Information Systems 48 (2015) 241–247

Contents lists available at ScienceDirect

Information Systems

journal homepage: www.elsevier.com/locate/infosys

# Multiscale rank-based ordered dither algorithm for digital halftoning

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ARTICLE INFO

Available online 14 July 2014

*Keywords:*
Ordered dither
Error diffusion
Multiscale error diffusion
Halftoning
Thresholding
Dither array

ABSTRACT

In this paper, we proposed a simple and efficient algorithm that is based on the ranking of brightness within block. It builds the cumulative intensity quadtree for each block and generates the digital halftone's image using its information. We did the quality assessment for the result image of the proposed algorithm. As a result of experiment, it generates the digital halftone's image that is a little worse than that generated by error diffusion method, but it has merits to be implemented easily in parallel hardware because of block processing and simple operations. So we can conclude that the proposed algorithm is a very practical method to apply to the hardware implementation.



## 1. Introduction

Digital halftoning is a technique to display an image with only black and white colors. Since halftoning has been around for quite a long time, there have been a number of techniques developed to make high quality halftone [1–4]. This process is necessary when a monochrome or color image is printed by a printer with limited number of ink colors. These techniques have used screens and gauzes and then have been translated directly to digital halftoning techniques.

Among these techniques, the popular digital solution is the ordered dither technique, where a two-dimensional threshold array is designed and the halftoning process is accomplished by a simple pixel-wise comparison of the grayscale image against the array [1,2]. The more popular technology of halftoning algorithms is error diffusion method that propagates quantization errors to unprocessed neighboring pixels according to some fixed ratios. The error diffusion preserves the average intensity level between the original input images and the binary output image. Further, the error diffusion produces good half tone image despite relatively low cost [5–7].

However, since ordered dither and error diffusion algorithm may generate worm artifacts especially in the image areas of flat intensity, various modification are proposed [1–7]. Also there is another research area of halftone in the parallel on a GPU [8]. Newer devices allow each ink to be printed in various intensities, essentially offering multiple quantization levels and thus reducing quantization noise and improving the appearance of the printed images [9–11].

Ordered dither is very simple and thus be able to be implemented easily in parallel hardware. So in this paper, we proposed the multiscale rank-based ordered dither (MRBOD) algorithm which is simple and implemented easily in hardware. This generates the better halftoning image than that generated by ordered dither technique, but the worse halftoning image than that generated by error diffusion method. But the proposed algorithm can be implemented easily like the ordered dither algorithm.

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http://dx.doi.org/10.1016/j.is.2014.06.012
0306-4379/

## 2. Related works

This section analyzes two main streams of digital halftoning algorithms and the algorithm related with my paper. Section 2.1 describes ordered dither array to threshold the value of image. Section 2.2 describes conventional error diffusion which uses a fixed error filter. Section 2.3 describes the multiscale error diffusion algorithm.

### 2.1. Ordered dither

Halftoning by ordered dither (OD) is a point processing where computation uses only the current pixel in the input image to generate the corresponding pixel in the output image. it means that no surrounding pixels are used [1–4]. The input is quantized based on a dither value from a deterministic and periodic dither array. The values of dither array are "ordered" rather than "random".

However the OD array is not unique. Two classes of OD array are commonly used: dispersed-dot and cluster-dot. In a dispersed-dot OD array, consecutive entries visited are far apart, while in clustered-dot dither, they are adjacent or almost so. Fig. 1 gives four examples of OD array [5]. In Fig. 1, (a) and (c) are dispersed-dot OD array; (b) and (d) are clustered-dot OD array.

Let $f(i, j)$ be the normalized grayscale image defined on domain $D$, where $D$ has the size of $I \times J$. A dither array $D$ is $m \times n$ array containing all the integers from 0 to $mn-1$. Then the set of threshold values of OD array is given as follows:

$$Th(k) = \frac{2k+1}{2mn}, \quad k = 0, 1, \ldots, mn-1. \qquad (2-1)$$

And the output image $b$ of the OD halftoning algorithm is like that as follows:

$$b(i, j) = \begin{cases} 1 & \text{if } f(i, j) \ge Th(D(i \bmod m, j \bmod n)) \\ 0 & \text{otherwise} \end{cases}. \qquad (2-2)$$

### 2.2. Error diffusion

Error diffusion algorithm was proposed by Floyd and Steinberg. They called their algorithm error diffusion (ED) because they diffused the quantization error over the neighboring continuous-tone pixels. This method is not a point process but a neighborhood process because the output is determined by the value of current pixel along with values of pixels surrounding it. The block diagram for grayscale ED method is shown in Fig. 2 [5–8].

In the ED algorithm, the pixel value $b(i, j)$ of output binary image is determined in raster (or serpentine) scan order. The value of $b(i, j)$ is determined simply by thresholding as follows:

$$b(i, j) = \begin{cases} 1 & \text{if } u(i, j) > 1/2, \\ 0 & \text{if } u(i, j) \le 1/2. \end{cases} \qquad (2-3)$$

Clearly, the quantization error is computed by

$$e(i, j) = u(i, j) - b(i, j) \qquad (2-4)$$

Note that the ED algorithm selects the pixel values of the output binary image to minimize the absolute value of error $|e(i, j)|$. After that, it distributes the weighted error to the set of unprocessed pixels as follows:

$$f(i+k, j+l) = f(i+k, j+l) + w_{k,l} \cdot e(i, j). \qquad (2-5)$$

where $w_{k,l}$ are coefficients of error filter. The commonly used coefficients for error filters are those as shown in Fig. 3. In Fig. 3, (a) are coefficients of Floyd–Steinberg (raster) algorithm, (b) are coefficients of Floyd–Steinberg (serpentine) algorithm, (c) is Javis (raster) algorithm and (d) is Stuki (raster) algorithm.

The success of ED algorithm lies in the fact that it is a "good blue-noise generator" as pointed out by Quing Yu [4]. In the academic literature, the nature of noise is often described by a color name: i.e., white-noise is so named because of its flat power spectrum. On the other hand, blue-noise has most of its energy located at high spatial frequencies with very little low frequency component. Patterns with blue-noise characteristics generally enjoy the benefits of aperiodically uncorrelated dot patterns without low-frequency graininess [6].

### 2.3. Multiscale error diffusion

The multiscale error diffusion (MED) algorithm was proposed by Katsavounidis and Kuo [9,10]. In contrast to

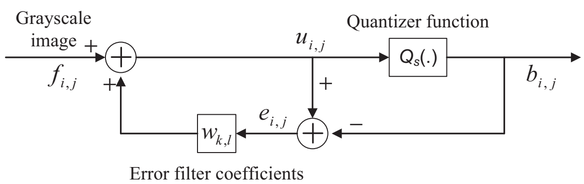


**Fig. 2.** The block diagram of error diffusion (ED) algorithm.

a

| | |
|---|---|
| 0 | 2 |
| 3 | 1 |

b

| | |
|---|---|
| 0 | 1 |
| 3 | 2 |

c

| | | | |
|---|---|---|---|
| 0 | 8 | 2 | 10 |
| 12 | 4 | 14 | 6 |
| 3 | 11 | 1 | 9 |
| 15 | 7 | 13 | 5 |

d

| | | | |
|---|---|---|---|
| 6 | 7 | 8 | 9 |
| 5 | 0 | 1 | 10 |
| 4 | 3 | 2 | 11 |
| 15 | 14 | 13 | 12 |

**Fig. 1.** Examples of ordered dither array.