A row-oriented multiscale error diffusion technique for digital halftoning

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Abstract

In this paper, a digital halftoning method is proposed to diffuse error with a more symmetric error distribution by making use of the concept of multiscale error diffusion. It can improve the diffusion performance by effectively reducing directional hysteresis. The diffusion is row-oriented rather than frame-oriented and hence can reduce the latency and a lot of computation effort as compared with conventional multiscale error diffusion schemes. This makes it possible for real-time applications.

Index terms (included in Electronics Letters): Signal representation, Image processing

Keywords (not included in Electronics Letters): Halftoning, Error diffusion, Quantization, Multiscale processing

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1 Introduction

Digital halftoning is a method that uses bilevel pixels (black and white pixels) to simulate a gray-scale image on a bilevel output device. Among the many available schemes we have nowadays, error diffusion[1] is believed to be one of the most effective approaches which can provide the best quality. However, directional hysteresis is unavoidable in conventional error diffusion schemes since sequential predetermined order is required to diffuse the quantization error. Some recently proposed schemes can reduce or even completely solve the problem. However, since they are typically either of iterative nature[2] or frame-oriented[3, 4], they may not be practical for real-time applications.

In this paper, a digital halftoning method eligible for real-time applications will be presented. This method diffuses error with a more symmetric error distribution by making use of the idea of multiscale error diffusion. multiscale error diffusion is superior to conventional error diffusion methods such as [1] in a way that no sequential predetermined order is required for error diffusion. The diffusion suggested in this paper is row-oriented rather than frame-oriented and hence can reduce a lot of computation effort as compared with conventional multiscale error diffusion schemes such as [3] and [4]. It also reduces the latency as it can start processing as long as a row instead of a frame is ready. These advantages make it practical for real-time applications.

2 Algorithm

Consider digital halftoning is applied to a gray-level input image $\mathbf{X}$ whose values are within [0,1] to obtain an output binary image $\mathbf{B}$. Without loss of generality, that they are of size $2^k \times 2^k$ each, where k is a positive integer, is assumed. The proposed algorithm is row-oriented and a row-by-row strategy is exploited. For each row, an appropriate number of dots are assigned one by one to the row and the error is diffused correspondingly in a diffused error image $\mathbf{E}$ until the total error of the row is bounded in absolute value by 0.5. Whether white dots or black dots are assigned depends on the total energy of the row. If the average energy of a pixel in the row is less than 0.5, white dots will be assigned. Otherwise, black dots will be assigned. This reduces the number of dots needed to be handled so as to reduce the realization effort further. The error image $\mathbf{E}$ is initialized to be $\mathbf{X}$ at the beginning. The following describes how to assign white dots to the row with a two-step iterative algorithm in details. When black dots are assigned to the row, the same procedures can still be exploited with a trick. Specifically, this can be achieved by inverting the elements of the current row and the next row of $\mathbf{E}$ with $e_{i,j} = 1 - e_{i,j}$ before processing the row, and, after processing the row, inverting the corresponding rows of the updated $\mathbf{E}$ and the output of the row in $\mathbf{B}$.

1. Determine the right location of a new dot:

The location where a new white dot (value=1) should be introduced is determined via the so-called 'maximum error intensity guidance'. It starts with the corresponding row of the error image $\mathbf{E}$ as the segment of interest. Then the segment of interest is divided into 4 non-overlapped subsegments of equal length. Any two adjacent subsegments are combined to form a candidate segment. From the three candidate segments formed, the one with the largest sum of its all elements is selected to be the new segment of interest. Whenever the segments are of equal amount of error, one of them is randomly selected. This step is repeated until a particular pixel location is reached. Unlike [3] and [4], the search is one-dimensional rather than two-dimensional and hence the realization effort can be greatly reduced.

