국부 평균과 공간 활성도를 이용한 에지 강조 오차확산법

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요 약

디지털 해프토닝은 연속계조영상과 시각적으로 유사한 이진 영상을 얻기 위한 방법이다. 이러한 해프토닝 방법 중에서 오차 확산 해프토닝은 다른 해프토닝 방법에 비해 우수한 화질을 보이지만 에지가 흐려지는 단점이 있다. 이러한 단점을 개선하기 위해, 본 논문은 인간의 시각이 국부 평균 밝기를 인식하고 공간적인 작은 변화량을 인식하지 못하는 특성을 이용하여 에지를 강조하는 개선된 오차 확산 해프토닝을 제안한다. 제안 방법은 원 화소의 명암값과 3×3 블록의 평균 명암값과의 차이 값에 공간적 위치 값에 따른 가중치를 결합하여 국부 공간 변화량을 구한다. 그 후 정규화된 공간 활성도(local activity)에 평균 명암도를 곱하여 에지 강조 정보량(IEE : information of edge enhancement)을 구하여 IEE를 양자화기 입력에 더하여 에지를 강조한다.

컴퓨터 시뮬레이션은 제안 방법이 기존의 방법에 비해 영상의 에지가 강조되어 시각적으로 선명한 영상을 생성하며 물체의 경계가 잘 보존됨을 보여준다. 또한 거리에 따른 에지 상관도와 로컬 평균 일치도에서도 기존의 방법에 비해 개선된 결과를 보여준다.

키워드 : 해프톤, 오차 확산, 에지 강조, 이진 영상, 공간 활성도

Edge-Enhanced Error Diffusion Halftoning using Local mean and Spatial Activity

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ABSTRACT

Digital halftoning is the technique to obtain a bilevel-toned image from continuous-toned image. Among halftoning methods, the error diffusion method gives better subjective quality than other halftoning ones. But it also makes edges of objects blurred. To overcome the defect, we proposes the modified error diffusion to enhance the edges using the property that human vision perceives the local average luminance and doesn't perceive a little variation of the spatial variation. The proposed method computes a spatialactivity, which is the difference between a pixel luminance and the average of its 3x3 neighborhood pixels' luminance weighted according to the spatial positioning. The system also usesof edge enhancement (IEE), which is computed from the normalized spatial activitymultiplied by the average luminance. The IEE is added to the quantizer's input pixel and feeds into the halftoning quantizer. The quantizer produces the halftone image having the enhanced edge.

The computer experimental results show that the proposed method produces clearer bilevel-toned images than conventional methodsand the edge of objects is preserved well. Also the performance of the proposed method is improved, compared with that of the conventional method by measuring the edge correlation and the local average accordance at some ranges of viewing distance.

Key Words : Halftone, Error Diffusion, Edge-Enhancement, Binary Image, Spatial Activity

1. Introduction

Bilevel-toned image devices including fax machines, printers, and plasma display panels have developed rapidly and profoundly. Although these devices usually have only two levels of tones or colors in consideration of technical and economic issues, the images output by the devices must be displayed as naturally as possible. Digital halftoning has been introduced to contend with such requirements [1, 2].

Of many halftoning algorithms studied before, the error diffusion method distributes errors made at a pixel level over surrounding pixels by quantizing the pixels into bilevel tones and using an error diffusing filter that makes the average error for the entire image be zero. It is a superior rendition of continuous-toned images than the

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other halftoning algorithms. However, the error diffusion filter is designed to retain the average tone of the original image, so a degradation of edge information of the bilevel-toned image produced by this method has to occur. Truly accurate bilevel-toned images have to retain the average tone of the original image and preserve original edge information.

