Modified Error Diffusion with Smoothly Dispersed Dots in Highlight and Shadow

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Abstract

Error diffusion (ED) method is a major stream in digital halftoning, but the unpleasant wormy textures have not been agreeable to the people who are familiar with halftone screen in the conventional printing. The wormy patterns are more noticeable in the highlight, shadow and flat gray scale areas. This paper proposes a simple and easy way to reduce these wormy patterns. 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. The wormy dot patterns are forced to be arranged by adding the periodic noise before thresholding. Furthermore, the phase angle of the periodic noise is modulated by the rule to suppress the regular textures which appear mostly in the flat gray scale areas. In this paper, the experimental results are reported using inkjet printer and the image quality 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. One of the most unpleasant factors in ED is "wormy textures" in the highlight and shadow area of the output image. The wormy patterns are unpleasant visually. In the lower dot density areas like highlight as well as shadow, uniform dot distributions are preferred to human vision. So far many modified algorithms are presented to reduce the wormy patterns. This paper proposes a simple algorithm to suppress those wormy patterns with lower computation costs. The algorithm employs a specialized periodic noise. By adding the periodic noise to the highlight and shadow areas before thresholding, the diffused errors from neighbor pixels are modified and wormy patterns are forced to be regularly arranged. Furthermore, the periodic noise is adjusted to be vanished in the midtone. Because the noise is symmetrically added to an input level, the intensity of output image is preserved. The sinusoidal wave is simply used as the periodic noise.

Error Diffusion Using a Periodic Noise

The proposed ED process is summarized as follows: Let I(x,y) and O(x,y) denote the input and output values at pixel(x,y) respectively. The error created as a result of the pixel binarization is diffused in according with the weights of ED filters, given by Floyd and Steinberg, Jarvis and Judice, and so on. In this paper, Floyd and Steinberg's filter is used because its output image is more detailed and the calculation is simpler.

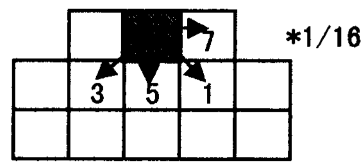


Figure 1. Weights Used in Floyd and Steinberg

The diffused error is added to the current pixel for determining the output pixel value. The modified input pixel value I'(x,y) is calculated from the input value I(x,y) and the diffused errors E(x,y) as given in Eq. (1). The output O(x,y) and error E(x,y) are expressed by Eq. (2) and Eq. (3):

$$I'(x,y) = I(x,y) + \frac{\sum_{i,j} a_{i,j} E(x+i, y+j)}{\sum_{i,j} a_{i,j}} \tag{1}$$

where $a_{i,j}$ is the coefficient of ED filter.

$$O(x,y) = \begin{cases} 0, & \mathit{if} \quad I'(x,y) < 128 \\ 255, & \mathit{otherwise} \end{cases} \tag{2}$$

$$E(x,y) = I'(x,y) - O(x,y) \tag{3}$$

Here, the periodic noise (PN) is added together with errors from neighbor pixels as follows:

$$I'(x,y) = I(x,y) + E(x,y) + PN \tag{4}$$

Where the periodic noise at the current pixel(x,y) is denoted as follows:

$$PN = A \sin\left(\frac{x}{\lambda} + \frac{y}{\lambda}\right) \tag{5}$$

We define the amplitude A by Eq. (6), 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.

$$A = Ao\left\{\frac{\sum_{m=-2,n=-2}^{2} I(x+m,y+n)}{25} - 127.5\right\}^{\delta} \qquad (6)$$

Where Ao is a constant and δ is set to $\delta > 1$.