2. Update error image $\mathbf{E}$:

After locating the right pixel position, a white dot is assigned to it. Without loss of generality, that the white dot is assigned to the pixel at location (m,n) by making $b_{m,n}$=1 and that a diffusion filter with a support window $\Omega \equiv \{(x, y)|\ 0 \leq x, |y| \leq half\ window\ size\}$ is used are assumed. Let $e_{i,j}$ be the value of the pixel of $\mathbf{E}$ at location (i,j) before the error diffusion. Then, after the error diffusion, the value of $e_{i,j}$ is updated to be

$$e_{i,j} := \begin{cases} 0 & if \quad (i,j) = (m,n) \\ e_{i,j} - w_{i-m,j-n}(1 - e_{m,n}) & else \end{cases} \tag{1}$$

where := is the assignment operator, $w_{u,v}$'s are the filter weights and $\sum_{(u,v)\in\Omega} w_{u,v} = 1$. Note this assignment causes no error leakage in the error diffusion and the algorithm works with any choice of filter, producing different results.

After assigning an appropriate number of dots to the row, there is some residue error in the row. It should be diffused to the next row. Let the current row be the i^{th} row of the image and $e_{i,j}$ be the residue error at position (i,j). Then the error of the next row is updated as follows.

$$e_{i+1,j} := e_{i+1,j} + \sum_{n=-W}^{W} w'_n e_{i,j-n} \qquad \forall\ j \tag{2}$$

where w'_n's are filter weights and $2W+1$ is the size of the error diffusion filter exploited in this step. In order to avoid error leakage, $\sum_{n=-W}^{W} w'_n = 1$ should be guaranteed.

After diffusing the residue error of the row, we proceed to process the next row. These steps are repeated until the whole image is processed.

3 Simulation results

Simulations have been carried out to evaluate the performance of the proposed algorithm. Figure 1a shows a 256 $\times$ 256 point light source pattern. Figures 1b-f show the results obtained with various algorithms. The two filters used in the proposed algorithm for generating the results are, respectively, $\begin{bmatrix} 0.25 & \bullet & 0.25 \\ 0.125 & 0.25 & 0.125 \end{bmatrix}$ and $\begin{bmatrix} 0 & \bullet & 0 \\ 1/3 & 1/3 & 1/3 \end{bmatrix}$, where $\bullet$ denotes the position from where the error diffuses. The figures are deliberately printed with a 600dpi laser printer so that the individual dots can be clearly printed and the effect of dot overlapping is not dominant. One can clearly see the pattern noise in Figures 1b and 1c especially in the upper right quadrant, while one hardly finds any in Figure 1f. As compared with Figures 1d and 1e, Figure 1f appears to be 'smoother', which report the original more faithfully.

4 Conclusion

In this paper, a new row-oriented digital halftoning algorithm based on multiscale error diffusion is proposed. Its row-oriented nature significantly reduces the latency and the complexity for processing and hence it is more suitable for real-time applications as compared with those frame-oriented multiscale error diffusion algorithms. Simulation results show that its diffusion result is better than those of other algorithms which are dedicated to removing directional hysteresis.

References

[1] Floyd, R. W. and Steinberg, L.: "An Adaptive Algorithm for Spatial Gray Scale," Proc. SID International Symposium Digest of Technical Papers, Society for Information Displays, 1975, pp.36-37.

[2] Kumar, A. and Makur, A.: "On the phase response of the error diffusion filter for image halftoning," IEEE trans. on image processing, Sep 1999, Vol.8, No.9, pp. 1282-1292

[3] Chan, Y.H.: "A modified multiscale error diffusion technique for digital halftoning," IEEE Signal Processing Letters, Nov 1998, Vol.5, pp.277-280.

[4] Katsavounidis, I. and Kuo, C.C.J.: "A multiscale error diffusion technique for digital halftoning," IEEE trans. on image processing, Mar 1997, Vol.6, pp.483-490.

[5] Fan, Z.: "Error diffusion with a more symmetric error distribution," Proc. of SPIE, Vol.2179, 1994, San Jose, CA, USA, pp.150-158.

Figure captions:

Figure 1.	(a):	Original test pattern;
	(b):	Diffusion result of standard error diffusion[1];
	(c):	Diffusion result of [5];
	(d):	Diffusion result of [2];
	(e):	Diffusion result of [3];
	(f):	Diffusion result of the proposed algorithm.

