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Appearance-Preserving Error Diffusion Algorithm Using Texture Information

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Abstract

Digital halftoning is a technique for converting a continuous-tone image into a binary image with the aim of reproducing it on a binary output device. Error diffusion (ED) is an algorithm that has proven to be effective for the halftoning process, and it has been widely applied to digital printing tasks. However, in images reproduced by conventional ED algorithms based on signal processing theory, the total appearance of objects—which includes properties such as glossiness, transparency, and roughness—is often lost. In this paper, we propose an appearance-preserving ED algorithm to improve the quality of printed images. We consider a texture-preserving approach to effectively represent the total appearance of objects. In this study, we utilized different weights for the error distribution based on the texture strength to permit stable representation of the pixels relevant to the texture. Experimental results using printed images demonstrated that the proposed algorithm improved the quality of printed images relative to images produced by conventional techniques.

Introduction

Digital halftoning, being essential to the printing process, is one of the oldest applications of image processing. Digital halftoning simulates a grayscale image using only black and white tones. A variety of halftoning methods have been proposed [1]-[3] and are commonly used together with error diffusion (ED) [4]. Many studies have been conducted on improving the "image quality" of ED with respect to tone, gradation, sharpness, among other parameters.

Of late, the representation of the "total appearance" of an image, which includes properties such as its glossiness, transparency, and roughness, has become important for reproducing images on display devices. Research projects on material appearance have been launched in the US, Europe [5],[6], and Asia [7],[8]. Discussions on the topic have also been held at the Material Appearance in Electronic Imaging conference. However, there has been little discussion on the reproduction of the total appearance in printing.

This paper proposes an appearance-preserving ED algorithm to improve the total-appearance qualities of halftone images. We address technical challenges in the software realm that will ultimately lead to a solver able to attractively represent the appearance of objects in an image, regardless of the tone of the image, without requiring new hardware to be developed. The design of our algorithm is based on the assumption that the total appearance is highly dependent on the texture representation of the image content. Therefore, we consider a texture-preserving approach to effectively represent the total appearance of objects. In this study, we prepared different weights for the error distribution between the texture and other regions to permit stable detection of the texture pixels.

Related Works

ED is one of the most popular half-toning methods proposed by Floyd and Steinberg [4]. Error diffusion is known to be an algorithm that is simple and fast, and which produces good results. There are a variety of ED masks designed to enhance Floyd's method (e.g., by Stucki [9], and by Shiau and Fan [10]). Additionally, there are many other approaches to improving error diffusion. One of the simplest techniques for improving the half-toning quality is to change the scanning direction and error diffusion masks. This approach, alternately scanning left to right and right to left, is called serpentine scanning. There are also ways to reduce banding effects by adding random noise.

Some research has focused on quality loss at the edges due to the ED algorithm. Fung and Chan [11] and Li [12] used algorithms that focused on edges and led to edge-preserving error diffusion techniques. In these studies, edge information was used directly. In another approach to improve the quality of quantized images by using edge information, Pang et al. [13], Lee et al. [14] and Shi & Li [15] focused on weak textures vanishing in the quantization process and proposed half-toning algorithms to preserve these weak textures using edges. Their methods aim to emphasize edges that disappear in the printing process, and do not satisfy the principle of quantizing with maintaining average pixel values.

There are some half-toning algorithms using printer models. Pappas [16], Lee [17], and Lai [18] proposed half-toning algorithms that focused on dot gain and overlap of ink. Yampolskiy et al. [19] proposed a special half-toning algorithm based on the genetic algorithm. Their methods were proposed for natural images, and these methods mainly improve tone reproduction. Therefore, their goals were different from ours.

Method

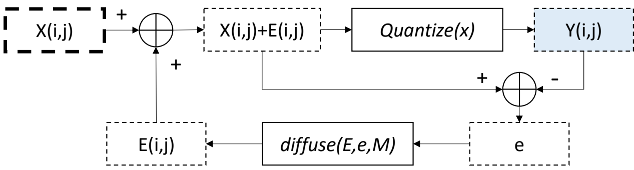
To detect texture pixels that are related to the total appearance, we construct an appearance-preserving ED algorithm using a novel function. Figure 1 shows the outline of (a) a typical ED algorithm and (b) the proposed ED algorithm.

