

Improved Error Diffusion Modified with AM/FM Periodic Noise

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Abstract

Error diffusion (ED) method is a major stream in digital halftoning, but the unpleasant wormy patterns have been disagreeable to the people who are familiar with halftone screen in the conventional printing. The major drawbacks of ED method lie in (1) wormy patterns (2) vertical textures (3) dots' delay. This paper proposes a simple and easy way to reduce these unpleasant artifacts. The wormy patterns are more noticeable in the highlight and shadow areas. The proposed modified ED algorithm employs a periodic noise whose amplitude is controlled to be higher in the highlight and shadow, while lower in the midtone areas. We named this noise the AM/ FM periodic noise. And we tried to extend this modified ED to the color. In this paper, the experimental results are reported using inkjet printer and the performance is discussed as compared with conventional ED.

Introduction

In the non impact-printing field, ED algorithm is most conveniently used to convert continuous tone image into binary image. However, the binary image obtained conventional ED algorithm exhibits various artifacts, which are visually unpleasing to human eyes. These undesirable artifacts are wormy patterns in the highlight and shadow areas, vertical textures in the midtone areas and dots' delay in the edge of image. We propose the algorithm used the AM/FM periodic noise to suppress wormy patterns1).

On the other hand, color correction technologies are indispensable to reproduce the true colors on hardcopies. We proposed the new color correction method that resulted in the precision color matiching2). This paper presents an Improved ED algorithm combined with the modified AM/FM periodic noise and color correction process.

Modified ED

To reduce undesirable artifacts in the conventional ED, We improved the algorithm by adding various processes as follows: (1) adding the AM/FM periodic noise (2) zigzag scannig (3) threshold modulation (4) swiching error filters. Furthermore, to improve the reproduction of color, we added (5) color correction. Fig.1 shows the schematic diagram of the improved ED.

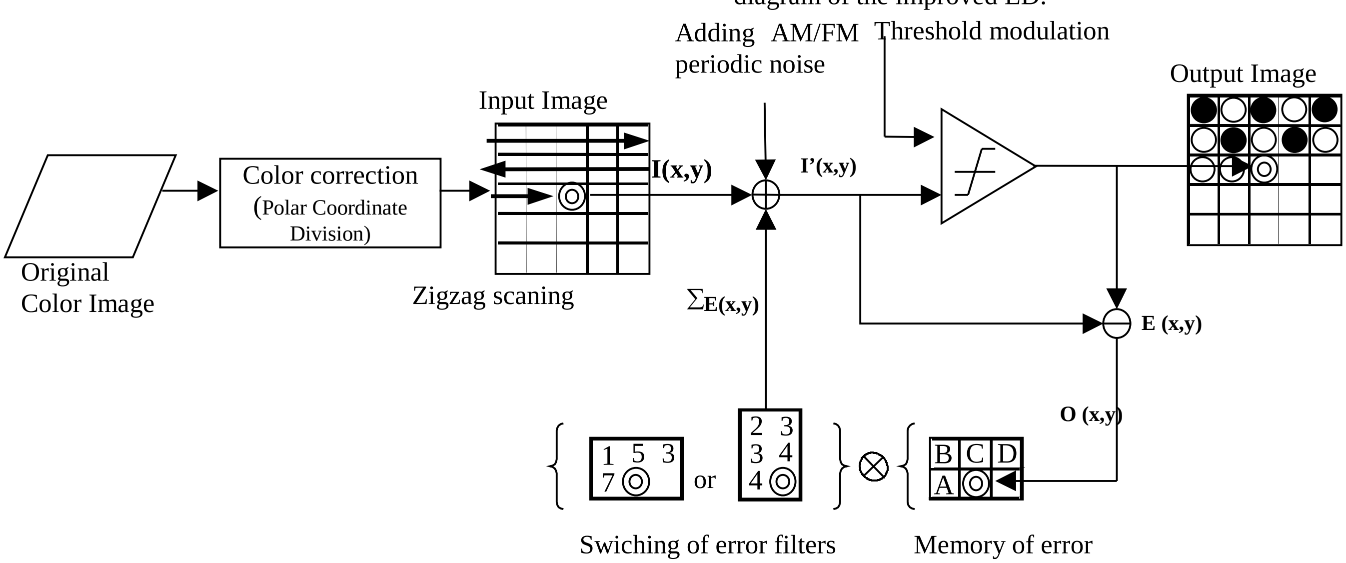


Fig.1 Improved error diffusion method

AM/FM periodic noise

In conventional ED the unpleasant wormy pattern usually appear on highlight and shadow. We reduce those textures by adding the AM/FM periodic noise. Fig.2 shows the shape of this periodic noise. The periodic noise is denoted as follows:

$$PN = A \sin \pi \left(\frac{x}{\lambda} + \frac{y}{\lambda} \right) \tag{1}$$

We define the amplitude A by Eq(2), which is controlled by parameter δ to work dominant in the highlight and shadow areas and to vanish in the midtone. Here, the average of input values within the 5*5 neighbors influences to the amplitude of the periodic noise.
Where *Ao* is a constant and δ is set to δ >1.

