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Inverse halftoning of color image using unsharp mask

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Abstract: The inverse halftoning is image restoration technique to make the grayscale image from binary image that is processed by digital halftoning. Inverse halftoning techniques need the removal of the noise. This is because the noise is added to reconstruct the pseudo grayscale image using black and white. In inverse halftoning image, important information also blurred when the noise in inverse halftoning image is reduced. In other hand, when the edge in inverse halftoning image is left, reducing the noise becomes insufficient. The goal of the inverse halftoning technique that can reduce the noise on inverse halftone image and that can emphasize the edge on inverse halftoning image. Therefore we propose inverse halftoning to emphasize the edge using unsharp mask. As a result of using unsharp mask, SNR became higher than conventional method and became easy to look visually.

Keywords: inverse halftonig, unsharp mask, canny method.

1 INTRODUCTION

The inverse halftoning is processing that restores the image made binary by the half tone processing to former gray-scale image. Inverse halftoning displays the pixel value with 0 (white) or 255 (black) bordering on a threshold value from 0 to 255. And, when the image is made binary, it is an expression technique as mixing the noise, and doing the one that is not a continuous step, etc. using the mistake of eyes of man who shows it. The one that is called the dither method and a random dither as a past technique is enumerated in the half tone processing. And, because the noise is mixed when the half tone was processed, it is necessary to remove it though the inverse halftoning returns the image made binary thus to former step value. Even perfection has not lived yet as a past technique of the inverse halftoning though the restoration of the image of the level that is only these past techniques can expect though a smoothing filter, a median filter, and gaussian filter, etc. are proposed. Because there is an evil such as growing dim of the edge part of the image to remove even the high frequency elements ,in a word, necessary information in the image other than the noise when it tries to obtain a smooth image by the inverse halftoning. Oppositely, the removal of the noise becomes insufficient when it tries to emphasize the edge part of the image, and the great result is not obtained so much as restoration accuracy of the image. The removal of the noise and the emphasis of the edge relate closely in the restoration of the image like this, and the design of processing where it can be difficultly achieved is expected as for doing the two highly accurate at the same time.

Therefore, we removed the noise by a mean filter and the gaussian filter, and performed unsharp mask to the edge part. From this, we are aiming that get the highly precise reconstruction image which satisfied both removal of the noise and emphasis of the edge.

2 INVERSE HALFTONING

Inverse halftoning is processing to return to the gradation of original image which is binarized by halftoning, and to become easy to look visually. Representative inverse halftoning processing includes a smoothing filter, a gaussian filter, a median filter.

In this paper, halftoning image is used Floyd & Steinberg..

2.1 Smoothing filter

The Smoothing filter is processing to let the mean of attention pixel and the pixel of the eight pixels of neighboring pixels be a pixel value of a new attention pixel. Fig. 1 shows that pixel (x,y) with a focus on nine pixels can be expressed as following equation**.**

$$f'(x,y) = f(x,y) * M(x,y) \qquad (1)$$

Here, * is the convolution of the above equation, M(x,y) is the mask of Fig. 2, f(x,y) is the attention pixel and the neighboring pixels, f'(x,y) represents a new pixel that.

(-1,1)	(0,1)	(1,1)
(-1,0)	(0,0)	(1,0)
(-1,-1)	(0,-1)	(1,-1)

Fig. 1. operator

$$\begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \times \frac{1}{9}$$

Fig. 2. smoothing filter

2.2 Gaussian filter

Gaussian filter is a process of determining the weighting factor of the neighborhood surrounding the pixel of interest using a Gaussian distribution. Gaussian distribution can be expressed as follows.

$$f(x,y) = \frac{1}{\sqrt{2}\pi\sigma}\exp(-\frac{x^2+y^2}{2\sigma^2}) \qquad (2)$$

In this paper, σ=0.53. Gaussian filter is obtained by convolving a mask that obtained by calculating the above equation as 3 × 3 pixels and attention pixel. Because Gaussian distribution is a normal distribution, the sum of the coefficients is always 1. Therefore, the pixel values before and after remains unchanged, so it can be folded in the coefficients.

