

## GENERATION OF ENGRAVED IMAGES BY STANDARD DEVIATION AND INVERSE FILTER

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**ABSTRACT.** *We propose a non-photorealistic rendering method for generating engraved images from gray-scale photographic images. Engraved images imitate an art expression created by carving a board with a chisel. First, our method performs the process using images created from the standard deviation in the window of photographic images and inverse filter. Second, the edges are extracted by Sobel filter from the images obtained by the first process. Finally, the edge images are equalized, and engraved images are generated. To verify the effectiveness of our method, we conduct experiments with changing the values of parameters of our method and experiments using various photographic images. As a result of the experiments, we reveal the appearance of engraved images.*

**Keywords:** Non-photorealistic rendering, Engraved image, Standard deviation, Inverse filter

1. **Introduction.** Non-photorealistic rendering (NPR) is a theme that has recently been attracted attention in the computer graphics community [1, 2, 3, 4, 5, 6, 7, 8]. NPR is performed by a program that takes images or three-dimensional data as input and generate new output images with the specified artistic style. NPR is utilized in the industrial field, the art field, the entertainment field, and the like. For example, it is used in technical illustrations in the industrial field, ink and painting style rendering in the art field, and extended expression of computer graphics in the entertainment field. In this paper, we focus on applications in the art field.

We propose a new NPR method for generating engraved images from gray-scale photographic images. The actual engraved pictures are created by carving a board with a chisel, putting ink on the board, and printing on paper. Engraved images imitate the expression of the engraved pictures. As far as our investigation, there is no research on NPR that generates engraved images. If we consider it as a similar research, there is research on woodcut printing [9]. However, [9] generates woodcut printing images interactively, and then it is not generated from photographic images like our method.

Our method is executed by an iterative calculation using inverse filter [10, 11] and the standard deviation in the window of photographic images. Then, our method extracts edges from the images obtained by the iterative calculation using Sobel filter, and equalizes the edge images. The feature of our method is that engraved patterns can be automatically generated by changes in luminance values of photographic images. In addition, our method can generate engraved patterns along edges of photographic images,

and it is easy to recall photographic images. To verify the effectiveness of our method, we conduct experiments with changing the values of parameters of our method using Lenna image. As a result of the experiments, we reveal the appearance change of engraved images by changing the values of parameters. In addition, we apply our method to various photographic images, and verify the appearance of engraved images.

The rest of this paper is organized as follows. Section 2 describes our method for generating engraved images. Section 3 shows experimental results, and reveals the effectiveness of our method. Finally, Section 4 concludes this paper.

**2. Our Method.** Our method generates engraved images from gray-scale photographic images. The flow chart of our method is shown in Figure 1. First, the iterative calculation using the standard deviation in the window of photographic images and inverse filter is performed. Inverse filter is calculated by a procedure that restores an image converted by certain processing to an original image. The restored image includes restoration errors. The restoration errors generated by the iterative calculation are source for generating engraved patterns. The next process extracts edges from the images obtained by the iterative calculation using Sobel filter. Sobel filter is a typical spatial filter used for edge detection. The last process emphasizes the edge images by equalization. Equalization is a process of converting so that the slope of the histogram cumulative frequency graph is constant. It is possible to improve the overall balance of images with poor contrast and uneven brightness.