$$A = A_0 \left\{ \frac{\sum_{m=-2,n=-2}^{2} I(x+m, y+n)}{25} - 127.5 \right\} \tag{2}$$

Thus, the periodic noise works strongly in the highlight and shadow area, gradually decreasing its amplitude into the midpoint of gray scale. The period denoted λ is changed according to input pixel value in the highlight and shadow areas as given by:

$$\lambda = \begin{cases} \frac{1}{\sqrt{2}} \sqrt{\frac{255}{I(x,y)}}, & \textit{if} \quad I(x,y) < 128 \\ \frac{1}{\sqrt{2}} \sqrt{\frac{255}{255 - I(x,y)}} & \textit{Otherwise} \end{cases} \tag{3}$$

For example, if the input pixel value is 1 or 254, the average distance between the dots is forced to be $16\sqrt{2}$.

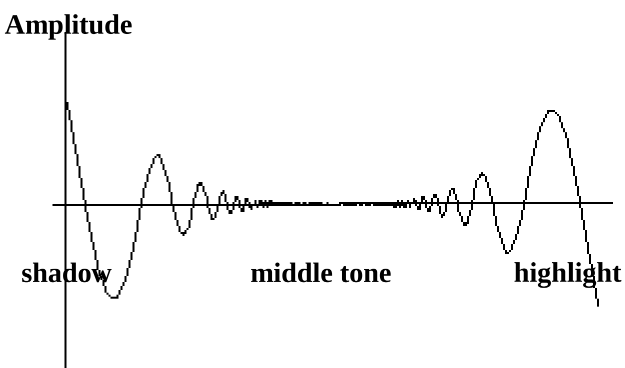
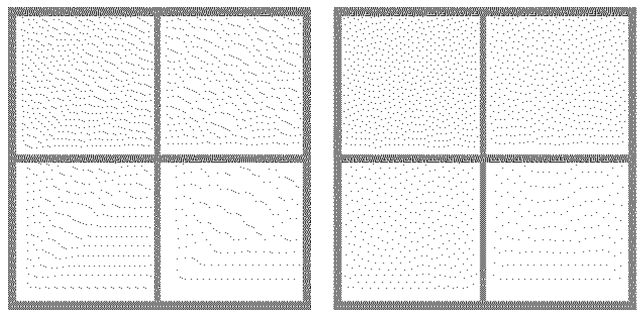


Fig.2 General shape of AM/FM noise

Zigzag scanning

Conventional ED uses raster scanning as basic scanning method. However, raster scanning method results non-uniform textures, because the error is dispersed depending on scanning direction. The zigzag scanning is introduced to diffuse the errors in bi-direction. As a result the irregular patterns are dispersed in uniform. Fig.3 shows the effect of zigzag scanning compared with the conventional ED.



Raster scanning Zigzag scanning

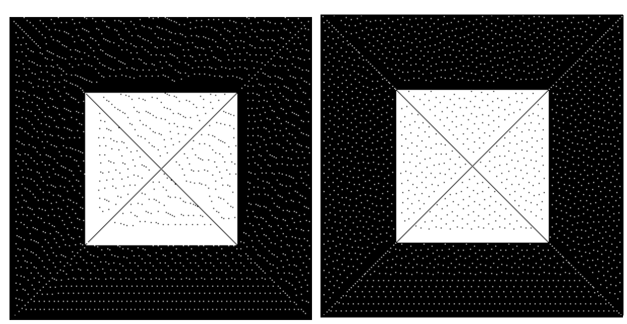
Fig.3 Zigzag Scan

Threshold modulation

The problem of the conventional error diffusion is not only wormy patterns. The dot's delay degrades the image quality so much. Threshold modulation is applied to solve this problem. Here the threshold is modulated by the input value. Actually, the threshold T (x, y) is given by using average filter *avg*(x, y) and laplacian filter *hps*(x, y) in Eq.(4).

$$T(x,y) = a \cdot avg(x,y) + b \cdot hps(x,y) \tag{4}$$

Where *a,b* are constant and a<0,b>0. Fig.4 shows the effect on the dot's delay by threshold modulation.