2.3 Median filter

Median filter is a processing of decreasing order of pixel values in the neighborhood surrounding the pixel of interest, and let the value of middle be attention pixel.

2.4 Unsharp mask

Unsharp mask, when interpreted literally, "Sharp eliminate" becomes a means, but it is actually sharpen the image processing. Unsharp masking is often used to correct blurry images. Unsharp mask algorithm is as follows.

Means to sharpen the image is that increasing the difference between the pixel values of adjacent pixels. Applying a blur to the contrary is a process that continuous gradation is smoothly. Plus the blurred images to original image minus the difference and original image then can get a large picture of the difference gradation. This is a basic algorithm of unsharp mask. However, when the entire image to be processed, it is too sharp, and sharpens the noise, the picture may become ugly. Therefore, unsharp mask determine "quantity" and "Range" and "threshold", and processes into the portion which fulfilled conditions.

"Quantity" specifies the percentage K of change in pixel value. K is determined how much a sharp is used. " Quantity" can be expressed as follows.

$$f'(x,y) = f(x,y) + \left(f(x,y) - g(x,y)\right) * K \qquad (3)$$

Here, f(x,y) is the image before blurring, g(x,y) is the image blurred.

"Range" specifies the range of processing in pixel value. when the range is small, processing is only reflected in neighboring pixels. But, when the range is large, processing is reflected in far pixel. Therefore, an effect becomes large, so that the range is large. In this paper, we perform an operation on nine pixels of 3 × 3.

"Threshold" specifies processing, when there is the gradation difference that is how much. If the threshold is high, the noise can be cut neatly, but cut it to the edge when too high. On the contrary, when the threshold is too low, a noise is left and becomes the dirty image. Therefore, it is necessary to determine the appropriate threshold. However, it cannot isolate the noise and the edge with one threshold, because inverse halftoning image has much noise. Therefore, this paper describes unsharp mask only edge part by canny method.

2.5 Canny method

Canny method is a method to detect edge that is t hinned by combining the Sobel filter and Gaussian filt er. Canny method algorithm is processing of the image smoothing; the calculation of the gradient direction ed ge strength, edge thinning process is performed in the order of Hysteresis thresholding. Each step of the Can ny method is described as follows.

- Image smoothing

  Performed by the Gaussian smoothing filter to the input image image, and reduce the effects of noise.

- The calculation of the gradient direction edge strength

  After obtaining the derivative in each direction by Sobel filter, the strength and direction of each pixel are calculated. Sobel filter to calculate differential value of the horizontal fx and vertical fy by convoluting the mask in Fig. 3,4 and the attention pixel. Edge intensity E and gradient direction θ obtained by the following equation is obtained from fx and fy.

$$e = \sqrt{fx^2 + fy^2} \qquad (4)$$

$$\theta = \frac{fy}{fx} \qquad (5)$$

  The gradient direction θ calculates the pixel edge direction in 3 × 3, can be classified into four directions, as shown in Fig. 5,6,7. Four-way can be classified by splitting in the range of θ is calculated.

$$\begin{cases} 0° \text{ direction}: -0.4142 < \theta \le 0.4142 \\ 45° \text{ direction}: \quad 0.4142 < \theta < 2.4142 \\ 90° \text{ direction}: \quad |\theta| \ge 0.4142 \\ 135° \text{ direction}: -2.4142 < \theta \le -0.4142 \end{cases}$$

Here, the red line in Fig. 5,6,7,8 is the direction of an edge pixel, the black pixels is adjacent pixels in the vertical direction of the edge pixels.