X, Y, and E represent an 8-bit input image, the quantized output image, and the error image, respectively. $X(i, j)$ denotes the (i, j)-th element of the image matrix. In a typical ED algorithm in Fig. 1(a), we quantize the pixels from left to right, in descending order as follows:

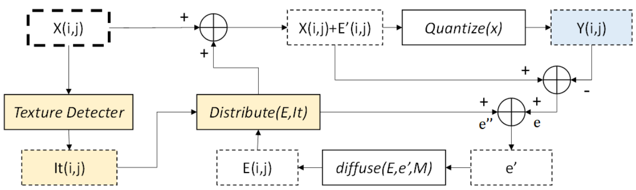
$$Y(i,j) \Leftarrow Q(X(i,j)+E(i,j)) \tag{1}$$

where $Q(x)$ is a quantization function given by

$$Q(x)=\begin{cases}0, & x<128\\ 255, & 128\le x\end{cases}. \tag{2}$$



(a) Typical ED algorithm.



(b) Proposed algorithm.

Figure 1. Outline of quantization processing performed by ED algorithms.

The quantization error can then be calculated as follows:

$$e \Leftarrow X(i,j) + E(i,j) - Y(i,j). \tag{3}$$

The error is diffused by applying a mask M to the neighborhood pixels. Upon renewing the error image E, we apply the procedure to the subsequent pixels.

In principle, the above ED spatially distributes the error regardless of whether the pixel of interest is included in the texture portion. In this study, we preprocess the original image by obtaining texture information from it. This texture information is preserved by means of the ED. Various methods exist for detecting texture, but we use the following method. First, a Sobel filter is applied to the original image to calculate the intensity of edge $I_e(i,j)$. Next, to exclude contour information from the information on detected edges, the edge variance $I_\sigma(i,j)^2$ of the surrounding pixels is calculated. The texture information $I_t(i,j)$ is then calculated as

$$I_t(i,j) = I_e(i,j)\left(1 - F\left(\frac{I_\sigma(i,j)}{\max I_\sigma}, g, \theta\right)\right), \tag{4}$$

$$F = \frac{1}{\exp(-g(x-\theta))}, \tag{5}$$

where the parameters of the s-curve function are empirically obtained and set to $g = 16$ and $\theta = 0.2$.

In the ED process, we quantize each pixel based on the texture information. The important thing is that using the texture information for the distribution weight, we obtain a mechanism that does not distribute error to pixels with a strong texture. As shown in Fig. 1(b), this processing algorithm is applied repeatedly to all pixels, one by one, in raster scan order as follows:

$$Y(i,j) \Leftarrow Q(X(i,j) + E'(i,j)) \tag{6}$$

where the error image *E'* is calculated by

$$E'(i,j) \Leftarrow E(i,j) \times I_t(i,j). \tag{7}$$

The quantization error can then be calculated as follows:

$$e' \Leftarrow e + e'', \tag{8}$$

where

$$e \Leftarrow X(i,j) + E'(i,j) - Y(i,j), \tag{9}$$

$$e'' \Leftarrow (1 - I_t(i,j)) \times E(i,j). \tag{10}$$

As shown in Eqs.(9) and (10), in the proposed method, in addition to the normal quantization error e, the cumulative error e'' that was not distributed according to the intensity of the texture is added.

Experiments

Physical Performances

We verified the physical performance of the proposed method by quantizing continuous-tone test images into half-tone images and comparing the results to those of conventional methods, like Floyd's [4], Pang's [13], Lee's [14], and Shi's [15] ED algorithms. Thirteen test images, including standard test images as well as test images by Pang, were used, as shown in Figure 2. Figure 3 presents an example of quantized images. This result shows an example of the effect of the proposed algorithm. Figures 3(a) and 3(b) show a continuous gray image and the detected texture using our algorithm, respectively. Figures 3(c) and 3(d) show images after halftoning. Figure 3(c) shows the result using the Floyd-Steinberg algorithm [4], and Figure 3(d) shows the result by using our algorithm. We can confirm that the proposed method can represent the texture well.

