Hybrid Error Diffusion with Mask Perturbation

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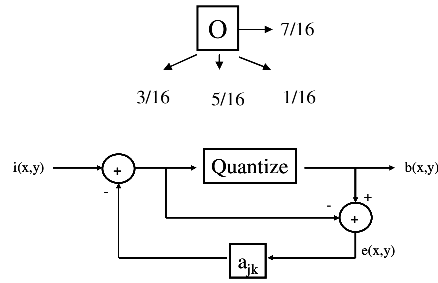
Abstract

The error diffusion algorithm is widely used in digital image halftone. The algorithm is very simple to implement and very fast to calculate. However, it is known that standard error diffusion algorithms such as Floyd-Steinberg produce undesirable artifacts in the form of structure artifacts such as checkerboard patterns, diagonal stripes and other repetitive structures. The boundaries between structure artifacts break the visual continuity in regions of low intensity gradients and may be therefore responsible for false contours. In this paper, we propose a new halftone method to reduce the structural artifacts and to increase the gray expression, called hybrid error diffusion, by the concept of "error diffusion by perturbing the error coefficient with randomly selected mask". The proposed algorithm consists of two steps in each position. In the first step, a perturbation is calculated using the internal pseudo-random number and randomly selected 4x4 mask, similar to dither mask (R,G,B different). In the second step, error diffusion weights are calculated with the criterion for each pixel values. So, the proposed hybrid method can reduce the structure artifacts with keeping the advantage of the error diffusion. This paper discusses the performances of proposed algorithm with experimental results for natural test images.

Introduction

The digital halftone technology pays an important role in transforming a continuous tone (gray or color) image to an image with a reduced number of gray levels for display device. For example, there is the transform of a 24bit color image to a 3bit color image.

For a halftone technology, there are many factors for the image quality, visibility, gray linearity, contrast ratio, color, sharpness, etc. Figure 1 shows a block diagram of the conventional error diffusion algorithm. Each pixel value is determined to white or black compared with the threshold value, and the quantization error is fed back, and added to adjacent pixels [1],[2].The conventional error diffusion has an advantage of the simple implementation, fast speed for calculation. It also used the concept of overflow, diffuse the quantization error and reset the diffusion. It means the overflow is dependent on the input data. The diffusion direction is dependent on the input data and error diffusion filter coefficient and shape. But, on the other hand, the conventional gray-scale error diffusion introduces the distortion reducing the visibility, worms and false textures, or additive noise. To solve these problems, many digital halftone algorithms have been proposed to improve the halftone quality. Examples include using variable thresholds [3], variable filter weights [4]-[6]. Especially, the color relation must be also considered for the color halftone. There was also an approach for color image to improve the color halftone visibility, considered the color channel correlation [7],[8]. But these methods required the complex process and long calculation time or many look-up tables.



$$b(x,y) = q[i(x,y) - \sum (a_{jk} \cdot e(x-j, j-k))]$$

$$e(x,y) = b(x,y) - i(x,y) + \sum (a_{jk} \cdot e(x - j\Delta x, y - k\Delta y))$$

Figure 1: *General block diagram of conventional error diffusion.*

In this paper, we propose the well organized halftone algorithm to improve the conventional halftone artifacts and enhance the visibility of color. The proposed algorithm is also very simple, easy to implement and can reduce the structure artifacts with keeping the advantage of the error diffusion. We use the concept of perturbing error filter weight using the mask randomly selected with the pseudo-random number. The proposed algorithm is basically same for using the 4 tap style error filter similar to that of the Floyd-Steinberg error diffusion algorithm [1] as shown in Fig.1. The basic procedure of proposed algorithm is like below:

(1) Determine the mask value for each color plane & added to pseudo-random number
(2) Calculate the error filter weights for each color plane

The used mask is similar to the ordered dither mask. This mask value is selected by pixel, line, and each color plane. The results of proposed algorithm show the good performance for reducing the artifacts, worm and false texture. We also use the different error filter weights for each color plane to enhance the color visibility. The error filter weights were calculated by using the different mask for each color plane.

In remainder of the paper is organized as follows. In Sec.2, we explained the hybrid error diffusion algorithm in detail. Section 3 will show results of the algorithm and compare our algorithm with conventional methods using halftone statistical analysis. Conclusion will be given in Sec.4.

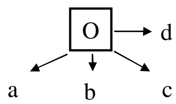
Hybrid Error Diffusion

Now, we propose the well organized error diffusion algorithm to improve the conventional halftone artifacts and enhance the visibility of color.

