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Edge Enhanced Error Diffusion Based on Local Average of Original Image

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Abstract - **The error diffusion is a good method to reconstruct the continuous tones of an image to the bilevel tones. However, the reconstruction of edge characteristic by the error diffusion is represented weak when power spectrum is analyzed for display error. In this paper, we present an edge enhanced error diffusion method to preprocess original image to achieve the enhancement for the edge characteristic. The preprocessing algorithm consists of two processes. First, the difference value between the current pixel and the local average of the surrounding pixels in original image is obtained. Second, the weighting function is composed by the magnitude and the sign of the local average. To confirm the effect of the proposed method, it is compared with the conventional edge enhanced error diffusion methods by measuring the radially averaged power spectrum densities (RAPSDs) for their display errors. The comparison results demonstrate the superiority of the proposed method over the conventional ones.**

I. INTRODUCTION

Image output devices, including printers and faxes, usually have only the two levels of tones or colors because of technical and economical reasons. However the devices must output images as natural as possible even if such limitations are imposed. Halftoning is introduced to content with the requirement.

Halftoning is the process to convert the continuous-toned image into the bilevel-toned one and let see the latter as the former when looked at from a distance. Of many halftoning algorithms studied before, the error diffusion is noticeable due to its superior blue-noise property [1]. The error diffusion was proposed by Floyd et al. It distributes the error made over the surrounding pixels by quantizing the current pixel into bilevel tones to use an error diffusion filter that makes the average error of the entire image be 0.

However, the error diffusion filter is designed to retain the average tone of original image, i.e. direct current element frequency, so the degradation of the original image for high frequency edge information has to be made [2]. The bilevel-toned image has the contradictory necessities. That is, it has to make the direct current element of display error power spectrum be 0 to retain the same average tone to original image, while it has to minimize the high frequency error power to preserve the original edge information.

The studies conducted to achieve the error diffusion include the methods to modify the error diffusion filter, to adaptively adjust filter coefficients to minimize local errors, to introduce the property of human visual system (HVS), to utilize the characteristics of printers, and so on [3],[5],[6]. Most of all, the edge enhanced error diffusion proposed by Eschbach et al. to emphasize the edge of original image and get more clear bilevel-toned image is remarkable. This method adds a multiple of a number to original image in the process of error diffusion.

This paper studies an error diffusion method to more enhance the edge emphasis and proposes a preprocessing filter to reduce the distortion of original image for high frequency edge information. The proposed filter consists of the difference value between the current pixel and the local average to the surrounding area in original image, and the weighting function to use the difference.

The paper, hereafter, is organized as follows. Section 2 describes the preprocessing filter algorithm proposed by this paper. The performance of the proposed filter is compared with those of the existing edge enhanced methods in radial averaged power spectrum density (RAPSD). Finally, section 5 concludes this paper by summarizing the results.

II. PREPROCESSING FILTER ADDED EDGE ENHANCED ERROR DIFFUSION

This paper designs the preprocessing filter to more improve the edge enhanced error diffusion proposed by Eschbach et al. [7]. The entire error diffusion system is depicted in Fig. 1. The proposed filter is designated by the dotted box and the rest modules are the processes proposed by Floyd et al. [1]. In the figure, $i(m,n)$ and $b(m,n)$ are the input image and the bilevel-toned image of $M \times N$ samples, respectively. It is assumed that $b(m,n)$ has 0 or 1 and $i(m,n)$ is belong to the range $[0,1]$. $e(m,n)$ is the error generated from quantization into 0 or 1.

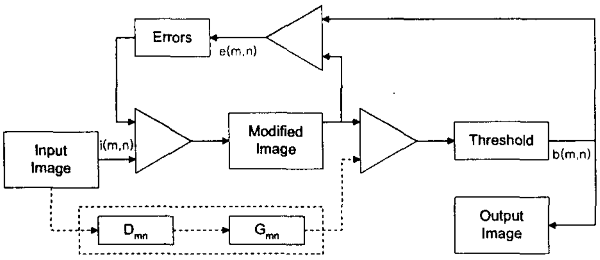

Fig. 1. The edge enhanced error diffusion to which the preprocessing filter is added.