There is no objective index for evaluating total appearance. Therefore, we first consider the physical performance of the method using general image reproduction indices.

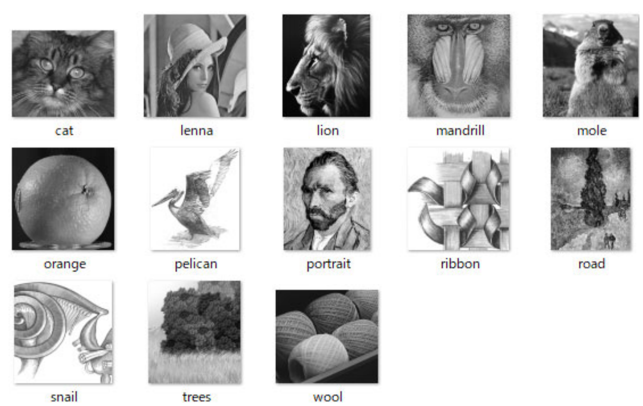


Figure 2. Test images used for physical evaluations.

Computation Time

A comparison of the performance of several algorithms, with regard to average computation time for all test images, follows. The algorithms are presented, beginning with the fastest.

Pang >> Floyd > Ours > Lee >> Shi

PSNR

The performance of several algorithms, with regard to the average PSNR for all test images, is compared below, in order of highest value to lowest.

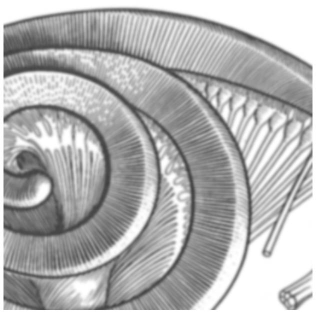
Ours ≃ Floyd > Pang > Lee ≃ Shi

The PSNR was calculated for images blurred with a Gaussian function to account for their visual characteristics.

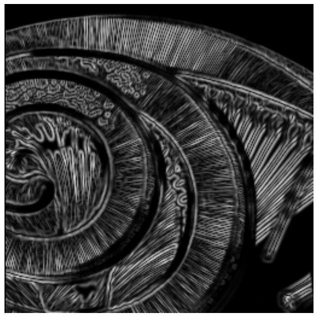
M-SSIM

The performance of the algorithms with regard to the average M-SSIM for all test images was as follows, in order of highest value to lowest.

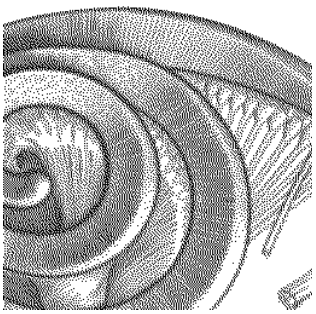
Pang > Ours ≃ Floyd >> Shi > Lee



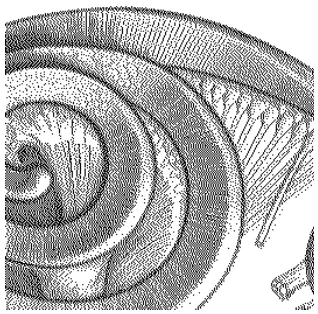
(a) Continuous-gray image



(b) Texture information



(c) Floyd's ED method



(d) Proposed ED algorithm

Figure 3. Experimental results.

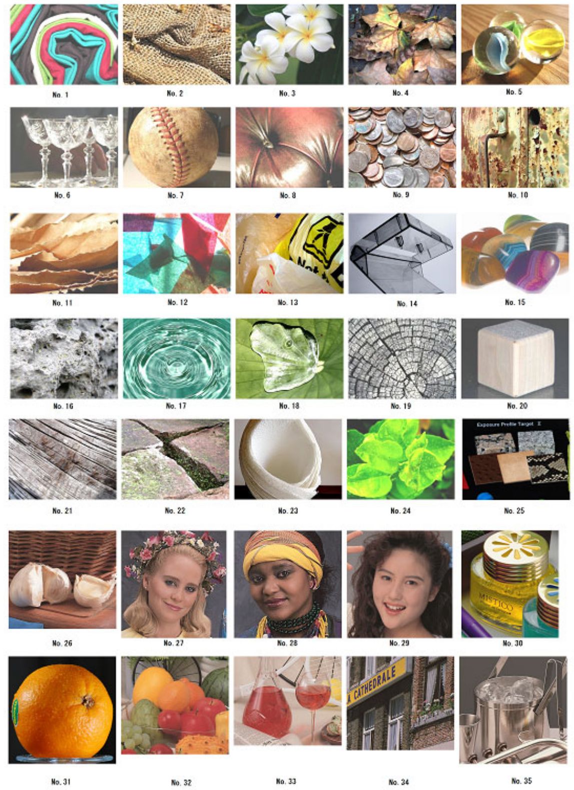
Based on these indices, the proposed method was observed to approximately perform as well as Floyd's ED algorithm. However, as mentioned above, these conventional metrics cannot evaluate the total appearance. Therefore, a psychophysical evaluation was also conducted.

