# PRESERVING IMAGE FEATURES IN DIGITAL HALFTONING WITH A MULTISCALE ERROR DIFFUSION TECHNIQUE

*Yuk-Hee Chan and Sin-Ming Cheung*

Center for Multimedia Signal Processing
Department of Electronic and Information Engineering
The Hong Kong Polytechnic University
Hung Hom, Kowloon, Hong Kong

## ABSTRACT

Multiscale error diffusion is superior to conventional error diffusion methods in digital halftoning as it can completely eliminate directional hysteresis. However, there is a bias to favor a particular type of dots in the course of the halftoning process. In this paper, a new multiscale error diffusion method is proposed to improve the diffusion performance by reducing the aforementioned bias. The proposed method can also eliminate the boundary effect found in conventional multiscale error diffusion methods and preserve the local features of the input image in the output. This is critical to the quality when the resolution of the output is limited by the physical constraints of the display unit.

## 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. Recently, a multiscale error diffusion technique has been proposed [1]. Methods using this technique are superior to conventional error diffusion methods such as [2] 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.

Multiscale error diffusion is basically realized with a two-step iterative 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. At each iteration, a white dot (value=1) is first introduced at one location of the output image **B**. The location is chosen in a greedy way based on a corresponding diffused error image **E**. Then the error at that position is diffused to the neighbors of that pixel to update the error image **E**. These procedures are repeated until the sum of all elements of **E** is bounded in absolute value by 0.5. The error image **E** is initialized to be **X** at the beginning.

An interesting observation we have had is that, in this multiscale error diffusion technique, only white dots are assigned to **B**. Black dots are not concerned during the process. This implies that the diffusion technique favors bright area or bright features. Conceptually, such a bias should be avoided. In other words, one should assign black dots as well as white dots to **B** in the halftoning process as typical error diffusion schemes such as [2] do. Another observation we have had is that, in a bright region, the positions of black dots are more critical than that of white dots. Minority dots are generally more outstanding in a region and hence they should be used to highlight the local features in the region. Accordingly, in a bright region, black dots instead of white dots should be handled first due to their higher priority. Similar consideration should be made when handling a dark region. In this case, white dots should be of higher priority.

In this paper, based on the idea we have presented, a new diffusion algorithm is proposed to improve the multiscale error diffusion technique by reducing the bias to a particular type of dots and preserving the features in a particular region of the image in the output to a certain extent. A simple trick is also presented in this paper to reduce the boundary effect introduced in Katsavounidis's algorithm[1].

## 2. ALGORITHM

Our proposed algorithm is also a two-step iterative algorithm. At each iteration, we first introduce a dot at one location of the output image **B**. 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 **E** is bounded in absolute value

This work was supported by POLYU Grant G-W034.

0-7803-7503-3/02/$17.00 ©2002 IEEE

by 0.5. The error image $\mathbf{E}$ is initialized to be $\mathbf{X}$ at the beginning.

First of all, the default type of dots used in the halftoning process is determined. The total energy of the image is estimated to determine how many white dots we have to introduce during the halftoning process. If it is more than half of the total number of pixels, it is better to introduce black dots instead of white dots so as to reduce the realization effort. Black dots will be used as the default type of dots in this case. Otherwise, white dots will be used by default. Here, without losing the generality, we assume white dots should be introduced. If it is the opposite, one can invert $\mathbf{X}$ before carrying out the proposed algorithm and complement the output at the end.

1. Determine the right location of a new dot:

At the beginning of each iteration, we assume a white dot is to be introduced in the iteration. Note that this assumption is based on the default type of dots we have selected. In contrast to conventional multiscale error diffusion algorithms, The location where a new white dot should be introduced is determined via the 'extreme error intensity guidance' instead of the 'maximum error intensity guidance'. We start with the error image $\mathbf{E}$ as our region of interest. Then we divide the region of interest into subregions and select the one with the largest sum of its all elements to be the new region of interest. This step is repeated until a particular subregion of particular size is reached. Then, we investigate whether the average energy of $\mathbf{E}$ in that subregion is larger than a threshold $T_e$. If the criterion is satisfied, the subregion will be declared to be a bright region and we will further check whether the number of black dots introduced to the region does not exceed the total number of black dots should be introduced. If this criterion is also satisfied, the dot to be introduced should be changed to a black one in this iteration. This can be realized by inverting the active elements of $\mathbf{E}$ in the corresponding subregion with $e_{i,j}$=1-$e_{i,j}$, where $e_{i,j}$ denotes the value of the pixel of $\mathbf{E}$ at location (i,j). Active elements are those elements whose corresponding elements in $\mathbf{B}$ have not yet been assigned a dot. After making the decision and working accordingly, we repeat the aforementioned division procedure as before until a particular pixel location is reached. Note, even though we always select the region with the largest sum of its all elements, we are not following the 'maximum error intensity guidance' as the $\mathbf{E}$ may be inverted in the course. We are actually following the 'minimum error intensity guidance' when it is inverted.

