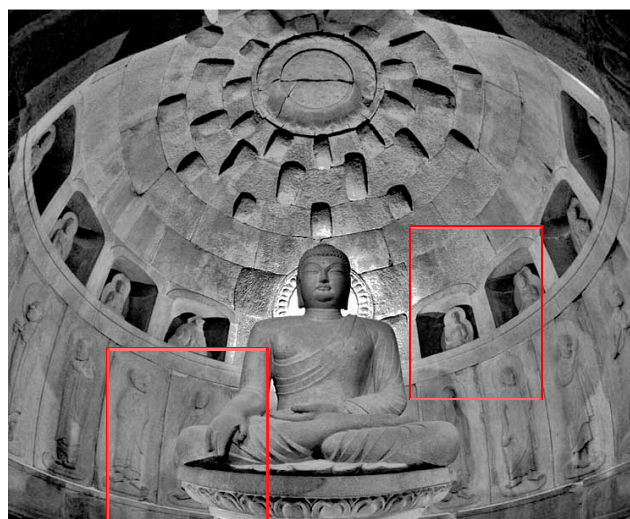


Fig. 4 Enlargement of selected regions in Fig 3. (a) original image, (b) Floyd-Steinberg method, (c) Jarvis-Judice method, (d) edge-directed method, (e) proposed method 1, and (f) proposed method 2

first problem, we provide the edge-enhancing filter by using gradients related to four neighboring pixels and quantization error information of a current pixel. We also propose the use of an artifact-suppressing filter to minimize worm artifacts. As a result, despite using the same size of a filter as Floyd-Steinberg method, the proposed method can enhance the edge and at the same time remove the worm artifacts of a halftone image.

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(a)



(b)



(c)



(d)



(e)



(f)



(g)



(h)



(i)



(j)



(k)



(l)



(m)

Fig. 5 Simulation result of (a) Buddha image and six enlarged images for (b) original image, (c) Floyd-Steinberg method, (d) Jarvis-Judice method, (e) edge-directed method, (f) proposed method 1, and (g) proposed method 2