Concept

The concept of the proposed hybrid error diffusion is shown in Fig.2. We use the concept of perturbing error filter weight using the mask randomly selected with the pseudo-random number. The $b(x,y)$ is the output halftoned image, $e(x,y)$ is the accumulated error which will be diffused to adjacent pixel. The 4 tap style error filter weight of proposed algorithm is similar to that of the Floyd-Steinberg error diffusion algorithm. But the error filter weight a_{jk} (a,b,c,d) is varied with the internally calculated pseudorandom number and the mask value. The used mask is similar to the ordered dither mask. This mask value is selected by pixel, and line. So the error filter weight is varied with the pixel position, line, and color plane. Finally, the error filter weight a_{jk} values are determined by the criterion of Eq.(1) in pixel by pixel.

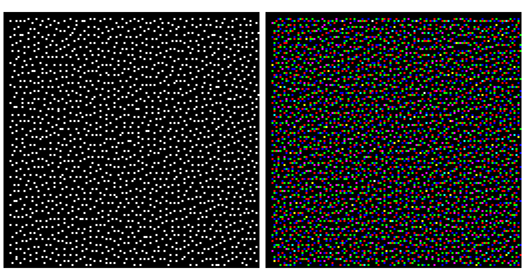
$$\sum h_m(a_{jk}) = 1, h_m(a_{jk}) \geq 0 \tag{1}$$



$$b(x,y) = q[i(x,y) - \sum (a_{jk} \cdot e(x-j, j-k))]$$
$$e(x,y) = b(x,y) - i(x,y) + \sum (a_{jk} \cdot e(x - j\Delta x, y - k\Delta y))$$
$$a_{jk} = Normalized(RandomNum + MaskValue)$$

***Figure 2:** Hybrid error diffusion process*

We use the different mask for each color plane to improve the color visibility. The results are compared in Fig.3. The Green, Blue mask is generated by using the Red mask. The Red mask is generated with the relation of check board weight. So, the Green mask is generated by moving 1 pixel distance to left from the Red mask. The Blue mask is generated by moving 2 pixel distance to left from the Red mask.



(a) *(b)*

(a)

R

8	3	11	0
7	14	4	13
10	1	9	2
5	12	6	15

G

8	3	11	0
7	14	4	13
10	1	9	2
5	12	6	15

B

8	3	11	0
7	14	4	13
10	1	9	2
5	12	6	15

(b)

R

8	3	11	0
7	14	4	13
10	1	9	2
5	12	6	15

G

3	11	0	8
14	4	13	7
1	9	2	10
12	6	15	5

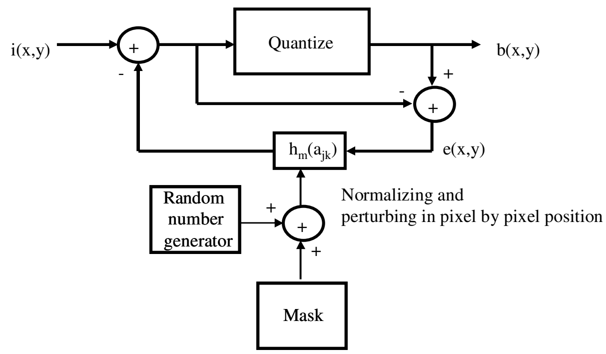
B

11	0	8	3
4	13	7	14
9	2	10	1
6	15	5	12

***Figure 3:** Results of gray-level 28 : (a) R,G,B same mask (b) R,G,B different mask*

Structure

The block diagram of proposed algorithm is shown in Fig.4. The fundamental structure is similar to the conventional Floyd-Steinberg algorithm. But the internal pseudo-random number generator and mask selector is added to that. The procedure of calculating the error carry is like below. Firstly, the mask value is determined for each color plane, pixel position and line position. Pseudo-random number is added to the pre-determined mask value. Finally, for each pixel, color plane, the error filter weights are determined. Then the diffusion process is carried out. It is also possible to control the error diffusion pattern by controlling the mask value in hybrid error diffusion algorithm. The proposed algorithm shows the good performance for reducing the artifacts, worm because the overflow of error and the direction of generated carry is varied by the mask value in pixel by pixel.



