Consideration of Image Quality of Dithered Picture by Constrained Average Method Using Various Probability Distribution Models

Mitsuhiro Sato[1], Madoka Hasegawa[2], and Shigeo Kato[2]
[1]Graduate School of Engineering, Utsunomiya University
[2]Faculty of Engineering, Utsunomiya University
7-1-2 Yoto, Utsunomiya, Tochigi 321-8585, JAPAN
Tel.&Fax.:+81-28-689-6267
E-mail: satom@mclaren.is.utsunomiya-u.ac.jp

Abstract: The constrained average method is one of dither methods which combines edge emphasis and grayscale rendition to provide legibility of textual region and proper quality of continuous tone region. However, image quality of continuous tone region is insufficient compared to other dither methods, such as ordered dither methods or the error diffusion method. The constrained average method uses a uniform distribution function to decide number of lit pixels related to the average intensity in a picture area. However, actual distribution of continuous tone region is closer to the Laplacian distribution or triangle distribution. In this paper, we introduce various probability distributions and the actual luminance distribution to decide the threshold value of the constrained average method in order to improve image quality of dithered image.

1. Introduction

Half toning techniques are used in case that a multilevel image is displayed or recorded in bi-level devices like facsimile equipments. Dither method is widely utilized as a half toning technique for its fine capability of reproducing continuous-tone scene with the same number of pixels as an original image.

The constrained average method, which is one of dither methods, is able to enhance contours and represent continuous-tone in a single process, so that it is suitable for dithering an image containing not only multi-level regions but also textual, or line drawing parts [1] [2]. However, the continuous-tone representation capability of the constrained average method is inadequate compared to the ordered dither method or the error diffusion method.

In the constrained average method, the average luminance of the current pixel and its surrounding pixels is calculated to determine the threshold value which is used to compare with current pixel. Conditional luminance distribution of current pixel is assumed to be uniform in the conventional constrained average method. Therefore, the threshold value is calculated from the ratio of the average luminance value to the dynamic range, and the on or off state of the current pixel in the dithered image is determined by comparing the current pixel with the threshold. However, the actual conditional luminance distribution of the current pixel in a continuous tone region is closer to the Laplacian distribution or the triangle distribution. In this paper, we introduce various probability distribution models and the actual luminance distribution to decide threshold value of the constrained average method in order to improve image quality of the dithered image.

2. Constrained Average Method

In the constrained average method, the on or off state decision for the pixel $I_{x,y}$ is determined by following steps. First, the mean luminance $B_{x,y}$ in the neighborhood of $I_{x,y}$ is calculated.

Secondly, a threshold value $T_{x,y}$ is calculated by modeling the conditional luminance distribution of the current pixel. As shown in figure 1, in the conventional method, conditional luminance distribution of the current pixel is assumed to follow a uniform distribution of width γ and centers on the mean luminance value.

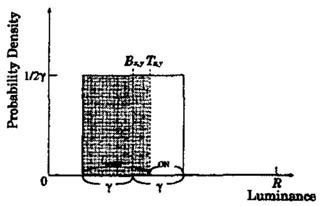

Fig.1. Uniform distribution

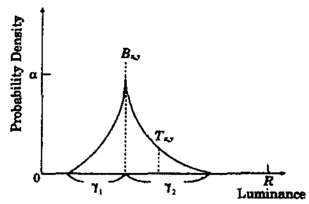

Fig.2. Laplacian distribution

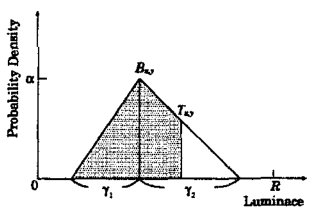

Fig.3. Triangle distribution

The threshold value $T_{x,y}$ is set up by equation (1), where $B_{x,y}$ is the mean luminance given by equation (2), R is the maximum of luminance, and $B_{x,y}/R$ is the possibility that the current pixel value is greater than the mean luminance.

