Improvement of Color Images Halftoning with Simulated Annealing

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Keyword : halftoning, simulated annealing, color image, quantization, cost function

Abstract

In this paper, it introduced simulated annealing (SA) as a method of halftoning in the color image. 3 methods called Type1, Type2 and Type3 are research in the paper. Type1 is using the SA with resolving of color image into three primary colors ingredient of Red (R), Green (G) and Blue (B). Those applied the halftoning by SA respectively, and composed process result. In the Type2, a color regards as the 3 dimensions vector of R, G and B. Not only size of error vector but also angle error added to cost. In the Type3, the basis of above two results, it made not to consider the cost of angle error at Type2. The appropriation pixel becomes R=G at the process image when R=G of original image was formed. Similarly, in case of becoming R=B and B=G, it were assumed to a restriction.

In case of SA is adapted to the halftoning in color image. we could get result the superior image quality using Type3. Therefore, availability to the halftoning to the color image of SA became clear.

1.Introduction

Halftoning [1)~3)] has an important role in the hard copy of a printer and facsimile communication system. The digital halftoning of the gray scale images has dither method [1)] , error diffusion method [2)] , application of the solution of combinatorial optimization proble [3),6)] and various methods.

In case halftoning is thought as combinatorial optimization problem, ideal image to visual sensation is searched. It has been proposed that genetic algorithms (GA) on the process to the gray scale image. String size is not taken greatly, there is influence by the non-continuity in the boundary [3)] . For this reason, we introduce makes to hasten calculation speed substantially clear at using SA [4)~6)] . In this paper, it introduces Simulated Annealing (SA) at the halftoning in the color image. We can get result that halftoning of color image is good visual sensation and when input image became a gray scale image, gray scale image can be obtained in process image.

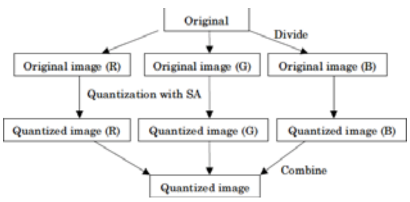


Fig. 1 Procedure of the halftoning with deviding the three primary colors

2. Extension to color image of halftoning used SA in gray scale image

It is mentioned procedure for halftoning of color image based on halftoning [6)] for gray scale image as mentioned using SA. At the color image the case of Windows Bit Map, the three primary colors of R, G and B has density information of 0-255 respectively. These 3 plains would be piled with regarding R, G and B as three gray scale images. It stands for the flow of this process to Fig. 1, and states the process to the following. This method is called Type1.

1) The color image is resolved into 3 planes on three primary colors of R, G and B.
2) It uses Cost function that is the same as the case of the gray scale image and carries out SA on each planes.
3) Process image can be obtained by each solution.

Cost function used in the SA is assumed to stand by linear combination with cost E_m on present of gray level and cost E_c on contrast of edge, those showed by following equation.

$$E = \alpha_m E_m + \alpha_c E_c \tag{1}$$

Here, α_m and α_c are each weight. The relation is filled $\alpha_m + \alpha_c = 1$.

Cost E_m on present of gray level showed by following equation.

$$E_m = \sum_{(x,y)\in block} \frac{1}{N_p} \left| F(x,y) - q_F(x,y) \right| \tag{2}$$