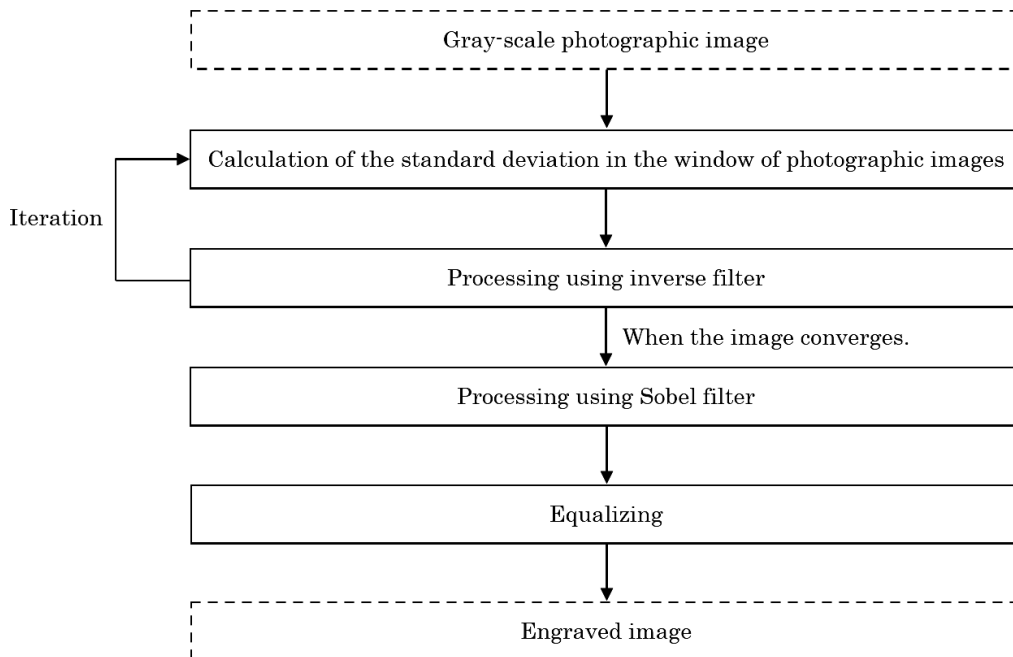


FIGURE 1. Flow chart of our method

Let input pixel value on coordinate  $(i, j)$  of a gray-scale photographic image be  $f_{i,j}$ . The pixel value  $f_{i,j}$  has value of 256 gradation from 0 to 255. Let output pixel value after the first process be  $f_{i,j}^{(t)}$ , where  $t (= 1, 2, 3, \dots)$  is the iteration number and  $f_{i,j}^{(1)} = f_{i,j}$ . The standard deviation  $\sigma_{i,j}^{(t)}$  of the pixel values in the window size  $W (= 3, 5, 7, \dots)$  around the pixel  $(i, j)$  is calculated. Let the minimum and maximum values of all standard deviations  $\sigma_{i,j}^{(t)}$  be  $\sigma_{\min}^{(t)}$  and  $\sigma_{\max}^{(t)}$ , respectively. The pixel value  $g_{i,j}^{(t)}$  of the standard-deviation image is calculated as follows.

$$g_{i,j}^{(t)} = 255 \frac{\sigma_{i,j}^{(t)} - \sigma_{\min}^{(t)}}{\sigma_{\max}^{(t)} - \sigma_{\min}^{(t)}} \quad (1)$$

The pixel value  $h_{i,j}^{(t)}$  is calculated using inverse filter as follows.

$$h_{i,j}^{(t)} = a \left( f_{i,j}^{(t)} - g_{i,j}^{(t)} \right) + f_{i,j} \tag{2}$$

where  $a = (W - 1)/2$ . Let the minimum and maximum values of all pixel values  $h_{i,j}^{(t)}$  be  $h_{\min}^{(t)}$  and  $h_{\max}^{(t)}$ , respectively. The pixel value  $f_{i,j}^{(t+1)}$  is calculated as follows.

$$f_{i,j}^{(t+1)} = 255 \frac{h_{i,j}^{(t)} - h_{\min}^{(t)}}{h_{\max}^{(t)} - h_{\min}^{(t)}} \tag{3}$$

The above calculation is repeated  $T$  times.

An edge image is created by extracting edges from the pixel value  $f_{i,j}^{(T)}$  of the image using Sobel filter. The operators for Sobel filter with window size  $3 * 3$  are as follows.

$$s_x = [-1, 0, 1; -2, 0, 2; -1, 0, 1] \tag{4}$$

$$s_y = [-1, -2, -1; 0, 0, 0; 1, 2, 1] \tag{5}$$

The values in the operators in Equations (4) and (5) are for the upper left, upper, upper right, left, central, right, lower left, lower, and lower right pixels in the window in that order. In the calculation of  $SF \left( f_{i,j}^{(T)} \right)$ , the operators in Equation (4) and (5) are first used to find  $SF_x \left( f_{i,j}^{(T)} \right)$  and  $SF_y \left( f_{i,j}^{(T)} \right)$ , respectively, and then  $SF_s \left( f_{i,j}^{(T)} \right)$  is taken as the square root of the sum of squares of  $SF_x \left( f_{i,j}^{(T)} \right)$  and  $SF_y \left( f_{i,j}^{(T)} \right)$  as follows.