In Katsavounidis's approach [1], a region of interest is partitioned into 4 non-overlapped subregions to locate the next region of interest. At a particular scale, the borders of regions are fixed, which restricts how to locate the next region of interest to a certain extent. In other words, boundary effect exists. A simple trick is introduced in our algorithm to reduce this effect. Before realizing the proposed two-step algorithm, an 1-pixel frame of value 0 and an 1-pixel frame of value 1 are, respectively, added to $\mathbf{E}$ and $\mathbf{B}$ first. At each iteration, the size of the starting region of interest remains to be that of the original $\mathbf{E}$ but the region is shifted by a random offset ($x_{off}$, $y_{off}$), where $x_{off}$ and $y_{off} \in$ [-1,0,1]. By doing so, the borders of regions vary at different iterations and hence the boundary effect can be reduced. After all dots are assigned, the frame of $\mathbf{B}$ is removed to get the final halftoned output.

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

After locating the right pixel position, a dot is assigned to it. The dot could be a white dot or a black dot and it depends on the decision we have made in step 1. Here, we assume a white dot is assigned to the selected position, say, (m,n), by making $b_{m,n}$=1 and a noncausal diffusion filter with a support window $\Omega \equiv \{(x,y)|\ 0 \leq |x|,|y| \leq half\ window\ size\}$ is used. Let $e_{i,j}$ and $b_{i,j}$ be respectively the values of the pixels of $\mathbf{E}$ and $\mathbf{B}$ at location (i,j) after the dot assignment but before the error diffusion. Then, after the error diffusion, the new value of $e_{i,j}$, say $e'_{i,j}$, is assigned to be

$$e'_{i,j} = \begin{cases} 0 & if \quad (i,j)=(m,n) \\ e_{i,j} - w_{i-m,j-n}\bar{b}_{i,j}(1-e_{m,n})/s & else \end{cases} \tag{1}$$

where $w_{u,v}$'s are the filter weights, $\bar{b}_{i,j} = 1 - b_{i,j}$, and

$$s = \sum_{(i-m,j-n)\in\Omega} w_{i-m,j-n} \times \bar{b}_{i,j} \tag{2}$$

Note this assignment causes no error leakage in the error diffusion and the algorithm works with any choice of filter, producing different results. In the case when s=0, we exploit a filter with larger support window to make $s \neq 0$ and keep the algorithm work.

In Katsavounidis's approach [1], quantization error at (m,n) will be diffused to its neighbors even though they are already assigned to be white dots. this amount of error will then be stored in these locations forever and will not contribute to the following quantization and diffusion stages. This effect results in an uneven error image $\mathbf{E}$ at the end and makes the introduced dots not properly distributed in a local region. Our proposed approach can obviously solve this problem.

If the dot to be assigned to the position is a black one, the same procedures for assigning a white dot can still be exploited. Since **E** was inverted earlier, carrying out the same procedures is actually equivalent to assigning a black dot to the position as long as an adjustment is performed afterwards. Specifically, the adjustment is made by inverting the active elements of the updated **E** in the concerned subregion with $e_{i,j}$=1-$e_{i,j}$ and inverting $b_{m,n}$ back to zero after performing the procedures described above..

## 3. SIMULATION RESULTS

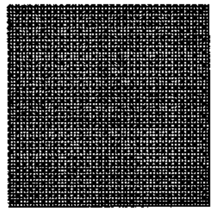
Simulations have been carried out to evaluate the performance of the proposed algorithm. Figure 1 shows some of the simulation results. They are actually cut from the halftoning results of image *Lena*. Figures 1b and 1c show the results obtained with our algorithm while Figure 1d shows the results obtained with Katsavounidis's algorithm. The 3×3 non-causal diffusion filter used in [1] was used to realize all three algorithms. However, the size of the filter used was adjusted when s=0 happened in realizing our algorithms. The decision of introducing a white dot or a black dot is made when the region of interest is of size 16×16. By comparing the figures, one can see that the local features are clearly preserved in Figures 1b and 1c while some of them are missing in Figure 1d. This is especially observable in the hair and the rim of the hat. The diffusion result of [2] is shown in Figure 3e for reference. The local features are also missing in the figure.

The region of interest can be divided into 9 overlapped subregions instead of 4 non-overlapped subregions to locate the next region of interest at a particular scale [3]. The proposed algorithm works better with the 1-to-9 scheme as it is less restricted. Figures 1b and 1c, respectively, show the case of using the 1-to-4 scheme and that of using the 1-to-9 scheme.

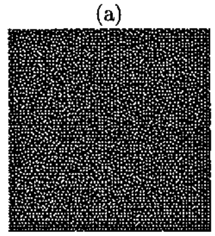
Figure 2 shows the diffusion results of different algorithms when they are used to process a flat gray-level image of intensity level $\frac{50}{255}$. One can see that there is serious pattern noise in Figure 2a. As Katsavounidis's algorithm partitions a region into non-overlapped subregions in a fixed manner, it results in a fixed dot assignment pattern and hence pattern noise is unavoidable in a flat region. The proposed approach can definitely solve this problem.