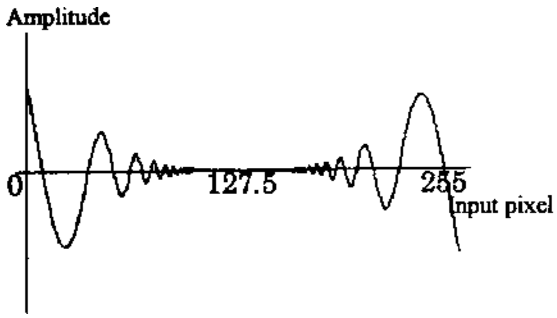


Figure 2. General shape of the periodic noise

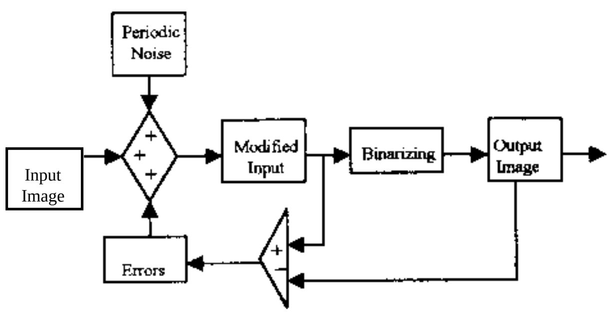


Figure 3. Graphical representation of proposed algorithm

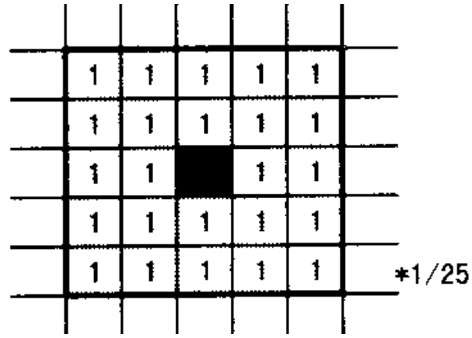


Figure 4. The averaging filter to decide the amplitude of the periodic noise

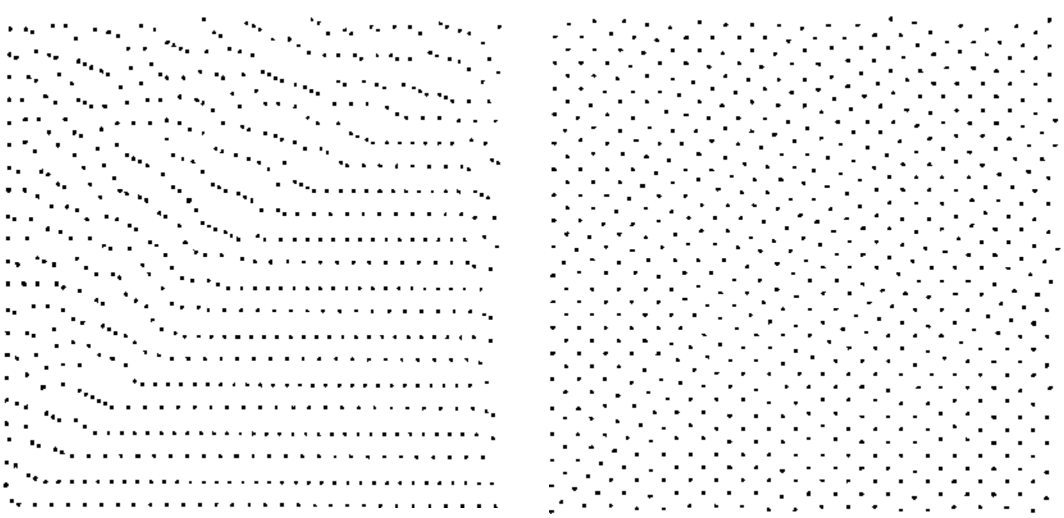
Thus, the periodic noise works strongly in the highlight and shadow area, gradually decreasing its amplitude into the midpoint of gray scale as shown in Fig. 2. The period denoted λ is changed according to input pixel value in the highlight and shadow area as given by:

$$\lambda = \begin{cases} \dfrac{1}{\sqrt{2}} \cdot \sqrt{\dfrac{255}{I(x,y)}}, & if \;\; I(x,y) < 128 \\ \dfrac{1}{\sqrt{2}} \cdot \sqrt{\dfrac{255}{255 - I(x,y)}}, & Otherwise \end{cases} \qquad (7)$$

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

Experimental Results

The proposed algorithm has been tested on several images. In all cases, the original weights suggested by Floyd and Steinberg have been used for the computation and $\delta = 3$ has been selected experimentally. Fig. 5(a) shows



(a) standard ED *(b) propsed ED*

Figure 5. Binary images applied to gray level "247".