$$SF_x \left( f_{i,j}^{(T)} \right) = -f_{i-1,j-1}^{(T)} + f_{i+1,j-1}^{(T)} - 2f_{i,j-1}^{(T)} + 2f_{i,j+1}^{(T)} - f_{i-1,j+1}^{(T)} + f_{i+1,j+1}^{(T)} \tag{6}$$

$$SF_y \left( f_{i,j}^{(T)} \right) = -f_{i-1,j-1}^{(T)} - 2f_{i,j-1}^{(T)} - f_{i+1,j-1}^{(T)} + f_{i-1,j+1}^{(T)} + 2f_{i,j+1}^{(T)} + f_{i+1,j+1}^{(T)} \tag{7}$$

$$SF_s \left( f_{i,j}^{(T)} \right) = \sqrt{SF_x \left( f_{i,j}^{(T)} \right)^2 + SF_y \left( f_{i,j}^{(T)} \right)^2} \tag{8}$$

Let  $SF_{s,\min}$  and  $SF_{s,\max}$  be the minimum and maximum values of  $SF_s \left( f_{i,j}^{(T)} \right)$ , respectively. The pixel value  $o_{i,j}$  of the edge image is calculated as follows.

$$o_{i,j} = 255 - 255 \frac{SF_s \left( f_{i,j}^{(T)} \right) - SF_{s,\min}}{SF_{s,\max} - SF_{s,\min}} \tag{9}$$

In equalization, the appearance frequency of the pixel value  $o_{i,j}$  of the edge image is obtained, and then the edge image is converted so that the appearance frequency becomes the same. An engraved image is generated by equalizing the edge image.

**3. Experiments.** We applied our method to gray-scale Lenna image (Figure 2) with  $512 * 512$  pixels and 256 gradation. We visually evaluated the change in appearance to engraved images when the values of the parameters  $T$  and  $W$  were changed. In the following experiments, the base reference values of the parameters  $T$  and  $W$  were respectively set to 100 and 5, and each parameter was changed separately.

First, the value of  $T$  was changed to 5, 20, 50 and 100. The engraved images are shown in Figure 3. As the iteration number  $T$  became bigger, engraved patterns became clear. Since the change of engraved images was small even if the value of  $T$  was made too large, the value of  $T$  should be 100.

Next, the value of  $W$  was changed to 3, 5, 7 and 9. The engraved images are shown in Figure 4. As the window size  $W$  became bigger, engraved patterns became wider.

Depending on the image size and the usage of the user,  $W$  should be set to an appropriate value.