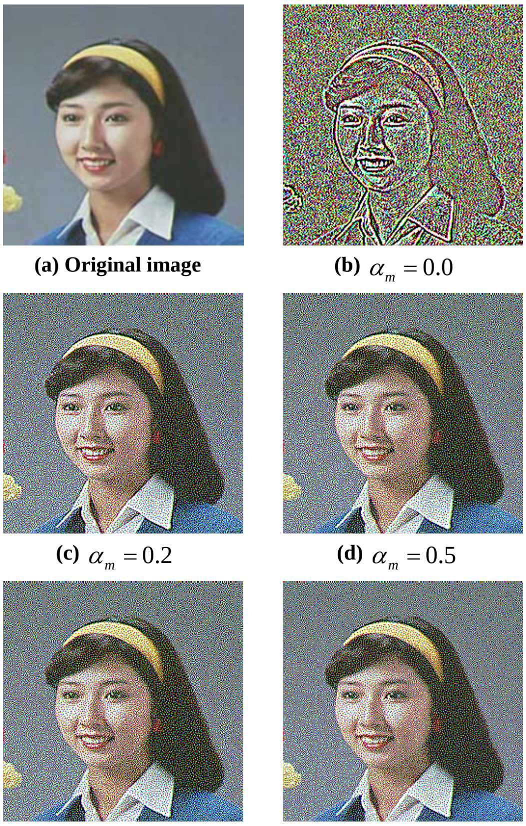
Here, gray level density of original image regards $F(x,y)$ and gray level density of process image regards $Q(x,y)$ in coordinates (x,y). Then $q_F(x,y)$ is gray level density of binary pattern in Gaussian filter convolute, N_p is pixel number in $block$. In case of changing color of a pixel, $block$ in this equation is domain where effect cost function. It indicates the pixel and 24 neighborhood pixels here. Cost E_c about the contrast shown by following equation.

$$E_c = \sum_{(x,y)\in block} \frac{1}{N_p} \left| F'(x,y) - Q'(x,y) \right| \tag{3}$$

$$\begin{cases} F'(x,y) = F(x,y) - f_s(x,y) \\ Q'(x,y) = Q(x,y) - M/2 \end{cases} \tag{4}$$

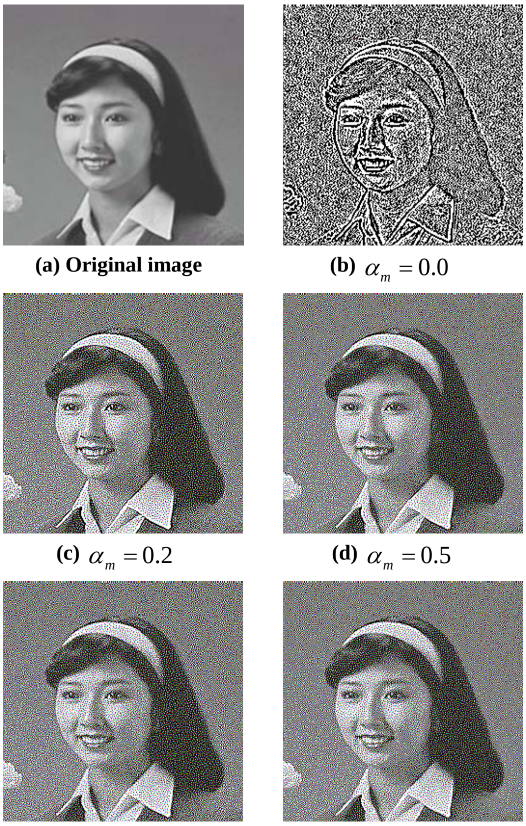
Here, $f_s(x,y)$ is local average of $F(x,y)$ in 5×5 pixels. M is gray level number in original image.

The process image could be got by the method that is shown a Fig. 2.



(a) Original image (b) $\alpha_m = 0.0$
(c) $\alpha_m = 0.2$ (d) $\alpha_m = 0.5$
(e) $\alpha_m = 0.8$ (f) $\alpha_m = 1.0$

Fig. 2 Halftone Images using the Procedure Type1 (Original images is full color image)



(a) Original image (b) $\alpha_m = 0.0$
(c) $\alpha_m = 0.2$ (d) $\alpha_m = 0.5$
(e) $\alpha_m = 0.8$ (f) $\alpha_m = 1.0$

Fig. 3 Halftone Images using the Procedure Type1 (Original images is gray scale image

