An Improved Error Diffusion Algorithm Based on Laplacian Transform and Adaptive Median Filter

Xiaoguo Shi and Xueqing Li

Department of Computer Science and Technology, Shandong University
Jinan, 250101, China
rockworldto@hotmail.com, xqli@sdu.edu.cn

Abstract. In this paper, we propose an error diffusion algorithm that produces higher visual quality results while preserving fine texture details and high contrast present in the original images. Based on the analysis of the Laplacian kernel, we get an edge-enhanced image with the Laplacian transform. Next, we use the adaptive median filter to remove noises and preserve sharpness in the edge-enhanced images. Besides, error diffusion(E-D) by Stucki is adopted to get our halftoning results. Multiple experiments show that our method is superior to the improving mid-tone E-D especially in preserving texture details and contrast. Combined good visual properties with fast speed, our method has significantly improved the user perception and may be applied to most real-world applications.

Keywords: Halftoning, Laplacian transform, Error diffusion, Adaptive median filter, User perception.

1 Introduction

Halftoning refers to converting a continuous-tone image into a pattern of black and white dots. For high practical value, halftoning techniques have been continuously studied for several years [1]. Typical algorithms such as ordered dithering [2], Floyd-Steinberg E-D [3], and dot-diffusion [4] have been widely applied into the fields of printing devices and image display. Although ordered dithering has the fastest speed, its poor quality can't meet the needs of many practical applications.

Analoui et al.[5] first introduced a model based halftoning using direct binary search. It is a typical iterative algorithm to obtain the minimal difference between the halftone image and human visual perception via a HVS model. More recently, the high-profile structure-aware halftoning has been introduced by Pang et al. [6]. Although excellent results are generated, these methods can't be applied into real-world applications due to a large amount of computing time.

At present, researchers mainly focus on improving existing halftone algorithm. For instance, many methods have been proposed to improve E-D algorithm in aspects such as threshold optimization, diffusion coefficients and processing paths. Stucki [7] improved E-D by extending the distribution range to second-level unprocessed neighbors(neighbors of neighbors). Ostromoukhov [8] put forward intensity-dependent variable diffusion coefficients in order to remove patches of regular structure. To break regularities near critical intensity levels, Zhou and Fang [9] further developed this

C. Stephanidis (Ed.): HCII 2014 Posters, Part I, CCIS 434, pp. 540–545, 2014.

method by introducing intensity-dependent noise. Howerver, blurred texture details and poor contrast are two big drawbacks for methods of this type.

Contrast is a topic often neglected, though not inevitably. To preserve the contrast as well as texture details to the original images, we present an improved E-D algorithm based on the Laplacian operator [10] and adaptive median filter [11]. To begin with, the original image is processed with the Laplacian operator, then we obtain an edge-enhanced image. Next, adaptive median filter acts on edge-enhanced images with fine contrast to remove noises and preserve sharpness. Finally, error diffusion by Stucki [7] is run to get the final halftoning results.

To verify the performance of our method, we applied it to various types of images. Simulation results show that our algorithm preserves fine visually sensitive texture details with an ideal contrast especially for the weak texture regions. Our method has successfully improved the user experience due to its good visual perception and fast speed.

2 Our Approach

As shown in Figure 1, we present an overview of our improved E-D algorithm based on the Laplacian operator [10] and adaptive median filter [11] in this section. In the following parts,we analyze our approach in detail.

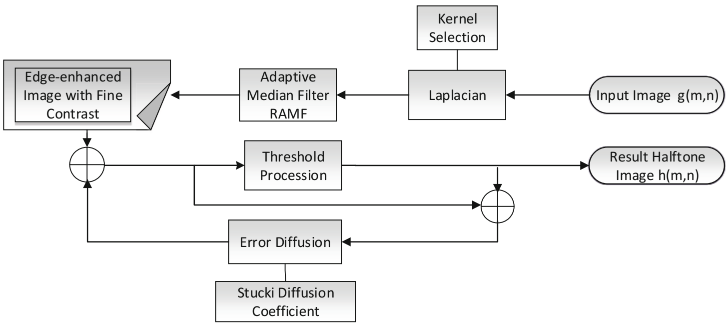

Fig. 1. Schematic representation of the architecture of our method. Please refer to Section 2 for the meaning of all terms.

2.1 Original Image Enhancement

We assume that $g(m, n)$ is an original grayscale image. The Laplacian transform [10] of $g(m, n)$ is defined as

$$\nabla^2 g(m, n) = \partial^2 g(m, n)/\partial m^2 + \partial^2 g(m, n)/\partial n^2 \tag{1}$$

After the original grayscale image $g(m,n)$ is processed with the Laplacian transform, we get an edge-enhanced result $e(m,n)$ which is defined as follows:

$$e(m,n) = \begin{cases} g(m,n) - \nabla^2 g(m,n) & C(m,n) < 0 \\ g(m,n) + \nabla^2 g(m,n) & C(m,n) > 0 \end{cases} \quad (2)$$

where $C(m,n)$ is the center coefficient of Laplacian transform. Experimental results show that the edge-enhanced effect in $e(m,n)$ changes with different Laplacian kernels. We will further analyze Laplacian kernels in Section 3.1.