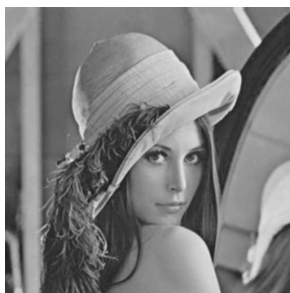


FIGURE 2. Lenna image

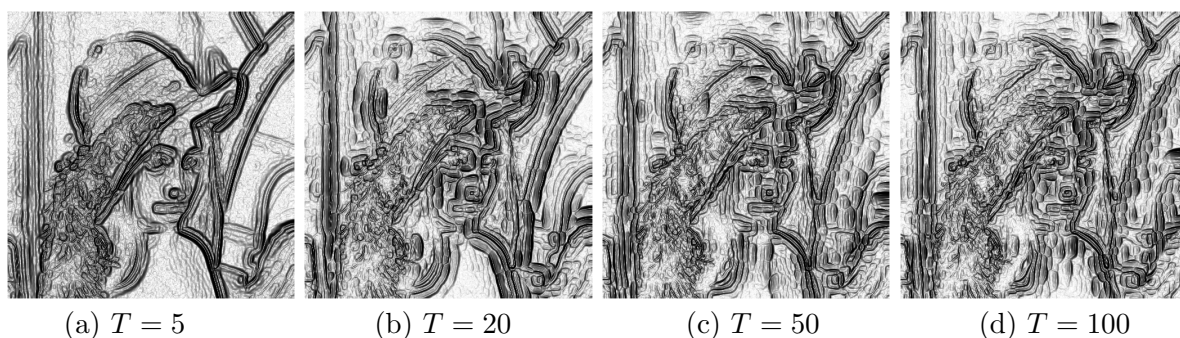


FIGURE 3. Engraved images in the case of  $T = 5, 20, 50$  and  $100$

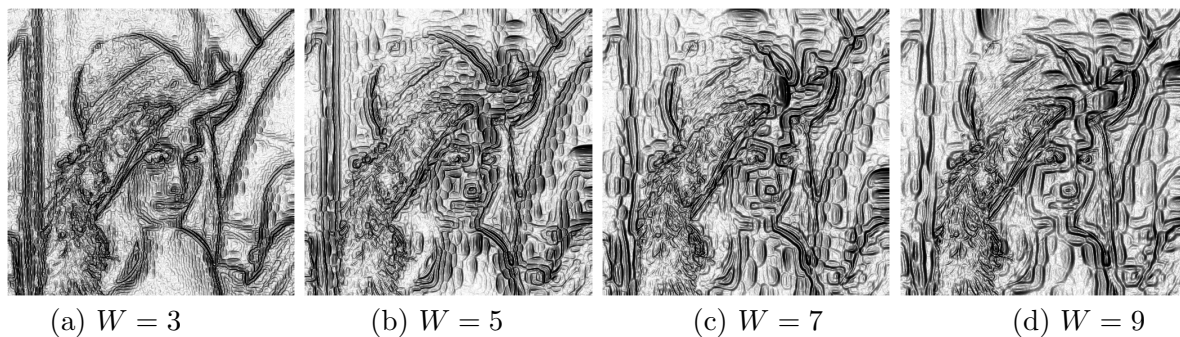


FIGURE 4. Engraved images in the case of  $W = 3, 5, 7$  and  $9$



FIGURE 5. Enlarged view of engraved image in the case of  $T = 100$  and  $W = 5$

For reference, an enlarged view of engraved image in the case of  $T = 100$  and  $W = 5$  is shown in Figure 5.

Finally, we applied our method to eight gray-scale images with  $512 * 512$  pixels and 256 gradation. Eight photographic images are shown in Figure 6. The values of  $T$  and  $W$  were set to 100 and 5. The results are shown in Figure 7. In all cases, engraved patterns could be automatically generated by changes in luminance values of photographic images. And, our method could generate engraved patterns along edges of photographic images.