The studies conducted to obtain a further achievement of the error diffusion include methods to modify the error diffusion filter [3], to adaptively adjust filter coefficients to minimize local errors [4], to introduce the filter to model the property of the human visual system (HVS) [5], to utilize the characteristics of printers [6], and so on. Knox *et al.* [7] proposed the edge-enhanced error diffusion method to make clear bilevel-toned image. This method adds multiples of a current pixel to the original image in the process of error diffusion to emphasize the edges of the original image. Hwang *et al.*[8] proposed the edge-enhanced error diffusion method with a preprocessing filterin consideration of the property that HVS perceives not a pixel but also the average tone. Compared with Knox's method, thismethod generated a more natural image with enhanced edge information. However, because the method used only the difference between the current pixel and the local average of surrounding pixels to enhance edge information, it didn't preserve the detailededge of the original image. To reduce this defect, we propose the edge-enhanced error diffusion method using the local average of thecurrent pixel and the spatial activity of the surrounding pixels. The proposed method computes a local activity, which is the difference between a pixel luminance and the average of its 33 neighborhood pixels' luminance weighted according to the spatial positioning. The system also usesinformation of edge enhancement (IEE), which is computed from the normalized spatial activitymultiplied by the average luminance. The IEE is added to the quantizer's input pixel and feeds into the halftoning quantizer. The quantizer produces the halftone image having the enhanced edge.

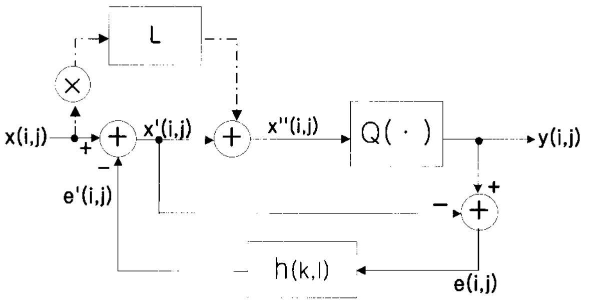
We describe the conventional error diffusion method in section 2 and explain the error diffusion method proposed by this paper in section 3. In section 4, the performance of the proposed method is compared with that of the conventional edge-enhanced methods and we conclude in section 5.

2. Error diffusion method

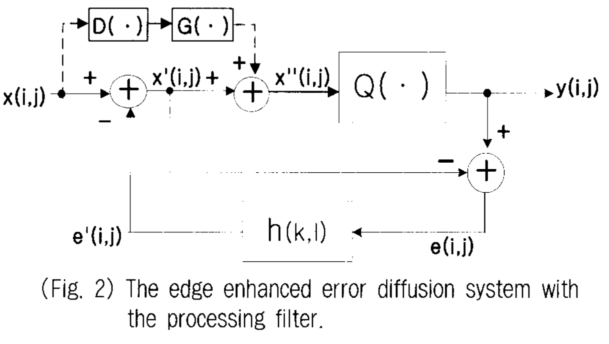
(Fig. 1) illustrates error diffusion halftoning circuit with a multiplicative parameter L by Eschbach and Knox [7]. First, the halftoning yields the modified input $x'(i,j)$ by adding a part of the quantization error generated from the previous pixels to a pixel $x(i,j)$ of an input image. Then the halftoning adds the input multiplied by multiplicative parameter L to the modified input to produce the quantizer input $x''(i,j)$. The quantizer produces $y(i,j)$ getting its result (±0.5) from a combination of the constant 0.5 and the sign of the input. The quantization error $e(i,j)$, which is the difference between the modified input $x(i,j)$ and the quantizer output $y(i,j)$, is diffused to surrounding pixels through the error filter $h(\bullet)$.

Hwang *et al.* proposed the preprocessing filter to enhance edges using the local luminance difference of the original image in consideration of the property that HVS perceives not a pixel but also the average tone. This method computes the value of the difference between the current pixel and the local average of surrounding pixels in the original image and composes a weighting function by the magnitude and the sign of the local average. The resultingweighting function is added to the input of the quantizer to enhance the edge. The overall error diffusion system by Hwang *et al.* is depicted in (Fig. 2).

In (Fig. 2), $D(\bullet)$ is the difference between the current pixel $x(i,j)$ and the local average of the 5×5 pixels surrounding the pixel in the original image. $G(\bullet)$ is the weighting function and defined with the magnitude and the sign of $D(\bullet)$. $D(\bullet)$ and $G(\bullet)$ are computed as follows:



(Fig. 1) Error diffusion halftoning circuit.