2.2 Adaptive Median Filter

To smooth noise in the reconstructed continuous tone image and reduce distortion around the object edge, we process $e(m,n)$ with the $RAMF$ (ranked-order based adaptive median filter [11]), which has variable window size for removal of impulses while preserving sharpness.

$$e'(m,n) = |ifft\{fft[e(m,n)] \cdot RAMF\}| \quad (3)$$

where fft is the Fourier transform and $ifft$ is the inverse Fourier transform.

2.3 Diffusion Coefficient Selection

In order to better preserve textures in the error diffusion process, we adopt Stucki's [7] diffusion coefficients which extend the distribution range to second-level unprocessed neighbors. Table 1 shows the Stucki error diffusion filter.

Table 1. Stucki E-D filter

		X	8	4
2	4	8	4	2
1	2	4	2	1

3 Results and Analysis

In this section, we analyze the Laplacian kernel to archive an satisfactory edge-enhanced image firstly. Then the performance of our method is evaluated with visual comparison. In our work, we test our algorithm with the set of images[Figure 2,3,4] already shown in Pang's paper [6]. This test set comprises a wide range of important natures: smooth tone gradation, rich details of various contrasts and visually identifiable textures.

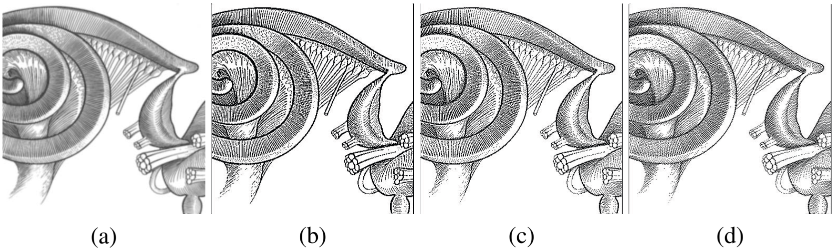

Fig. 2. Image "snail shaped organ" with the resolution of 384×399. Edge-enhanced images with different Laplacian kernels. (a) Original image; (b) kernel = [-1 -1 -1; -1 9 -1; -1 -1 -1]; (c) kernel = [0 -1 0; -1 5 -1; 0 -1 0]; (d) kernel = [1 -2 1; -2 5 -2; 1 -2 1];

3.1 Laplacian Kernel Analysis

In our algorithm, the Laplacian kernel is required to control the edge-enhanced effect. Figure 2 illustrates that how results produced by our method can be influenced by the Laplacian kernel. Experiments show that satisfactory results including subjective and objective evaluations can always be obtained when kernel = [1 -2 1; -2 5 -2; 1 -2 1]. Therefore, we test our algorithm with the above Laplacian kernel in the following parts.

3.2 Visual Comparison

Figures 3 and 4 visually compare our results to those of Folyd-Steinberg E-D, Stucki's method [7] and the improving mid-tone E-D [9]. Compared to these methods, our results better reproduces the range of contrasts and texture details. In addition, our method preserves fine texture details and clear lines especially for the low contrast and weak texture regions. However, the other three methods all lose the structure of textures more or less in the same areas. It represents that our algorithm performs excellent in structure preservation. In Figure 4, we leave out the result of Folyd-Steinberg E-D because of space, since this method has been undeniable outperformed by the improving mid-tone E-D.

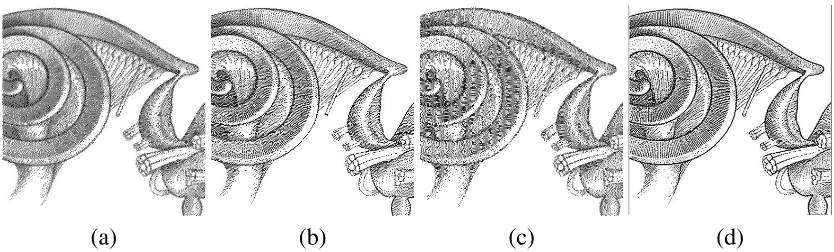

Fig. 3. Halftoning images with different algorithms. (a) Floyd-Steinberg E-D; (b) Stucki's method; (c) Improving mid-tone E-D; (d) Our method;

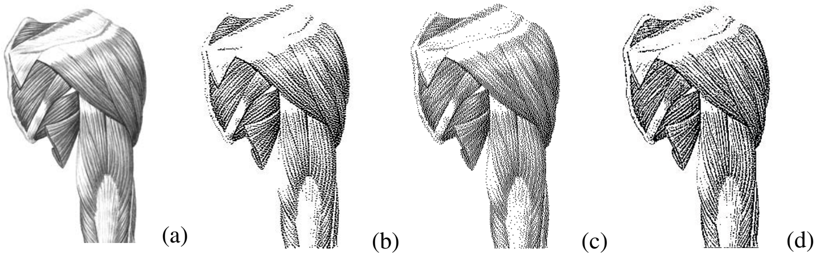

Fig. 4. Image "arm" with the resolution of 200×307; (a) Original image; (b) Stucki's method; (c) Improving mid-tone E-D; (d) Our method;

4 Conclusion

In this paper, we have presented an error diffusion algorithm based on the Laplacian transform and adaptive median filter. Results in the experiment show that our method combines texture details and contrast successfully. Compared to the well-known halftoning algorithms [3] [7] [9], our algorithm outperforms these approaches and presents both fine texture details and high contrast.

Due to its excellent user experience, our method has successfully enhanced the user perception for the regions with low contrast and weak textures. Meanwhile, the visually pleasing halftone images are more easily identified by the human eyes, especially in the field requiring a color quantization algorithm.

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