$$\int_{T_{x,y}}^{B_{x,y}+\gamma} \frac{1}{2\gamma} dI = \frac{B_{x,y}}{R} \tag{1}$$

$$B_{x,y} = \frac{1}{9} \sum_{i=-1}^{1} \sum_{j=-1}^{1} I_{x+i,y+j} \qquad (2)$$

Threshold $T_{x,y}$ is given by rearranging the equation (1).

$$T_{x,y} = \gamma + \left(1 - \frac{2\gamma}{R}\right) B_{x,y} \qquad (3)$$

Figure 6 and figure 7 show dithered images which are obtained by applying conventional constrained average method to original images, figure 4 and figure 5, respectively.

Here, figure 4 is an image to evaluate similarity and continuous-tone reproducibility, and figure 5 is an image to evaluate legibility.

Fig.4. Original image(512×512pixel, 8bit/pel)

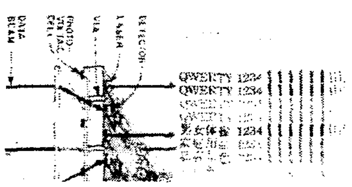

Fig.5. Original image(512×256pixel, 8bit/pel)

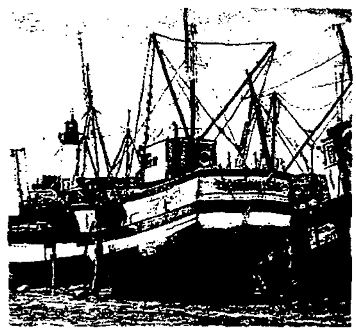

Fig.6. Constrained average method (512×512pixel, 1bit/pel)

3. Constrained Average Method Considering Actual Luminance Distribution

In the constrained average method, it is assumed that a conditional luminance distribution of the current pixel

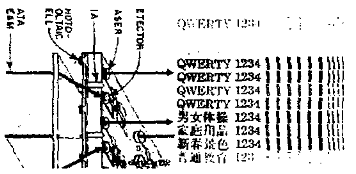

Fig.7. Constrained average method (512×256pixel, 1bit/pel)

follows a uniform distribution centering on the mean luminance of the current pixel. However, as shown in figure 8, in many cases the actual conditional luminance distribution does not follow a uniform distribution.

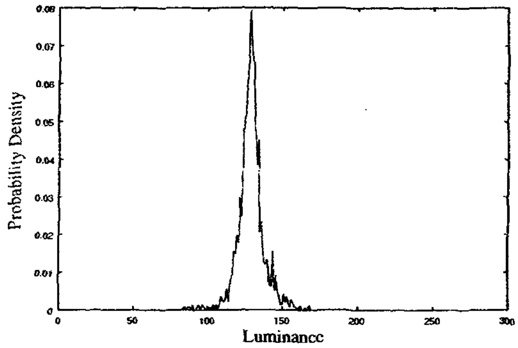

Fig.8. Actual luminance distribution

Thus, in our method, the conditional luminance distribution is supposed to follow the Laplacian distribution shown in figure 2, and threshold value is given by equation (4) in consequence.

We also studied in case that the conditional luminance distribution follows the triangle distribution shown in figure 3, and the threshold value is given by equation (5).

$$T_{x,y} = \begin{cases} B_{x,y} - \dfrac{ln(e^{-\beta_2\gamma_2 + \frac{\beta_2 B_{x,y}}{\alpha R}})}{\beta_2} & (B_{x,y} < R/2) \\ B_{x,y} + \dfrac{\{1 - \frac{\beta_1 B_{x,y}}{\alpha R} + \frac{\beta_1}{\beta_2}(1 - e^{-\beta_2\gamma_2})\}}{\beta_1} & (B_{x,y} \geq R/2) \end{cases} \qquad (4$$

$$T_{x,y} = \begin{cases} B_{x,y} + \gamma_2 - \sqrt{\frac{2B_{x,y}\gamma_2}{\alpha R}} & (B_{x,y} < R/2) \\ B_{x,y} - \gamma_1 + \sqrt{\frac{2\gamma_1}{\alpha}(1 - \frac{B_{x,y}}{R})} & (B_{x,y} \geq R/2) \end{cases} \qquad (5)$$

In these equations, the width of the distribution γ_1, γ_2 are changed according to mean luminance value.