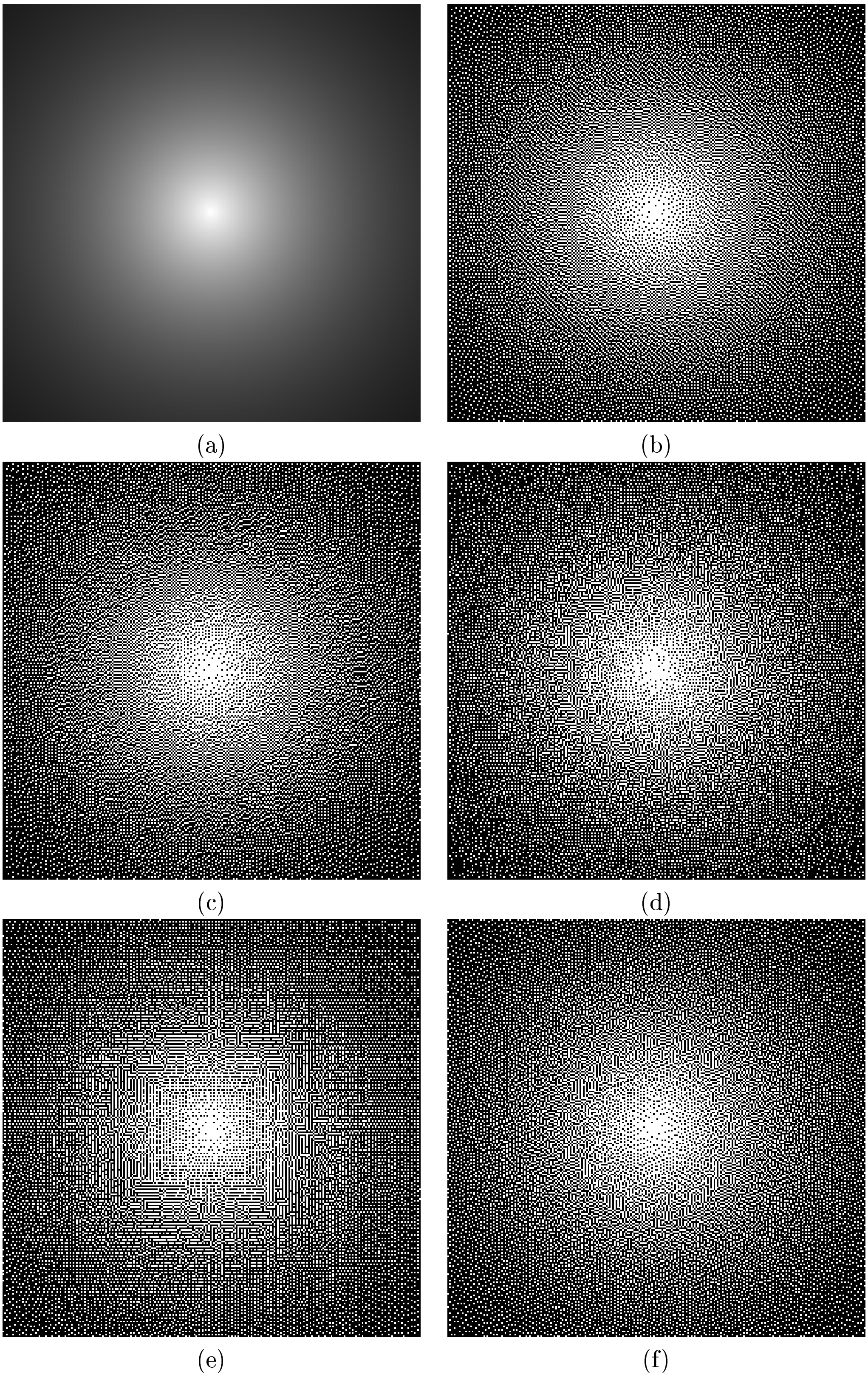

Figure 1: (a): Original test pattern; (b): Diffusion result of standard error diffusion[1]; (c): Diffusion result of [5]; (d): Diffusion result of [2]; (e): Diffusion result of [3]; (f): Diffusion result of the proposed algorithm.