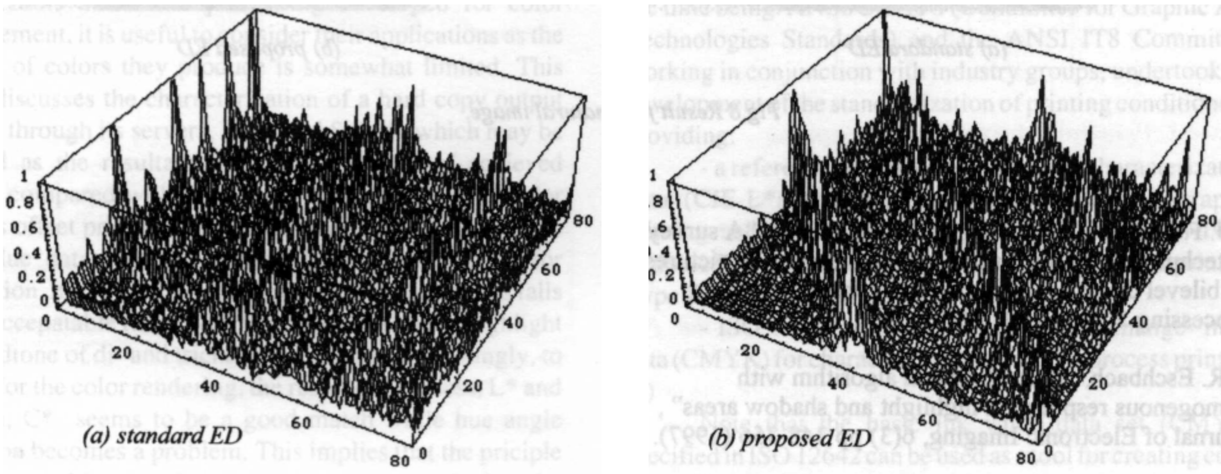
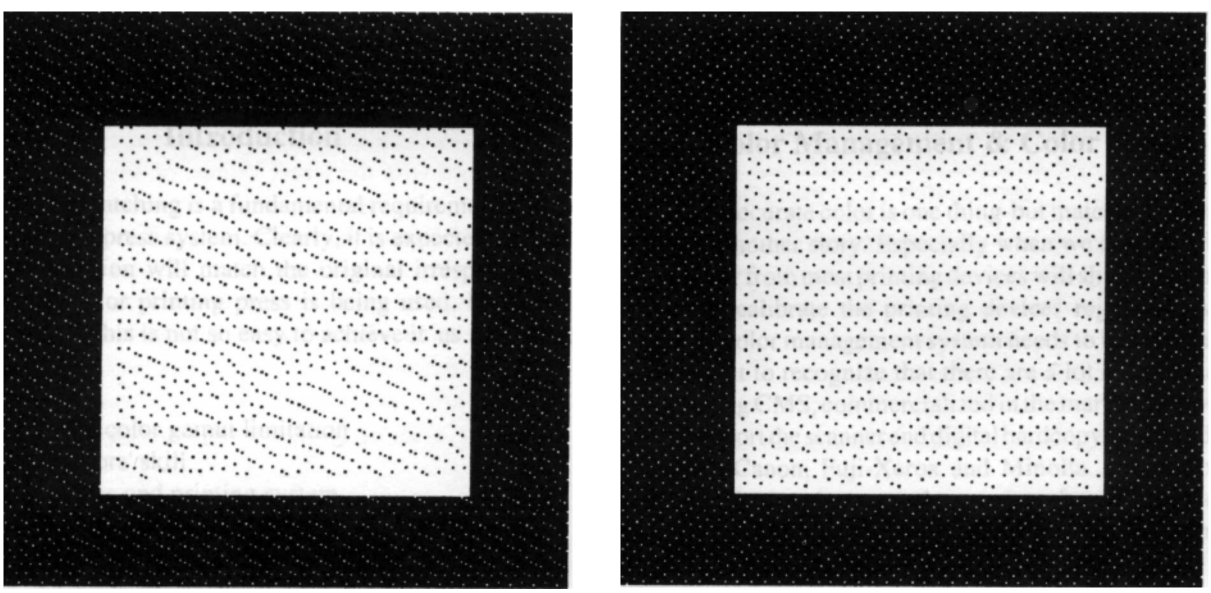


Figure 6. Spatial frequency distributions for gray level “247”.



(a) standard ED *(b) propsed ED*

Figure 7. Binary images applied to a set of patches with gray levels “247” in highlight and “15” in shadow.

(a) standard ED

(b) propsed ED

Figure 8. Result for natural image.

the result of binarizing the highlight with gray level 247 using the standard ED by Floyd and Steinberg. The wormy patterns are clearly visible. Fig. 5(b) shows the result by the proposed algorithm applied to the same input gray level, where the wormy patterns in the gray scales are greatly reduced. Fig. 6 shows spatial frequency distribution of the gray level by discrete Fourier transform (DFT). The lower frequency spectra unpleasant to human vision are suppressed and major energies are concentrated to the higher frequency areas. Fig. 7 shows another result to be noticed. As seen in Fig. 7(a), standard ED can't generate the dots at the bottom of the highlight area. This vacant area is caused by storing effect of diffusion errors before thresholding. On the other hand, in Fig. 7(b), the proposed algorithm can generate the dots at the boundaries of black and white patterns. Fig. 8(a) shows the result by the standard ED algorithm applied to the image of woman's face. The part of her hair shows some random white dot patterns. On the other hand, in (b) by the proposed algorithm, the random patterns are changed into regularly arranged white dots.

Conclusion

The highlight and shadow behavior of error diffusion is very important in the reproduction of the images with smoothed gray scales. Adding a periodic modulation noise to input in the ED process, the distributions of output dots tend to be regularly arranged. This effected both uniform dispersion and early occurrence of dots. The proposed algorithm is available to generate high quality binary images with lower computation costs.

References

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