A ROW-ORIENTED 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 a lot of computation effort as compared with conventional multiscale error diffusion schemes. This makes it possible for real-time applications.

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. Numerous techniques have been developed to alleviate the problem. The simplest one might be reversing the direction of processing every scanline, but it just covers the problem without solving it from the root. 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, 5], they may not be practical for real-time applications.

The idea of multiscale error diffusion technique is first proposed by [4] and further developed by [3]. Algorithms based on this idea are superior to the conventional error diffusion methods such as [1] in a way that no sequential predetermined order is required for error diffusion. Accordingly, non-causal filters can be used in diffusing quantization error to avoid directional hysteresis. However, as we have mentioned, these algorithms are frame-oriented and hence are not suitable 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. The diffusion 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], which makes it possible for real-time applications.

2. ALGORITHM

Consider we want to apply digital halftoning to a gray-level input image **X** whose values are within [0,1] to obtain an output binary image **B**. Without loss of generality, we assume they are of size $2^k \times 2^k$ each, where k is a positive integer. Our proposed algorithm is a row-oriented algorithm. We proceed with a row-by-row strategy. For each row, we assign appropriate number of white dots one by one to the row and diffuse the error correspondingly until the total error of the row is bounded in absolute value by 0.5. Then, we diffuse all residue error in that row to the next row at a time. These steps are repeated until the whole image is processed.

The assignment of white dots to a row is a two-step iterative algorithm. At each iteration, we first introduce a white dot (value=1) at one location of the corresponding row of the output image **B**. The location is chosen in a greedy way based on a corresponding diffused error image **E**. Then we diffuse the error to the neighbors of that pixel to update the error image **E**. These procedures are repeated until the sum of all elements of the corresponding row of **E** is bounded in absolute value by 0.5.

The error image **E** is initialized to be **X** at the be-

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ginning. The following describes how to assign white dots to the row in details.

1. Determine the right location of a new dot:

The location where a new white dot should be introduced is determined via the so-called 'maximum error intensity guidance'. We start with the corresponding row of the error image **E** as our line segment of interest. Then we divide the segment of interest into subsegments and select the one with the largest sum of its all elements to be the new segment of interest. Whenever the segments are of equal amount of error, we randomly select one of them. This step is repeated until a particular pixel location is reached.

Note we partition the line segment of interest into 3 overlapped subsegments instead of 2 non-overlapped subsegments as shown in Figure 1. Flexibility is introduced by doing so as more possible paths are available to reach a particular location. It is potentially difficult to be trapped in a local optimum and hence the segment of the most significant error can be taken care in a earlier stage. Besides, it is difficult to fall into a particular dot assignment pattern caused by the limited number of paths, which is helpful to reduce the pattern noise in the output. Finally, since we allow subsegments to overlap each other, there will not be any boundary effect.

2. Update error image **E**:

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

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

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 appropriate number of white dots to the row, there are residue error in the row. We diffuse all residue error in that row 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.

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

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, we have $\sum_{n=-W}^{W} w'_n = 1$.

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 2a shows a 256 × 256 point light source pattern. Figures 2b-f show the results obtained with various algorithms. The two filters used in our algorithms for generating the results are respectively given as $\begin{bmatrix} 0.25 & \bullet & 0.25 \\ 0.125 & 0.25 & 0.125 \end{bmatrix}$ and $\begin{bmatrix} 0 & \bullet & 0 \\ 1/3 & 1/3 & 1/3 \end{bmatrix}$, where • denotes the position from where the error diffuses. We deliberately printed the figures using 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 2b and 2c especially in the upper right quadrant while hardly find any in Figure 2f. Figures 3a-d show another simulation result on a ramp image of size 256 × 256. One can see that the diffusion result of the proposed method is subjectively better than others.

4. CONCLUSION

In this paper, we proposed a new row-oriented digital halftoning algorithm based on multiscale error diffusion. The proposed algorithm can effectively reduce pattern noise and eliminate the 'blackhole' effect. Its row-oriented nature 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.