## 4. CONCLUSIONS

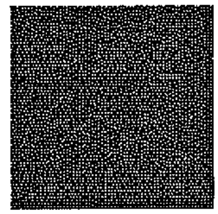
In this paper, we proposed a new digital halftoning algorithm based on multiscale error diffusion. In contrast to [1], the "extreme error intensity guidance" principle is adopted. This reduces the bias to bright areas and preserves the local features in the image. Besides, the proposed algorithm can effectively remove the boundary effect.



(a)



(b)



(c)

Figure 2: Diffusion results of a flat image of gray level $\frac{50}{255}$ (a): Katsavounidis's algorithm [1]; (b): proposed algorithm with the 1-to-4 division scheme; (c): proposed algorithm with the 1-to-9 division scheme.

## 5. REFERENCES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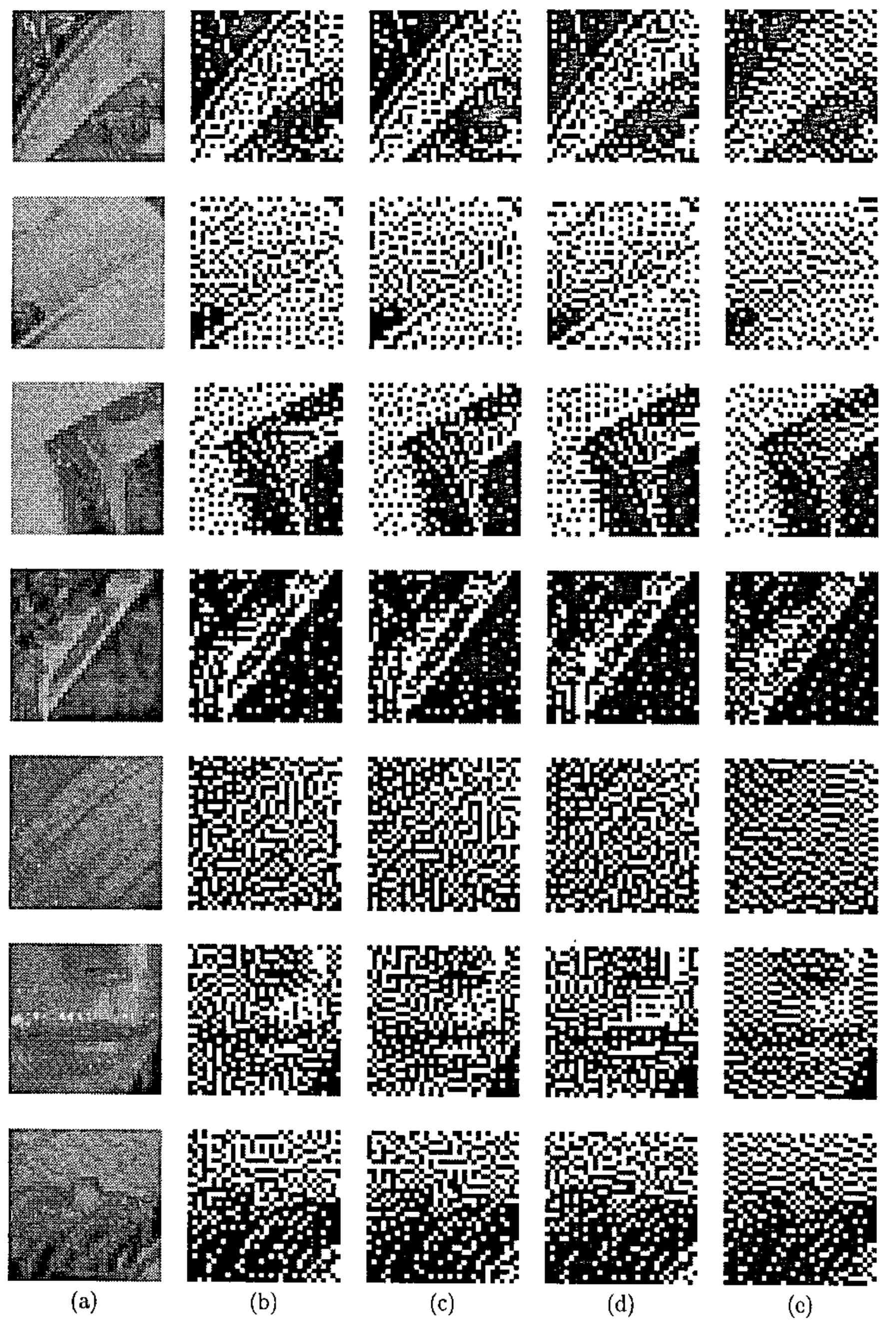

Figure 1: Regions of (a): original image *Lena*; (b): diffusion result of the proposed algorithm (with the 1-to-4 division scheme); (c): diffusion result of the proposed algorithm (with the 1-to-9 division scheme); (d): diffusion result of [1]; (e): diffusion result of [2].