We also propose the method which uses an actual conditional luminance distribution of current pixel instead of some probability distribution models. In this case, the threshold value $T_{x,y}$ is determined by equation (6).

$$\sum_{i=0}^{T_{x,y}} H(i) = \left(1 - \frac{B_{x,y}}{R}\right) \sum_{i=0}^{R} H(i) \qquad (6)$$

Where, $H(i)$ is occurrence frequency of luminance i.

4. Experimental Results

Figure 9 to figure 14 show dithered images obtained by proposed methods. In these figures, method 1, method 2, and method 3 correspond to the method using triangle distribution, the method using Laplacian distribution, and the method using the actual conditional luminance distribution, respectively .

Fig.9. method 1 (512×480pixel, 1bit/pel)

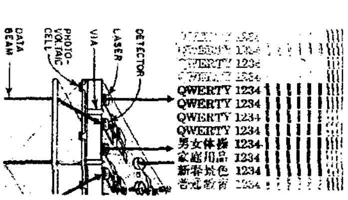

Fig.10. method 1 (512×256pixel, 1bit/pel)

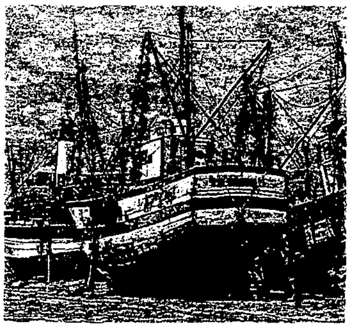

Fig.11. method 2 (512×480pixel, 1bit/pel)

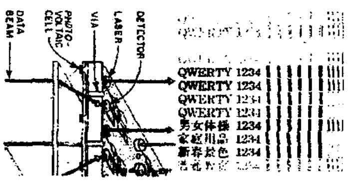

Fig.12. method 2 (512×256pixel, 1bit/pel)

We performed four subjective evaluation experiments to evaluate image quality of these images. We used Ura's method in Scheffe's method of pair comparisons [3] for subjective evaluation. All possible pairs of images are presented to a subject and the subject gives a score to

Fig.13. method 3 (512×480pixel, 1bit/pel)

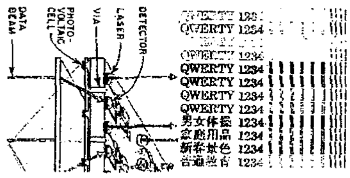

Fig.14. method 3 (512×256pixel, 1bit/pel)

each pair based on evaluation criterion categories shown in table 1. the mean score for each image is calculated, and each image is evaluated. Mean score $\hat{\alpha}(i)$ for an image A_i is given by equation (7).

$$\hat{\alpha}(i) = \frac{1}{2tN}\sum_{k=1}^{N}\sum_{j=1}^{t}(x_{ijk} - x_{jik}) \qquad (7)$$

Where, N denotes the number of subject, t denotes the number of image, and x_{ijk} denotes score when a subject k compared image A_i indicated in left with image A_j indicated in right. In our experiments, the number of subject is 10.

Table 1. Evaluation criterion category

Evaluation criterion category	Score
Left image is better than right image	2
Left image is slightly better than right image	1
Left image is equal to right image	0
Right image is slightly better than left image	-1
Right image is better than left image	-2

We call four experiments, namely experiment 1, experiment 2, experiment 3, and experiment 4. In experiment 1, dithered images which obtained by three proposed methods are compared. In experiment 2 to experiment 4, each proposed method is compared with the conventional constrained average method, the error diffusion method, and the ordered dither method, respectively. The proposed method in experiment 2, 3, and 4 is the constrained average method using the triangle distribution, the constrained average method using the Laplacian distribution, and the constrained average method using the actual conventional luminance distribution, respectively.