5. REFERENCES

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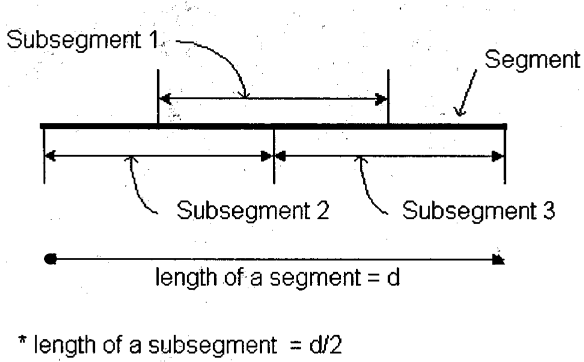

Fig. 1. Subsegments of a segment of interest.

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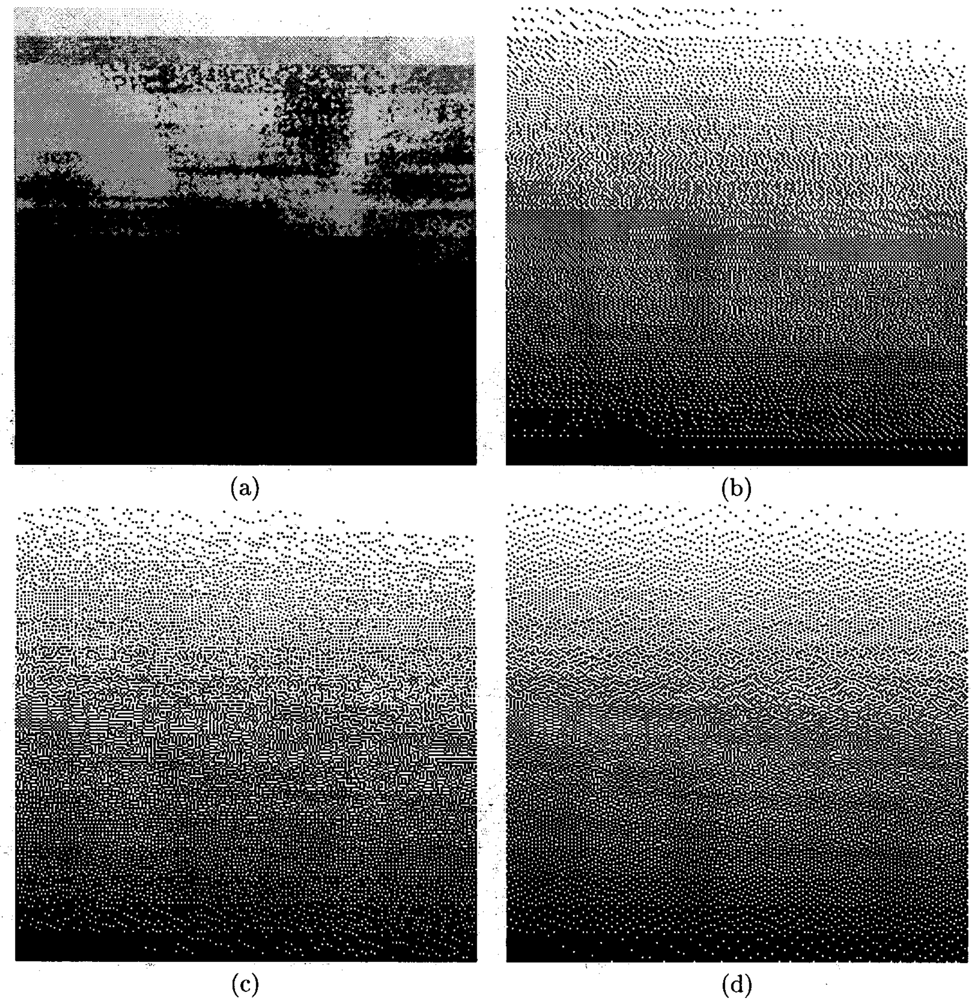

Fig. 3. (a): Original ramp image; (b): Diffusion result of [5]; (c): Diffusion result of [2]; (d): Diffusion result of the proposed algorithm.