The proposed filter adds to the quantizer the tone difference of the current pixel to the local area, while the method of Eschbach et al. multiplies a weighting value directly to original image and adds it to the quantizer. The proposed filter is represented by the formulation like these:

$$D_{mn} = G_C - \frac{1}{25}\sum_{k=-2}^{2}\sum_{l=-2}^{2} i(m+k, n+l) \tag{1}$$

$$G_{mn} = \frac{a_{mn}}{1 + b_{mn} \times |D_{mn}|} \times sign(D_{mn}) \tag{2}$$

where, D_{mn} is the difference between the current pixel tone G_C and the local average which is averaged for the 5x5 pixels surrounding to the current pixel in original image. G_{mn} is the weighting function and defined with the magnitude and sign of D_{mn}. D_{mn} outputs 0 for the even tone distribution, positive values for tones changing like peak, and negative values for tones changing like valley. When D_{mn} is 0, this means the area is flat in tone distribution and the average tones of bilevel-toned image have the similar characteristic to that of the Floyd et al. The coefficient a_{mn} of the weighting function G_{mn} controls the emphasizing level of edge reconstruction and b_{mn} the excessive edge emphasis according to steep tones changing.

III. EVALUATIONS AND ANALYSIS

To evaluate the effect of the edge enhanced preprocessing filter described in section 2, the two methods of Floyd et al. and Eschbach et al. are compared with the proposed method for Lena image. This paper adopts the RAPSD measurement for the objective comparison of them.

A. Radially Averaged Power Spectrum Density for Display Error

The RAPSD is a measurement to determine how similar the original image and the bilevel-toned image are to each other [8]. The preferable bilevel-toned image does not have direction biases in pixel pattern and should be radially symmetric. This criterion is tested by power spectrum. The power spectrum is defined as $\hat{P}(f)$ which conducts two-dimensional Fourier transform on the bilevel-toned image, squaring of the result, and dividing it by the number of samples. Although $\hat{P}(f)$ is represented in three-dimension, one-dimensional figure can be presented for effective observation of characteristics by the frequency. The one-dimensional figure is made by partitioning power spectrum into circular rings of width Δ like Fig. 2.

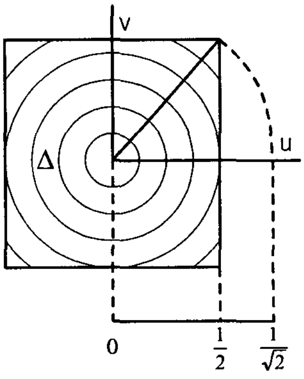

Fig. 2. Partitioning of power spectrum.

This paper constructs the preprocessing filter by utilizing the difference between the current pixel and the local average to the surrounding area in original image. Therefore, for the flat area in tone distribution, the effect of the preprocessing filter is generated little. In this paper, the display error is defined as the difference between the original image and the error diffused bilevel-toned image, and the RAPSD for the display error is presented in the evaluation results.

When the two-dimensional Fourier transform is designated by $\tau[\cdot]$, the power spectrum density is expressed by (3):

$$\hat{P}(u,v) = \frac{1}{M \times N}\left|\tau[i(m,n) - b(m,n)]\right|^2 \tag{3}$$

The power spectrum is partitioned into circular rings of the uniform width Δ on the basis of the center of the power spectrum as seen in Fig. 2. In the figure, it is noted that the circular frequency f_r is distant from the center of circular rings by $\Delta_r / \sqrt{2}$. The RAPSD $P_r(f_r)$ is obtained by integrating the power spectrum within the r-th circular ring area and dividing the result by the number of samples included in the area like (4):

$$P_r(f_r) = \frac{1}{N_r(f_r)} \sum_{i=1}^{N_r(f_r)} \hat{P}(u,v) \qquad (4)$$

where, $N_r(f_r)$ is the number of samples within the r-th circular ring area.