Conventional ED Threshold modulation

Fig.4 Threshold Modulation

Swiching of error filters

The error filters diffuse the error created as a result of the pixel binarization to the two-dimensional space. The structure of those filters varies the quality of halftone. The conventional Floyd filter often causes vertical textures in midtone areas. Thus, Floyd's filter3) is applied in highlight and shadow and Hong's filter4) in midtone. Fig.5 shows the switching error filter.

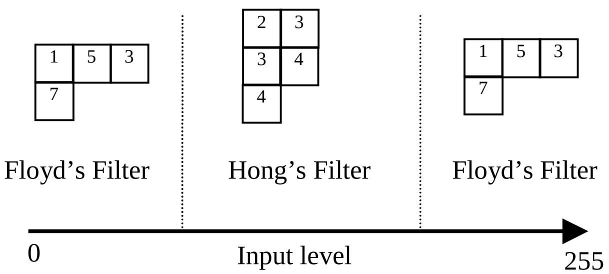


Fig.5 Error filters switching corresponding to the input value

As a result the vertical textures in midtone is well reduced Fig.6 shows comparison of EDs with and without switching.

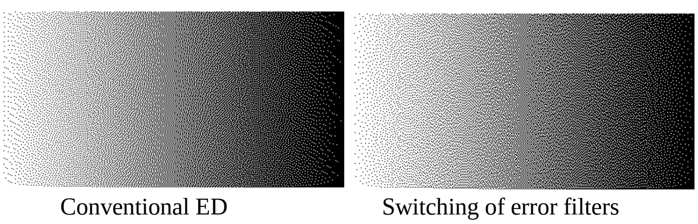


Fig.6 Switching of error filters

By combining all the above algorithms high quality binary image has been generated (Fig.7). Notice that ED Modified with AM/FM Periodic Noise is visually comfortable.

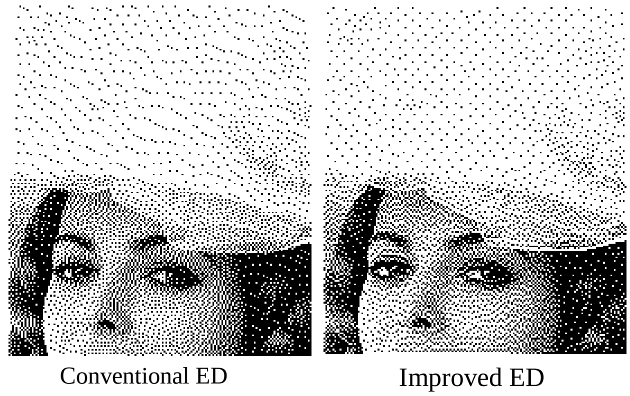


Fig.7 Improved error diffusion

Color correction

The color correction is indispensable to compensate the unwanted absorption of colorants and the nonlinear color mixing characteristics in printers. Usually the corrector is placed in front of the printer and works as the inverse transformer from the target tristimulus value $\boldsymbol{T}$ to printer drive signal $\boldsymbol{y}=[C, M, Y]^t$ as.

$$\boldsymbol{y}=\boldsymbol{\Phi}_{OUT}^{-1}(\boldsymbol{T})\cong \boldsymbol{M}_{PRNT}\, \boldsymbol{f}_P(\boldsymbol{D}) \qquad (5)$$

Here, the inverse transform $\boldsymbol{\Phi}_{OUT}^{-1}(\boldsymbol{T})$ is characterized by polynomial expansions $\boldsymbol{f}_P(\boldsymbol{D})$ derived from the tri-color density signal $\boldsymbol{D}$.