R

8	3	11	0
7	14	4	13
10	1	9	2
5	12	6	15

G

3	11	0	8
14	4	13	7
1	9	2	10
12	6	15	5

B

11	0	8	3
4	13	7	14
9	2	10	1
6	15	5	12

***Figure 4:** Block diagram of hybrid error diffusion.*

Pattern Estimation

We introduce the conventional point process statistics to estimate the halftone image. The candidates are *Pair Correlation* and *Radially Averaged Power Spectrum Density (RAPSD)* [9]. The pair correlation, first candidate, is the influence that the point at y has at any x in the spatial annular ring. The pair correlation is a strong indicator of the inter-point relationships for a given pattern. The pair correlation $R(r)$ is known like below:

$$R(r) = \frac{E\{\phi(R_y(r)) | y \in \phi\}}{E\{\phi(R_y(r))\}} \tag{2}$$

Where y is the point that is influenced by x. ϕ is the sample of point process. Spectral analysis was first applied to stochastic patterns by Ulichney [10] to characterize patterns created via error diffusion. To do so, Ulichney developed the radially averaged power spectra along with a measure of anisotropy. The radially averaged power spectrum is like below:

$$\hat{P}(f) = \frac{1}{K} \sum_{i=1}^{K} \frac{|DFT_{2D}(\phi_i)|^2}{N(\phi_i)} \tag{3}$$

Where $DFT_{2D}(\phi)$ represents the two dimensional, discrete Fourier Transform of the sample ϕ, $N(\phi)$ is the total number of pixels in the sample ϕ, and K is the total number of periodic area being averaged to form to estimate. Finally, the RAPSD is defined as follows:

$$P(f_\rho) = \frac{1}{N(R(f_\rho))} \sum_{f \in R(f_\rho)} \hat{P}(f) \tag{4}$$

Where $R(f_\rho)$ is the series of annular rings, $N(R(f_\rho))$ is the number of frequency samples in $R(f_\rho)$. The pair correlation is modified to extend the concept for color image as shown in Eq.(5). $R_{R+G+B}(r)$ is the color pair correlation result of halftone image. This result is simply obtained by replacing the input image from gray image to RGB color image because its concept is the influence that the point at y has at any x in the spatial annular ring.

$$R_{R+G+B}(r) = \frac{E\{\phi(R_y(r)) | y \in \phi\}}{E\{\phi(R_y(r))\}} \tag{5}$$

Experimental Results

Estimation

The results of pair correlation and RAPSD are shown in Figs. 5 and 6. The input image resolution is 128x128 pixel image with the gray-level 28 as shown in Fig.3. Figure 5 is the result of Floyd-Steinberg algorithm and Fig.6 is the result of hybrid error diffusion. For the result of pair correlation, $R(r)$=0 for r<3.5 is a consequence of the inhibition of points within a distance 3.5 of each other. The more frequent occurrence of halftone result is in the distance of 4.5<r<7.5 with the condition of $R(r)$>1. But there is no area for the case of $R(r)$=0 in the Fig.6. It means that the hybrid error diffusion can offer the chance of occurrence in the R,G,B mixed model.

For the result of RAPSD, the result has a power spectrum that is composed almost of high frequency in the case of Fig.5. But the power spectrum of hybrid error diffusion is extended to the lower frequency area and the high frequency components are suppressed. It means that the density of dot is increased and spread with the good pattern profile.

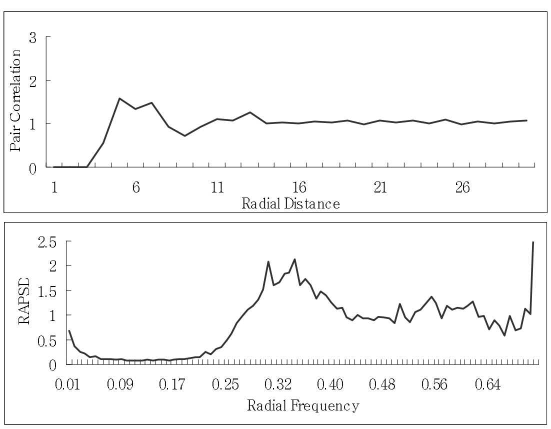


Figure 5: *Results of gray-level 28 with the floyd-steinberg algorithm : Pair Correlation / RAPSD*

Results

We compare the results of Floyd-Steinberg error diffusion, hybrid error diffusion with the source of "Elliptical Ramp" image in Fig.7 and "Closed Rose" image in Fig.8. The size of source image is 256x256, 256x128 pixel image. In Fig.7(b), false textures are prominent in the middle of elliptical ramp gradation. But as shown in Fig.7(c), there is no structural pattern caused by the error diffusion. In addition, the hybrid error diffusion does not suffer from the directional artifacts such as diagonal worms, which appears in the elliptical ramp edge and highlight area. The gradation of color rendition is also better for the hybrid error diffusion algorithm. The white dots in Fig.7(b) are replaced by the mixture of Red, Green and Blue which is less visible.