B. Experimental Results and Analysis

The RAPSD ($\Delta = 0.004$) for the display error made between the original image and the bilevel-toned image by the Floyd et al. for Lena is displayed in Fig. 3. In this figure, the range of f_r from 0 to 0.3 generates rare RAPSD and it means that the average tones of the original image are reconstructed very well by the method. However, the high frequency range from 0.5 to 0.7 generates high RAPSD. From the result, it can be known that the error diffusion by Floyd et al. has the relatively low reconstruction capability for edge area.

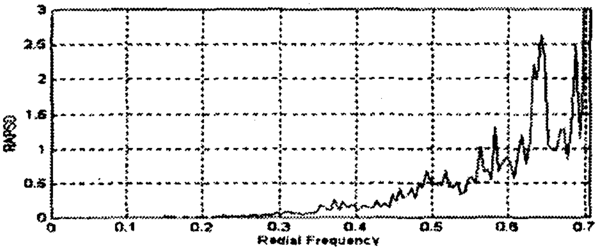

Fig. 3. RAPSD characteristic for the display error by the Floyd et al.

Fig. 4 reports the RAPSD for the display error by the Eschbach et al. As seen in the figure, the RAPSD for the high frequency range from 0.5 to 0.7 has lower level than that of Fig. 3 does. It indicates that the property of the method to enhance edge area is effective and the method improves the reconstruction of edge area over the Floyd et al. However, it is also detected that the RAPSD for the low frequency range does increase.

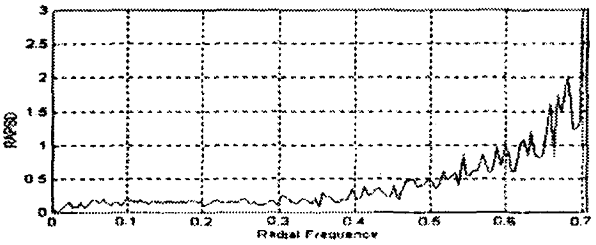

Fig. 4. RAPSD characteristic for the display error by the Eschbach et al.

Finally, Fig. 5 shows the RAPSD for the display error by the proposed method. To obtain the result, $a_{mn} = 2.5$ and $b_{mn} = 0.02$ are used for G_{mn} calculation. The RAPSD for the low frequency range from 0 to 0.2 is low as with Fig. 3, but over the upper frequency increases the RAPSD until 0.4. However, in the high frequency range from 0.5 to 0.7, the lower RAPSD over the Eschbach et al. is generated. The result like this means that when the proposed preprocessing filter is used, the reconstruction of edge area is enhanced while the property of the standard error diffusion by Floyd et al. is sustained for the flat area in tone distribution.

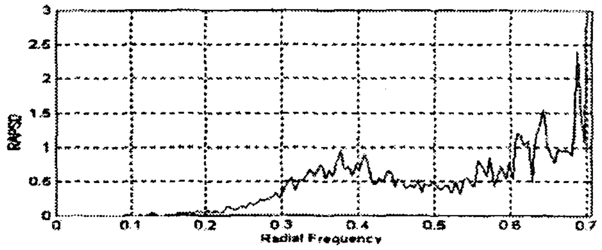

Fig. 5. RAPSD characteristic for the display error by the proposed preprocessing filter.

IV. CONCLUSION

So far this paper has been devoted to the preprocessing filter to emphasize the edge information of original image based on the standard error diffusions proposed by Floyd et al. Applying the filter to Lena image and analyzing the bilevel-toned image indicated that the more clear bilevel-toned image can be acquired over the error diffusion by Eschbach et al. From the result, it can be concluded that the proposed filter presents superior property than the Floyd et al. and the Eschbach et al. do for the high frequency range from 0.5 to 0.7 that includes most edge information in original image.

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