These images are $256(H) \times 256(V)$ pixels, 24bit images. Therefore, α_m shows cost on weight about the gray level density, α_c shows cost on weight about the contrast, $(\alpha_c = 1 - \alpha_m)$. In SA, initial temperature T_0 is equal to 100, decreasing coefficient α is equal to 0.995. The chapter is explained again about Compromise type of the initial temperature and the temperature fall coefficient. The gray scale image is well known [3)6)] for getting the best result at $\alpha_m = 0.2$. Also at the result of Fig. 2(b)-(f), the outline is clear and also the reappearance of color is good when the color image is used in case of $\alpha_m = 0.2$. Therefore, halftoning in the color image also consider ratio of weight about gray level density α_m and weight about contrast α_c is the same.

The same process is applied to the gray scale image (It is RGB24bit but calculates brightness information, and R=G=B is consisted). This is shown a Fig. 3. The color other than white and black is breaking out. The reason, it is because same solution can't get necessarily in R plane, G plane and B plane by multimodal of a solution in SA. And the result that convoluted them appeared the color other than white and black. Inherence the gray scale image is desirable that the color other than white and black is not to break out. Therefore, the color image could get good result. However, the gray scale image could get bad result.

3. Primary color process when it doesn't resolve into 3 primary colors ingredient

The color image is resolved into each ingredient of R, G, B, after did halftoning on SA, it was adapted to reset method in previous chapter. Original image is case of full color image, it became comparatively good result. However, Original image is case of gray scale image, the result is necessary to improve that the color other than white and black break out. Because in this chapter uses method that it is not resolved into three primary colors of R, G, B. This method is called Type2.

3.1 Process procedure

Fig. 4 is shown flow diagram in the quantization of color images on SA [6)]. It is not resolved into 3 planes on R, G, B, it process same procedure that halftoning used SA in the gray scale image. The procedure is shown a following.

1) Random pattern of 8 colors is selected as initial process image.

2) The element in each pixel of color is changed. It changes color by using random number of 0 form 7.

3) Cost E_{old} conducts before step 2 and cost E_{new} conducts after step 2 calculate. Change volume of cost function gets dE.

$$dE = E_{new} - E_{old} \tag{5}$$

4) The turning over can accept at probability p.

$$p = \begin{cases} 1 & (dE \le 0) \\ \exp(-\frac{dE}{kT(n)}) & (dE > 0) \end{cases} \tag{6}$$

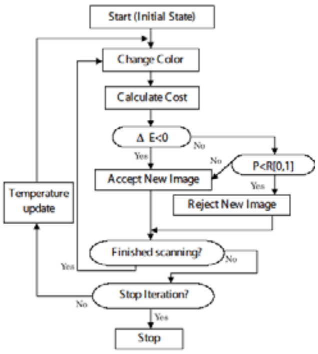


Fig. 4 Flow diagram

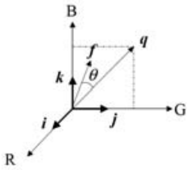


Fig. 5 Treatment of the vector for color

Here, $T(n)$ is temperature in the calculation, k is Boltzmann constant.

5) Trial of the above step2-4 does as order of raster operation against all pixels. After trial in all pixels finished, temperature $T(n)$ is let to fall, shown by following equation.

$$T(n) = \alpha T(n-1) \tag{7}$$

Here, α is constant how many 0 and over less than 1.

6) Step2-5 is repeated by change value of cost function becomes small.

3.2 Treating of cost function like the vector

The process method is shown in previous section needs to think about the cost function newly. Because it is not divided into the plane of 3 primary color. Treatment of the vector for color shows Fig. 5. Color vector c shows by following equation.

$$c = ri + gj + bk \tag{8}$$

Here, i, j, k are unit vector to each R, G, B direction. And r, g, b are shown size of vector to each R, G, B direction. Therefore, cost function E is considered as follow.