(Fig. 2) The edge enhanced error diffusion system with the processing filter.

$$D(i,j) = x(i,j) - \frac{1}{5\times 5}\sum_{k=-2}^{2}\sum_{l=-2}^{2} x(i+k, j+l) \qquad (1)$$

$$G(i,j) = \frac{a}{1+b\times|D(i,j)|}\times \mathrm{sign}(D(i,j)) \qquad (2)$$

Where x(i,j) is the current pixel at (i,j) and the coefficient a controls the emphasizing levelof reconstructed edge and b protects edge emphasis from being excessive by steep tone change.

3. Edge enhanced error diffusion using IEE

The edge-enhanced error diffusion proposed by Knox *et al.* [7] adds multiples of the current pixel to the original image in the process of error diffusion to emphasize the edges of the original image and get a clearer bilevel-toned image. However, the method generates excessive edge emphasis by steep tone change and blurs the detail of the edge because it uniformly applies the transformation to the original image without considering local area characteristics. Hwang *et al.* [8] proposed the edge-enhanced error diffusion method considering spatial information and improved the performance over that of Knox *et al.* However, as the difference value of the luminance of local area as spatial information is not enough to preserve the edge, the edge to be preservedis blurred and the bilevel-toned image is degraded. To reduce this defect, we propose a method using both the luminance average and the luminancevariation of the local area.

First, the luminance average at a 3× 3 local area is computed as follows.

$$\bar{x}(i,j) = \frac{1}{3\times 3}\sum_{k=-1}^{1}\sum_{l=-1}^{1} x(i+k, j+l) \qquad (3)$$

If the human visual system perceives the local average of the pixels surrounding thecurrent pixel at (i,j), the difference between the pixel x(i,j) and the local average is the visual perception error. Using the visual error, we define the spatial variation (V) of the current pixel. Because human vision perceives better according to horizontal and vertical directions than diagonal ones, the variation can be weighted by W(k,l) as follows:

$$V(i,j) = \sum_{k=-1}^{1}\sum_{l=-1}^{1} W(k,l)\left|x(i+k, j+l) - \bar{x}(i,j)\right| \qquad (4)$$

Where, W(k.l) is the weighting matrix for horizontal, vertical and diagonal directions. The rate of the diagonal value to the horizontal and vertical values is $1:\sqrt{2}$ and is normalized such that 0.1465 is obtained for the horizontal and vertical directions, and 0.1035 for the diagonal direction.

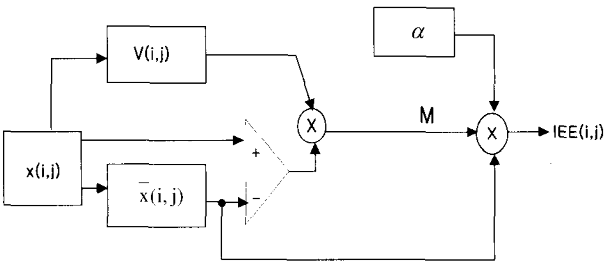
Spatial activity(M) is defined as the value of the spatial variation multiplied by the visual perception error.

$$M(i,j) = V(i,j)[x(i,j) - \bar{x}(i,j)] \qquad (5)$$

Information of edge enhancement (IEE) is defined as the multiplication of the local average and the spatial activity measure.

$$IEE(i,j) = \alpha \times x(i,j) \times M(i,j) \qquad (6)$$

where α is the controlling coefficient of IEE. If the local average ($\bar{x}(i,j)$) is larger than the current pixel, the sign of M is negative, otherwise M is positive. If the current pixel is equal to the local average, M is 0 and IEE is 0. It means that the area is flat in tone distribution and the average tone of the bilevel-toned image will have similar characteristics to that of the Floyd *et al.* The IEE represents the relation of the current pixel and the surrounding pixels of the pixel and is the weight to make the pixel of the bilevel-toned image appropriate for human vision. The IEE is added to input of the quantizer to enhance the edge. That is, IEE replaces L in (Fig. 1). (Fig. 3) illustrates the block diagram of the computation of IEE.