We evaluate three quality measures, that is, similarity, continuous-tone reproducibility, and legibility. We used figure 4 in evaluation of similarity and continuous-tone reproducibility and figure 5 in evaluation of legibility.

Table 2 to table 5 show results of subjective evaluation. In each table, 'Method 1' means the constrained average method using triangle distribution, and 'Method 2' means the constrained average method using Laplacian distribution, 'Method 3' means the constrained average method using the actual conditional luminance distribution, 'Conventional' means the conventional constrained average method. In the error diffusion, 5 × 3 matrix is used. In the ordered dither, 4 × 4 Bayer type matrix is used. Data in column index 1, index2, and index3 show similarity, continuous-tone reproducibility, and legibility, respectively.

These tables show the results of each experiment. The greater the values in quality index are, the better evaluation they mean.

Table 2. Result of experiment 1

method	evaluation item		
	index1	index2	index3
Method 1	−0.033	0.017	0.683
Method 2	−0.033	−0.050	-0.517
Method 3	0.067	0.033	−0.167

Table 3. Result of experiment 2

method	evaluation item		
	index1	index2	index3
Conventional	−0.325	−0.400	0.800
Ordered dither	−0.050	0.388	−1.213
Error diffusion	0.863	0.788	−0.150
Method 1	−0.113	−0.225	0.788

Table 4. Result of experiment 3

method	evaluation item		
	index1	index2	index3
Conventional	−0.713	−0.975	0.888
Ordered dither	−0.138	0.275	−1.113
Error diffusion	1.025	0.850	−0.138
Method 2	−0.175	−0.150	0.363

Table 5. Result of experiment 4

method	evaluation item		
	index1	index2	index3
Conventional	−0.488	−0.488	0.813
Ordered dither	−0.075	0.300	−1.175
Error diffusion	1.025	0.838	−0.250
Method 3	−0.113	−0.125	0.788

We can consider that the constrained average method can achieve good image quality by using a probability distribution model which is close to the actual conditional luminance distribution. We can see from table 1 that the method 3 obtained the best evaluation in similarity and continuous-tone reproducibility and the method 1 obtained the best evaluation in legibility. The effect of edge emphasis becomes strong in the method 1, because the threshold value in the method 1 is close to mean luminance value compared to the other proposed methods. Therefore, we can consider that textual region becomes distinct in the method 1.

In table 3 to table 5, we can see that our proposed methods are inferior in similarity and continuous-tone reproducibility compared to the error diffusion method and the ordered dither method. However, our methods could obtain very good evaluation in legibility.

In case of comparing with the conventional constrained average method, proposed methods could obtain better evaluation in similarity and continuous-tone reproducibility. Legibility of images which are generated by proposed methods are similar to that of the image which is generated by the conventional constrained average method except method 2.

Though image quality of proposed methods are insufficient compared to the error diffusion method and the ordered dither method, we can see that proposed methods can improve image quality while keeping legibility compared to conventional constrained average method.

5. Conclusion

In this paper, we proposed a constrained average method in consideration of the actual conditional luminance distribution. Experimental results show that our proposed methods can obtain the best image quality compared with the conventional constrained average method. In our future works, we will investigate the good dithering method for color images.

References

[1] J. F. Jarvis and C. S. Roberts, "A new technique for displaying continuous tone images on a bi-level display," IEEE Trans. Communications, COM-24, pp.891-898, Aug. 1976.

[2] J. F. Jarvis, C. N. Judice, W. H. Ninke, "A Survey of Techniques for the Displays of Continuous Tone Pictures on Bilevel Displays," Computer Graphics and Image Processing, Vol.5, pp.13-40, Mar. 1976.

[3] H. Scheffe, "An Analysis of Variance for Paired Comparisons," American Statistical Association Journal, pp. 381-400, Sept. 1952.