Where $\boldsymbol{f}_P(\boldsymbol{D})$ includes two steps of signal conversions as follows. First, CIE-XYZ tristimulus input $\boldsymbol{T}$ is transformed into CIE-RGB signal $\boldsymbol{x}_{RGB}$ by 3x3 linear matrix $\boldsymbol{M}_{RGB}$ as

$$\boldsymbol{x}_{RGB}=[R, G, B]^t = \boldsymbol{M}_{RGB}\, \boldsymbol{T} \qquad (6)$$

Next, $\boldsymbol{x}_{RGB}$ is converted into logarithmic density signal $\boldsymbol{D}_{RGB}$ as

$$\boldsymbol{D}_{RGB}=[-log_{10}R, -log_{10}G, -log_{10}B]^t=[D_R, D_G, D_B]^t \qquad (7)$$

The matrix $\boldsymbol{M}_{PRNT}$ is optimized to minimize the approximation errors in Eq. (5) by the method of least squares. In the simple color matching system, a single matrix $\boldsymbol{M}_{PRNT}$ is uniformly applied to correct all of the pixels in whole color space. Nonlinear color correction matrices has been conveniently applied to reduce the color

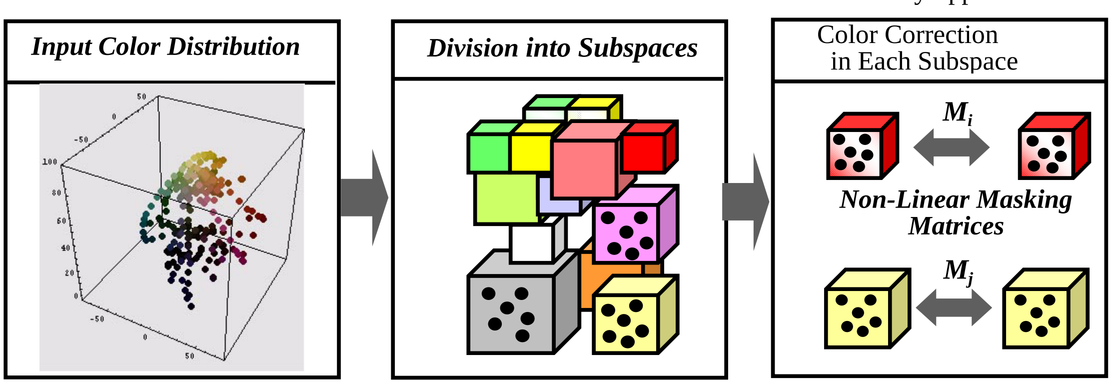


Fig.8 Color correction in subspaces with constant samples

reproduction errors. The color matching accuracy is expected to be furthermore improved when nonlinear matrices are optimized in subdivided smaller color spaces than in entire space. The smaller is the volume of subspace, the higher the color matching accuracy. However, as the number of partitions increases in the conventional uniform division, the enough sample number to determine the color masking coefficients is not always guaranteed in every subspace. We reported 2 a subspace division method based on constant sample number as shown in Fig.8 Here the Polar coordinate division method in Fig.9 has been applied to the partitioning where each subspace is bounded with nonuniform intervals to include the same number of color samples enough to the calculation. CIELAB color space is partitioned into M x N subspaces along the following two directions.

The forward transfer function of printer was characterized by measuring the tristimulus values of N=512 printed color patches for drive signal $\boldsymbol{y}$ and the 3 x 10 matries $\{\boldsymbol{M}_{PRNT}\}$ were optimized in M=8 subspaces by using the 2 nd order nonlinear masking function $\boldsymbol{f}_P(\boldsymbol{D})$.

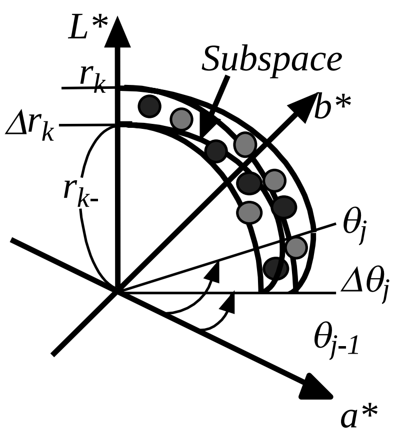


Fig.9 Polar coordinate division method

Result

Fig.10 shows the experimental results of printed color image.
(a): Conventional ED
(b): Modified ED
(c):Conventional ED with color correction
(d): Modified ED with color correction
comparing (a)~(c),color reproduction and image quality was improved in (d).

Conclusion

Conventional ED was improved and reduced unpleasant texture by the addition of the noise, zigzag scanning, threshold modulation and switching error filter. In addition to color correction the propose algorithm is available to generate high quality binary color image.

(a) Conventional ED (b) Modified ED

(c) Conventional ED with color correction (d) Modified ED with color correction

Fig.10 Resultant image(600 x 800pixels)

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Biography

Yasuhiko Kishimoto received the BS degree in Image Science from Chiba University in 1998. He is a student at Graduate School of and Technology, Chiba University. His current interests include color reproduction, error diffusion, and vector error diffusion for halftoning technology.