(Fig. 3) The computation of IEE.

4. Evaluation

To evaluate the performances of the proposed method, it and the other three methods, Floyd *et al.*, Knox *et al.*, and Hwang *et al.*, are compared with test images, "Lena", "Boat", "Airplane", and "Bridge". To obtain the result, we set the controlling parameter L of the method of Knox *et al.* to 2, and a and b of that of Hwang *et al.* to 2.5 and

0.02 respectively to properly enhance the edges. We set the coefficient α to 4.3. This paper adopts two objective measurements: edge correlation and local average accordance.

4.1 Edge correlation

The most important information is edge shapes. Therefore, it has objectiveness in quality assessment to measure the correlation for edge shapes between bilevel-toned and original image. The measuring function for edge correlation is defined as follows [8]:

$$\overline{C}_{XZ} = \frac{1}{M \times N}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1} C_{XZ}(i,j) \qquad (7)$$

$$C_{XZ}(i,j) = \sum_{k=-1}^{1}\sum_{l=-1}^{1} W(k,l)\ D_X(i,j;k,l)D_Z(i,j;k,l) \qquad (8)$$

Where D_X and $D_Z$are edge intensities for an original image X and the reconstructed image Z from bilevel-toned one by using a 7×7 lowpass filter [9]. The values are computed as follows:

$$D_X\ (i,j\ ;\ k,l) = x(i,j) - x(i-k,j-l) \qquad (9)$$

$$D_Z\ (i,j\ ;\ k,l) = z(i,j) - z(i-k,j-l). \qquad (10)$$

A large $\overline{c}$ means that edge area of the bilevel-toned image is consistent with that of the original image.

4.2 Local Average Accordance

It is important to retain the average tone of the original image for a bilevel-toned image. This is evaluated by a function to measure local average accordance between the original image and the bilevel-toned one. The original image is divided into rectangles of a specific size and the local average of a rectangle is designed as $\overline{x}_l$. The bilevel-toned image is reconstructed by using the 7×7 low pass filter mentioned in Section 4.1 and the local average for a rectangle of the reconstructed image is denoted as $\overline{z}_l$. The local average accordance $A_l$is defined by a reciprocal number of the difference between the two kinds of local average as follows:

$$A_l = \frac{1}{E[(\overline{X}_l - \overline{Z}_l)^2]} \qquad (11)$$

A large $A_l$means that the local average of the bilevel-toned image is consistent with that of the original image.

4.3 Experimental Results

<Table 1> shows the edge correlation values at a viewing distance of 10 inches. Table 2 shows the edge correlation values as to increasing viewing distances (10 inch, 15, 20, 25, 30) for Lena image. In <Table 1> and <Table 2>, the values of the proposed method are higher than those of the other three methods, meaning that the proposed method makes a more correct edge than the other three.

〈Table 1〉 Edge correlation values

methods images	Floyd et al.	Knox et al.	Hwang et al.	Proposed
Lena	146.8	151.2	147.4	152.8
Airplane	160.3	164.4	160.8	167.3
Boat	156.8	164.49	157.7	168.1
Bridge	198.6	207.1	198.3	210.9

〈Table 2〉 Edge correlation according to viewing distance

method Viewing distance[inch]	Floyd et al.	Knox et al.	Hwang et al.	Proposed
10	146.8	151.2	147.4	152.8
15	134.3	138.3	134.8	139.3
20	116.9	120.9	117.2	121.2
25	105.4	109.8	105.8	110.3
30	96.9	101.8	97.1	102.9

<Table 3> shows the local average at a viewing distance of 10 inches. <Table 4> shows the local average accordance values as to increasing viewing distances (10 inch, 15, 20, 25, 30) for Lena image. In <Table 3> and <Table 4>, the values of the proposed method are higher than those of other three methods. Therefore, the proposed method retains more correctly the average tone of the original image.