1) $F(x,y)$, $f_s(x,y)$, $Q(x,y)$, $q_F(x,y)$ is replaced in a foregoing chapter with each $\vec{F}(x,y)$, $\vec{f_s}(x,y)$, $\vec{Q}(x,y)$, $\vec{q_F}(x,y)$. And calculation of cost E that related to expression of gray level is shown follow equation.

$$E_m = \sum_{(x,y)\in block} \frac{1}{N_p} \left| \vec{F}(x,y) - \vec{q}_F(x,y) \right| \tag{9}$$

2) Similarly, cost E_c about the contrast shown by following equation.

$$E_c = \sum_{(x,y)\in block} \frac{1}{N_p} \left| \vec{F}'(x,y) - \vec{Q}'(x,y) \right| \tag{10}$$

$$\begin{cases} \vec{F}'(x,y) = \vec{F}(x,y) - \vec{f}_s(x,y) \\ \vec{Q}'(x,y) = \vec{Q}(x,y) - \vec{M}/2 \end{cases} \tag{11}$$

3) An angle error θ with color vector of original image and process image is considered because only using the above (1), (2) can be the result that is same as the one obtained in a foregoing chapter. It considers that length of vector becomes 0 in seven colors of other either if color of process image is black (R=G=B=0), an angle error θ is taken 0 too.

4) Cost function is shown by following equation from above result.

$$E = (1.0 + \beta\theta)(\alpha_m E_m + \alpha_c E_c) \tag{12}$$

In this expression, there is a constant 1.0 to prevent that the cost become 0 used an angle error θ, β is an angle error.

5) Calculation of cost in equation (19) is used $\alpha_m = 0.2$ and $\alpha_c = 0.8$.

Process image using SA above procedure is shown by Fig. 6 and Fig. 7. Fig. 6 is process image using color image as original image. Here, It follows that it is similar to the Fig. 2(c) that is process image in a foregoing chapter in the case of $\beta = 0$. However, it is become color reappearance such as achromatic color when β value is much. This is considered a ratio of angle error θ grows big and error of gray level density of color of each is made light of one. The above, $\beta = 0$ is considered that color image is effective and introduction of an angle error is meaningless.

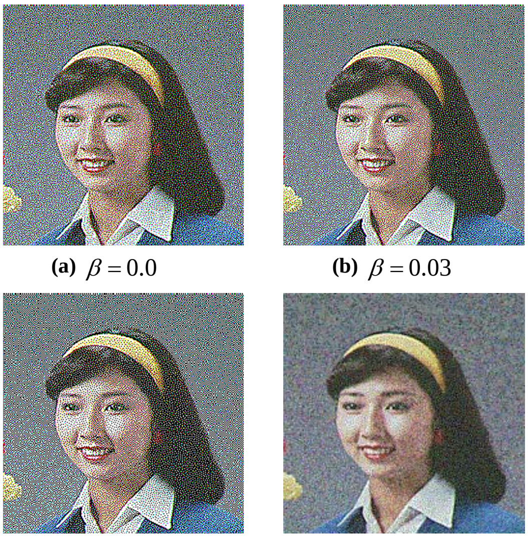
Fig. 7 is process image by use of gray scale image (It is RGB24bit, but $R = G = B$ is taken advantage of only intensity information) as original image. Here, in case of $\beta = 0$ follows that it is similar to Fig. 3(f) that it is process image a foregoing chapter. The reason is considered to make neighboring color vector average and it should become same color. However, there is not outbreak except for white color and black color when weight of an angle error θ is heavy. In this way the color except white and black does not appear in gray scale image when the angle error into the cost function introduced, but it become color reproduction such as achromatic color in the color image. Therefore, even this method is the method that is poor in versatility for color image and gray scale image.