- Edge thinning

  Proccess of edge thinning slim thickened edge by Gaussian filter. Comparing the pixel value of pixels adjacent vertical edges as in Fig. 5,6,7,8, and edge value to 0 if pixel value of edge is not max. Then, edge can be made thin.

- Hysteresis thresholding

  Two thresholds are set as high value and as low values. High threshold is detected as edge pixel, and low threshold is detected as there is no edge pixel. When a lower threshold than under a high threshold, attention pixel is detected as edge pixel if edge pixel exists in the neighborhood and attention pixel is detected as there is no edge pixel if edge pixel doesn't exist in the neighborhood. In this paper, high threshold to 128, low threshold to 20.

-1	0	1
-2	0	2
-1	0	1

Fig. 3. Horizontal direction fx

-1	-2	-1
0	0	0
1	2	1

Fig. 4. Vertical direction fx

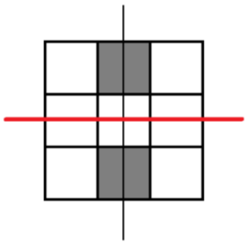

Fig. 5. 0^0 direction

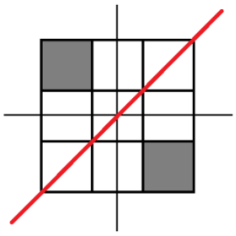

Fig. 6. 45^0 direction

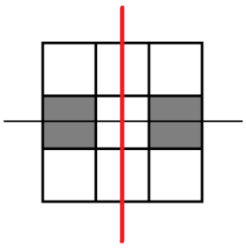

Fig. 7. 90^0 direction

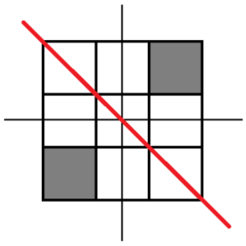

Fig. 8. 135^0 direction

3 PROCESS OF PROPOSAL METHOD

Fig. 9 shows the experimental procedure in this paper. The unsharp mask gradates processing use that smoothing filter, gaussian filter, a combination of three filter median filter. As a result of having inspected it with six pieces of images, the best thing is to use Gaussian filter twice. Therefore, gradate processing uses Gaussian filter twice in this paper.

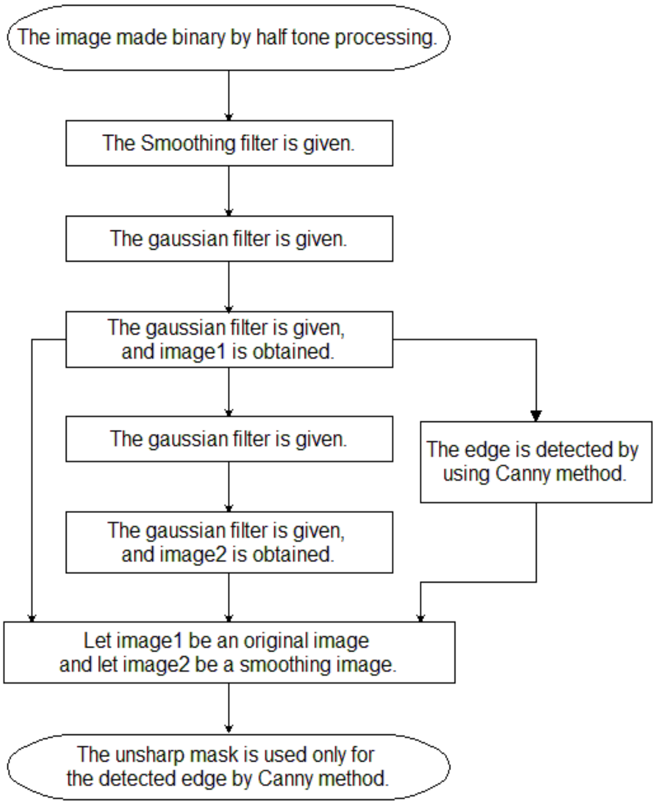

Fig. 9. Process of inverse halftonig

4 EXPERIMENTAL RESULT

We tested it in a procedure of Fig. 9 and verified the most suitable value of the unsharp coefficient K. Verification is used a representative sample images, "Airplane", "Lenna", "Milkdrop", "Parrots", "Pepper", "Sailboat".