〈Table 3〉 Local average accordance values

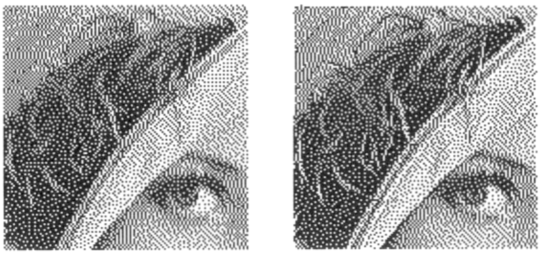
methods images	Floyd et al.	Knox et al.	Hwang et al.	Proposed
Lena	14.0	2.0	17.5	19.8
Airplane	11.6	1.7	15.2	27.9
Boat	15.2	2.0	15.1	27.7
Bridge	16.1	2.1	18.2	57.7

〈Table 4〉 Local average accordance according to viewing distance

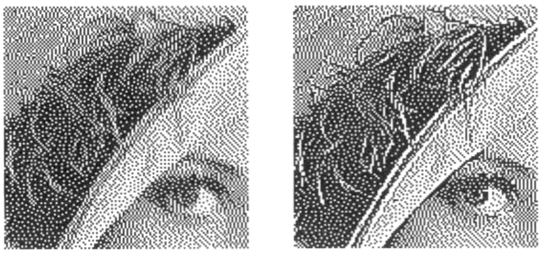
method Viewing distance[inch]	Floyd et al.	Knox et al.	Hwang et al.	Proposed
10	14.0	2.0	14.9	16.8
15	16.6	2.3	17.5	19.8
20	20.4	2.9	21.0	24.5
25	31.3	3.1	31.5	40.2
30	36.3	4.8	37.9	45.5

(Fig. 4) shows a sub-image cut down from 'Lena' to confirm the subjective quality of the printed image. The bilevel-toned images by the three conventional and the proposed method are depicted in (Fig. 5). The resulting images by Floyd *et al.* and Knox *et al.* have degradation of high frequency edge information. Hwang *et al.* are clearer bilevel-toned images than that by Floyd *et al.* However, the detail edges aren't preserved. The resulting image by the proposed method is the clearest and preserves the detailed edges of thehat and feathers. (Fig. 6) is the bilevel-toned images of Boat image. The resulting-image by the proposed method is preserves the detailed edges of and is .

(Fig. 4) A sub-image from Lena.



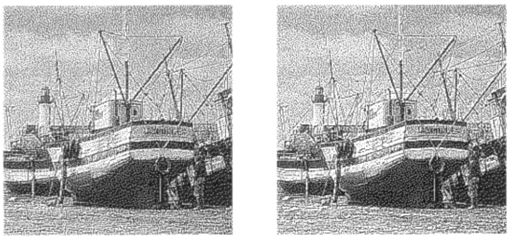
(a) Floyd's method (b) Knox's method



(c) Hwang's method (d) the proposed method

(Fig. 5) Bilevel-toned imagesof Fig. 4.

(a) Floyd's method (b) Knox's method



(c) Hwang's method (d) the proposed method

(c) Hwang's method (d) the proposed method

(Fig. 6) Bilevel-toned images of Boat image.

5. Conclusion

The conventional error diffusion method has a defect of edge degradation. To minimize the defect, we propose the edge-enhanced error diffusion method using local mean and spatial activity measure. Based on the property that the human visual system perceives not a current pixel but the average of the surroundings of the pixel, the proposed method computes a local average of the surroundings of the current pixel and gets spatial activity using the difference of the pixel and the local average of it. Two values are used to compute IEE. If the values of IEE have 0, the average tone of the bilevel-toned image will have similar characteristics to that of the Floyd *et al.* method. The IEE is added to the input of the quantizer to enhance edges. The proposed method improves the results of edge correlation and local average accordance compared withthe conventional methods. From the results, it can be concluded that the proposed method presents superior properties than the conventional methods for the overall range, includes the most edge information and preserves the average tone of the original image. Also, thesubjective tests show that the proposed method maintains the detailed edges.

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