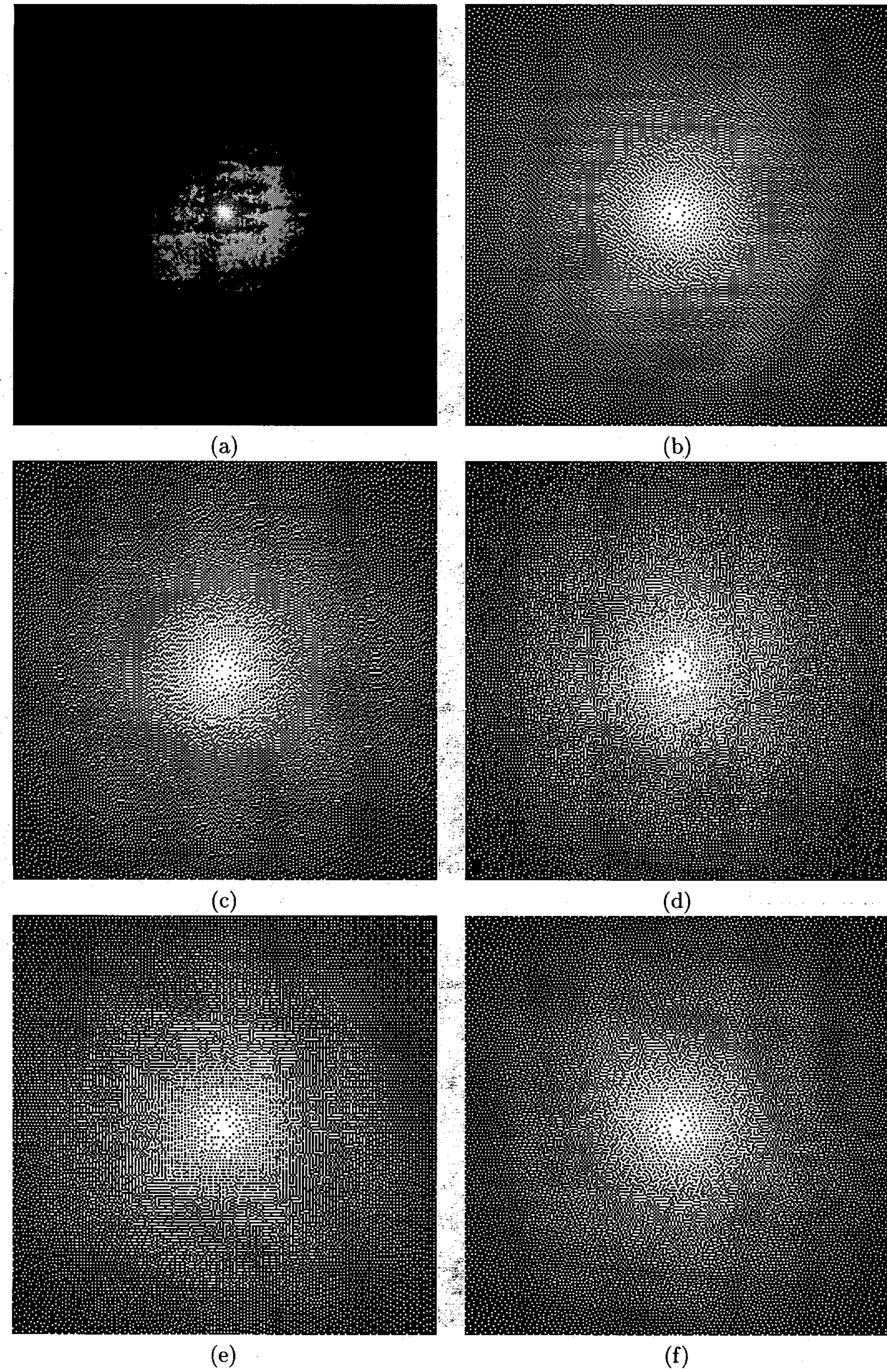

Fig. 2. (a): Original test pattern; (b): Diffusion result of standard error diffusion[1]; (c): Diffusion result of [5]; (d): Diffusion result of [2]; (e): Diffusion result of [3]; (f): Diffusion result of the proposed algorithm.