Experiment is used SNR as a method for evaluation of the accuracy of image reconstruction. SNR can be calculated as follows.

$$\mathrm{SNR} = 10\log_{10}\frac{\sqrt{\Sigma f(x,y)^2}}{\sqrt{\Sigma(f(x,y)-f'(x,y))^2}} \quad [dB] \qquad (6)$$

Here, f(x,y) is the original image, f'(x,y) is the processed image.

Fig. 10 shows that coefficient of variation of 6 images of images corresponding to SNR as a graph. SNR can't use as an evaluation function for inverse halftoning. So, coefficients K should be constant for any image. After we computed the mean of coefficient K when SNR of each image was the highest, and handling it, it was shown in table 1. Table 1 shows SNR when the coefficient K is average, comparison between maximum SNR and the SNR when the coefficient K is average, SNR of the conventional method. The conventional method used the good following combinations of Halftoning image affinity by Floyd & Steinberg.

1st : smoothing filter
2nd : gaussian filter
3rd : gaussian filter

"Airplane" and "Sailboat" is greatest difference between SNR of the conventional method and SNR of the proposal method in Table 1. Therefore, we show a disposal result of two images in Fig. 11,12,13,14,15,16.

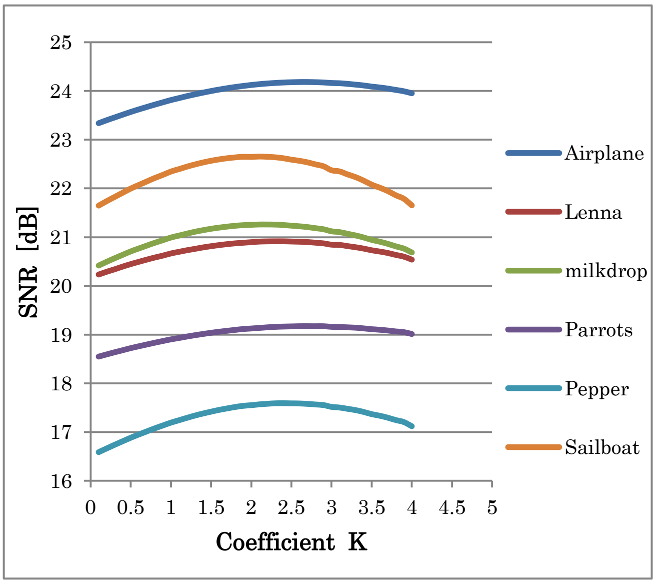

Fig. 10. Coefficient K corresponding to SNR

Fig. 11. Original image Airplane

Fig. 12. Original image Sailboat

Fig. 13. Unsharp mask

Fig. 14. Conventional method

Fig. 15. Unsharp mask

Fig. 16. Conventional method

5 CONCLUSION

In this paper, inverse halftoning was applied unsharp mask, it was confirmed that it is possible to restore some level of any image. In addition, the maximum difference between difference between the average and maximum values of the coefficient K wasn't little difference that was 0.04[dB]. Comparing the proposed method and the conventional method, SNR of each images are 0.5 [dB] higher, and became easy to look visually.

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Table 1. Average value of the coefficient K and conventional method

	unsharp mask			conventional method
	Average value of the coefficient K	*SNR [dB]*	*Difference between the average and maximum values of the coefficient K*	*SNR [dB]*
Airplane	2.41	24.18	0	23.36
Lenna		20.92	0	20.36
milkdrop		21.25	0.01	20.75
Parrots		19.17	0	18.65
Pepper		17.59	0	16.79
Sailboat		22.62	0.04	21.51