4. Introduction of a limitation condition in choice of a color

Type1 is suitable to halftoning of color image, but it is a problem to occur that the color except white and black when gray scale image is extended. Type2 dose not occur that the color except white and black in gray scale image, it is a problem of color reproduction such as achromatic color in the color image. Among both of a trade-off is connected with each other. Therefore, it must be think about a method to satisfy the following conditions at the same time.

1) Color image should be natural color reproduction visually.
2) Gray scale image should appear the color that except white and black.

To satisfy this condition, the method use the versatility to gray scale image of Type2 with good point of Type1. Therefore, there is following method.



(a) $\beta = 0.0$ (b) $\beta = 0.03$

(c) $\beta = 0.1$ (d) $\beta = 0.3$

Fig. 6 Halftone Images using the Procedure Type2 (Original images is full color image)

1) Weight $\beta = 0$ for angle error θ as cost function is following equation in Type2.

$$E = \alpha_m E_m + \alpha_c E_c \tag{13}$$

Here, it is assumed $\alpha_m = 0.2$, $\alpha_c = 0.8$ from an argument to a foregoing chapter.

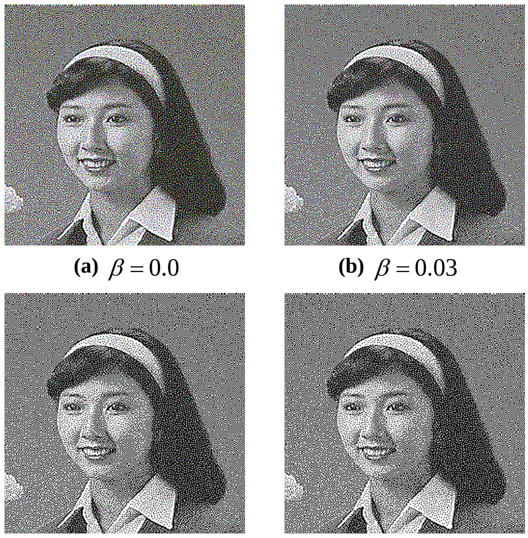
2) If there is a relationship of R=G in original image, the choice of color in process image should be restricted within the relationship of R=G.
3) If there is a relationship of G=B in original image, the choice of color in process image should be restricted within the relationship of G=B.
4) If there is a relationship of R=B in original image, the choice of color in process image should be restricted within the relationship of R=B.

The above method is called Type3. Process image obtained by this Type3 is shown as Fig. 8. This result is same as result of process image of Type1 with $\alpha_m = 0$ in color image. Only white and black appear in gray scale image and it is well result.

5. Conclusions

Type1 was the same as the knowledge in the gray scale image of SA, and when the weight of cost E_m on present of gray level, contrast E_c on contrast decides each 0.2, 0.8, the image understood to have become the expression were prominent subjectively by this method.

In case of using this method, It is adapted to the gray scale image that consist of R=G=B. Then the color other than black and white is breaking out by multimodal of a solution, as a result, process image does not become the gray scale image. Type2 could prevent the occurrence of others color in gray scale image. However, it became the process image of little saturation in color image. Follow, Type3 made the basis of above two results. When it made not to consider the angle error at Type2, the same process image could get by color image. And in case of gray scale image, the color other than black and white doesn't appear by process image.



(a) $\beta = 0.0$ (b) $\beta = 0.03$

(c) $\beta = 0.1$ (d) $\beta = 0.3$

Fig. 7 Halftone Images using the Procedure Type1 (Original images is gray scale image)

(a) Original image (d) gray scale image

Fig. 8 Halftone Images using (Type3)

Therefore, in case of SA is adapted to the halftoning in color image, we could get result good as the visual sensation at using Type3. Therefore, availability to the halftoning to the color image of SA became clear. Method of SA is calculated 15 minutes degree at CPU is 2GHz of Pentium4, Memory capacity is 1.5GB and OS is WindowsXP. Mention as assignment, the cutting of calculation cost and the shortening of process time.

6. References

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