Psychophysical evaluations

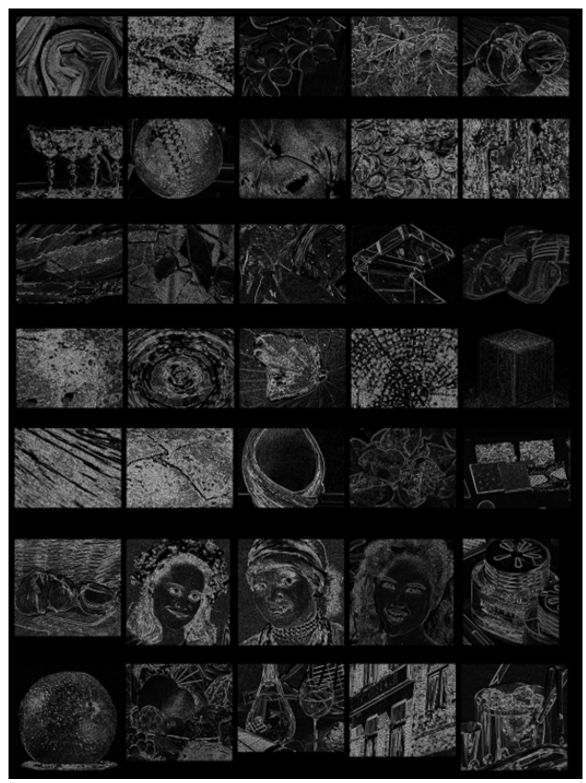
To subjectively evaluate the perceptual appearance of the test images produced by the proposed ED method and Floyd's ED algorithm, we conducted psychophysical experiments using images printed by an inkjet printer (Epson PM-A820). The ink was controlled by means of a custom-made printer driver.

Thirty-five color test images were prepared for the evaluation, as shown in Figure 4(a). Figure 4(b) shows the detected textures. Ten observers evaluated the appearance of the images with regard to glossiness, transparency, and roughness via the two-alternative forced choice (2AFC) method. 21, 13 and 35 images were selected for evaluating glossiness, transparency and roughness, respectively. Figure 5 shows an evaluation being performed by an observer.

The number of observers who favored the total appearance of images generated by the proposed ED method exceeded the number who favored that of images produced by Floyd's ED algorithm with respect to glossiness, transparency, and roughness as shown in Table 1.



(a) Test images



(b) Detected textures.
Figure 4. Test images used for psychophysical evaluations.

Figure 5. Evaluation by an observer.

Table 1. Percentage judged to have the high appearance of the enhanced print images compared with the original printed images.

	Floyd's	Proposed	Ratio
Glossiness	57.3%	77.0%	1.34
Transparency	71.2%	87.3%	1.23
Roughness	72.4%	91.6%	1.27

Conclusions

We proposed an appearance-preserving ED algorithm to improve the total-appearance qualities of halftone images. We prepared different weights for the error distribution between the texture and other regions. Experimental results demonstrated that the proposed algorithm improved the total-appearance of printed images relative to images produced by conventional techniques.

As a future work, we will continue verification on appearance other than glossiness, transparency, and roughness.

Acknowledgments

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Author Biography

Takuma Kiyotomo received the B.E. and ME degrees from Chiba University in 2016 and 2018, respectively. He was interested in quality improvement of printed images.