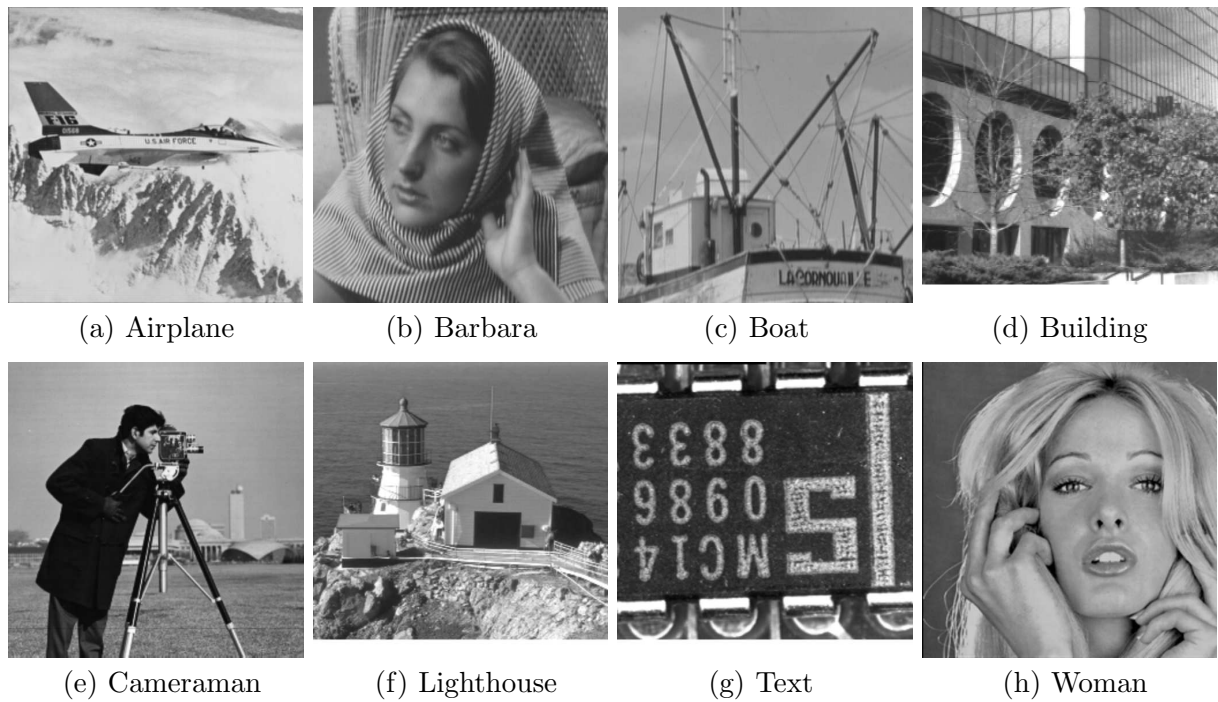


FIGURE 6. Photographic images

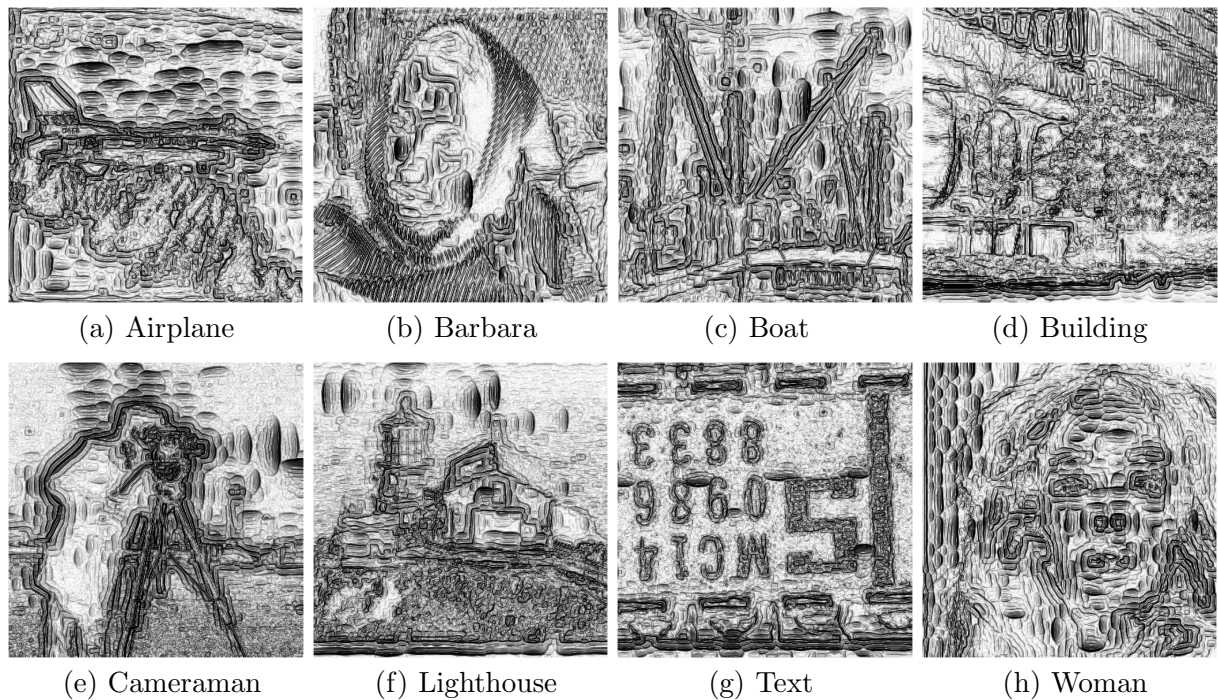


FIGURE 7. Engraved images

However, engraved patterns were unlikely to occur in fine texture regions like the upper right part in Figure 7(b) and the tree part in Figure 7(d).

**4. Conclusions.** We proposed a non-photorealistic rendering method for generating engraved images from gray-scale photographic images. Our method was executed by an iterative calculation using inverse filter and the standard deviation in the window of photographic images. To verify the effectiveness of our method, we visually evaluated the change in appearance to engraved images when the values of parameters of our method were changed. The results offer guidelines for generating engraved images from various photographic images. In addition, we applied our method to various photographic images. As a result of the experiments, it was found that engraved patterns can be automatically generated on the whole image.

A subject for future study is to generate engraved patterns in fine texture regions. Another subject is to expand our method for application to color photographic images and videos.

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