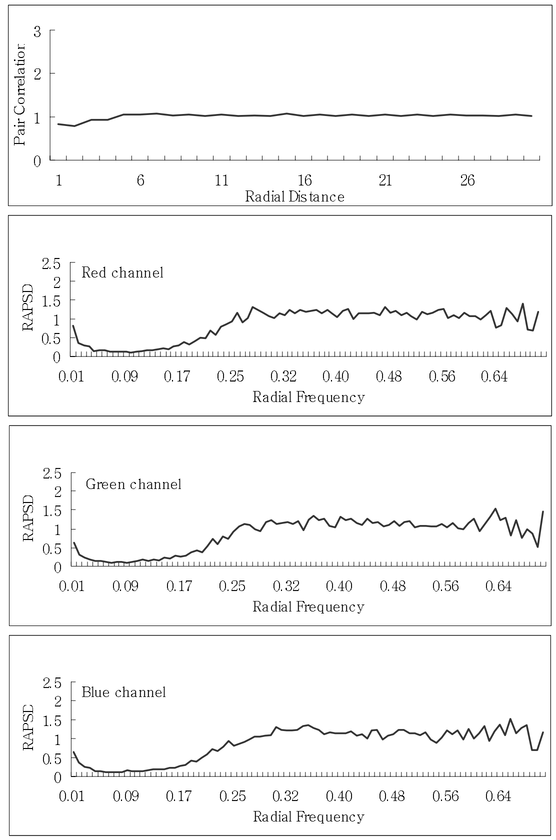


Figure 6: *Results of gray-level 28 with the hybrid error diffusion algorithm : Pair Correlation / RAPSD for each RGB channel*

Conclusion

In this paper, we proposed the new error diffusion algorithm, hybrid error diffusion. The proposed algorithm has the good performance for improving the gradation characteristics and reducing the structural pattern induced by conventional error diffusion. For the future works, we try to investigate the possibility of adaptation to the flat panel display.

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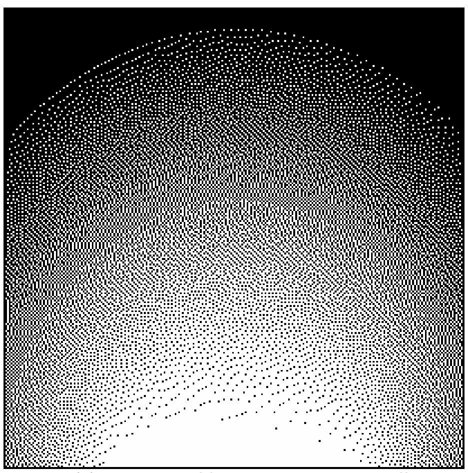
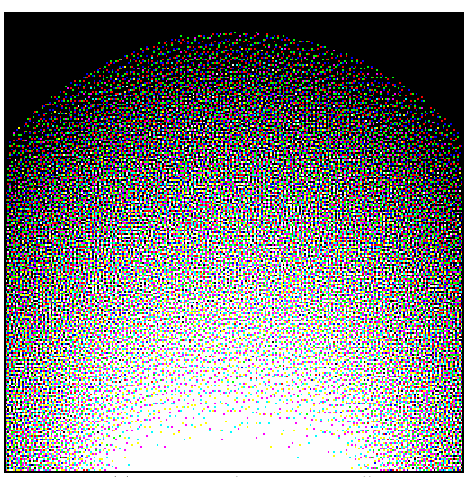
(a)Eliptical Ramp



(b)The result of floyd-steinberg error diffusion



(c)The result of hybrid error diffusion

Figure 7: *Results of floyd-steinberg algorithm and hybrid error diffusion algorithm*

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Author Biography

Jun Hak Lee received the B.S., M.S. degrees in electrical engineering fro-m Kyoungpook national university and Seoul national university, Korea in 1999 and 2001, respectively. From 2001 to 2005, he worked at the Digital Display Research Lab., LG Electronics Inc. in Seoul, Korea, as a member of the research staff, doing research on the plasma display image process-ing. His research interests are Image enhancement, device oriented digital image halftone.

(a)Closed Rose

(b)The result of floyd-steinberg error diffusion

(c)The result of hybrid error diffusion

Figure 8*: Results of floyd-steinberg algorithm and hybrid error diffusion algorithm*