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GENERATION OF CHARCOAL-DRAWING-LIKE IMAGES BY SINGULAR VALUE DECOMPOSITION AND INVERSE FILTER

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Abstract. *Many researches have been conducted on non-photorealistic rendering that generates charcoal-drawing-like images. These conventional methods have a problem that the processing is complicated. This letter proposes a simple non-photorealistic rendering method for generating charcoal-drawing-like images from photographic images. The proposed method generates charcoal-drawing-like images by an iterative processing using singular value decomposition and inverse filter from photographic gray-scale images. In order to verify the effectiveness of the proposed method, experiments using a gray-scale image of Lena are performed, and visual assessment of charcoal-drawing-like images is conducted by changes in appearance as the parameter values in the proposed method are varied. As an additional experiment, the proposed method is applied to several photographic images. As a result of the experiments, the proposed method was shown to be able to generate charcoal-drawing-like images, and the optimal value of parameters in the proposed method was found for charcoal-drawing-like images.*
Keywords: Non-photorealistic rendering, Charcoal drawing, Singular value decomposition, Inverse filter

1. **Introduction.** Researches on non-photorealistic rendering have been actively conducted for the purpose of assisting to make paintings and movies by computers [1, 2, 3, 4, 5, 6, 7]. Non-photorealistic rendering is a technique to generate non-photorealistic images with artistic expression such as oil painting, ink painting, pencil drawing, and charcoal drawing. Non-photorealistic images are generated from photographic images, photographic movies, and 3-dimensional models.

We force on non-photorealistic rendering to generate charcoal drawing from photographic images. Charcoal drawing is an art to draw the shape and brightness of an object in the plane using a charcoal, and has the rubbing texture of the charcoal. Many researches have been conducted on non-photorealistic rendering that generates charcoal-drawing-like images [8, 9, 10, 11]. Majumder and Gopi [8] proposed a method using contrast enhancement operators on textures and colors of 3-dimensional models. Johan et al. [9] proposed a method using luminance of strokes according to luminance of Voronoi regions. Liu and Akleman [10] proposed a method supporting reflection, shadow, atmospheric, depth, and weathering effects on 3-dimensional models. Du [11] proposed a method using a Barycentric shader that is based on degree zero B-spline basis function. These conventional methods have a problem that the processing is complicated.

We propose a simple on-photorealistic rendering method for generating charcoal-drawing-like images from photographic gray-scale images. Our method generates charcoal-drawing-like images by an iterative processing using singular value decomposition and inverse filter. Although the conventional methods require many coping processes and 3-dimensional models to express the strokes of charcoal drawing, our method is simpler to process than the conventional methods and does not use 3-dimensional models. Our method has characteristics that charcoal-drawing-like patterns can be automatically generated in accordance with the luminance and the shading of photographic images and are expressed in texture like cross hatching, and the roughness of charcoal-drawing-like patterns can be adjusted by changing the parameter values in our method. In order to evaluate the performance of our method, we conduct experiments on a gray-scale image of Lena shown in Figure 1 as the parameter values in our method are changed. As an additional experiment, our method is applied to several photographic images. As a result, we confirm that our method can generate charcoal-drawing-like images, and show the variations that could be generated in charcoal-drawing-like images as the parameter values in our method are changed.

FIGURE 1. Gray-scale image of Lena

The rest of this paper is organized as follows. Section 2 describes our method for generating charcoal-drawing-like images by an iterative processing using singular value decomposition and inverse filter. Section 3 shows experimental results, and reveals how to change charcoal-drawing-like images as the parameter values in our method are changed. Finally, Section 4 concludes this paper.

2. **Our Method.**

Our method generates charcoal-drawing-like images by an iterative processing using singular value decomposition and inverse filter from photographic gray-scale images. Singular value decomposition is a factorization of a real or complex matrix. In singular value decomposition, a matrix of I columns and J rows is expressed by the sum of the products of K number of transpose vectors of J elements and vectors of I elements. Inverse filter is calculated by using a procedure that restores an image converted by a processing to an original image. The procedure of inverse filter follows the iterative calculations of adding the difference between the pixel values before and after converting the image by the processing to the first converted image.

In our method, singular value decomposition is first performed on a gray-scale photographic image, and a reconstructed image is computed using several singular value and vectors. Next, the reconstructed image is restored to the gray-scale photographic image by inverse filter. The restored image includes a restoration error. By repeating the above processes, charcoal-drawing-like images are generated with the emphasized restoration error. The detailed procedure of our method is shown below.

Let input pixel values on coordinates (i, j) of the gray-scale photographic image be $f_{i,j}$ $(i = 1, 2, \ldots, I;\ j = 1, 2, \ldots, J)$. The pixel values $f_{i,j}$ have value of 256 gradation from 0 to 255.

First, compute singular value decomposition of $f_{i,j}$, let the k-th singular value and vectors be λ_k, $u_k = [u_{k,1}, u_{k,2}, \ldots, u_{k,I}]$, and $v_k = [v_{k,1}, v_{k,2}, \ldots, v_{k,J}]$ respectively, where $u_k u_k^T = 1$ and $v_k v_k^T = 1$. That is, the following equation holds.

$$f_{i,j} = \sum_{k=1}^{\infty} \lambda_k v_k^T u_k \tag{1}$$

Let output pixel value of the reconstructed image using from the first to K-th singular value and vectors be $SVD_K(f_{i,j})$.

$$SVD_K(f_{i,j}) = \sum_{k=1}^{K} \lambda_k v_k^T u_k \tag{2}$$

Next, compute the pixel values $f_{i,j}^{(t)}$ by using the inverse filter as

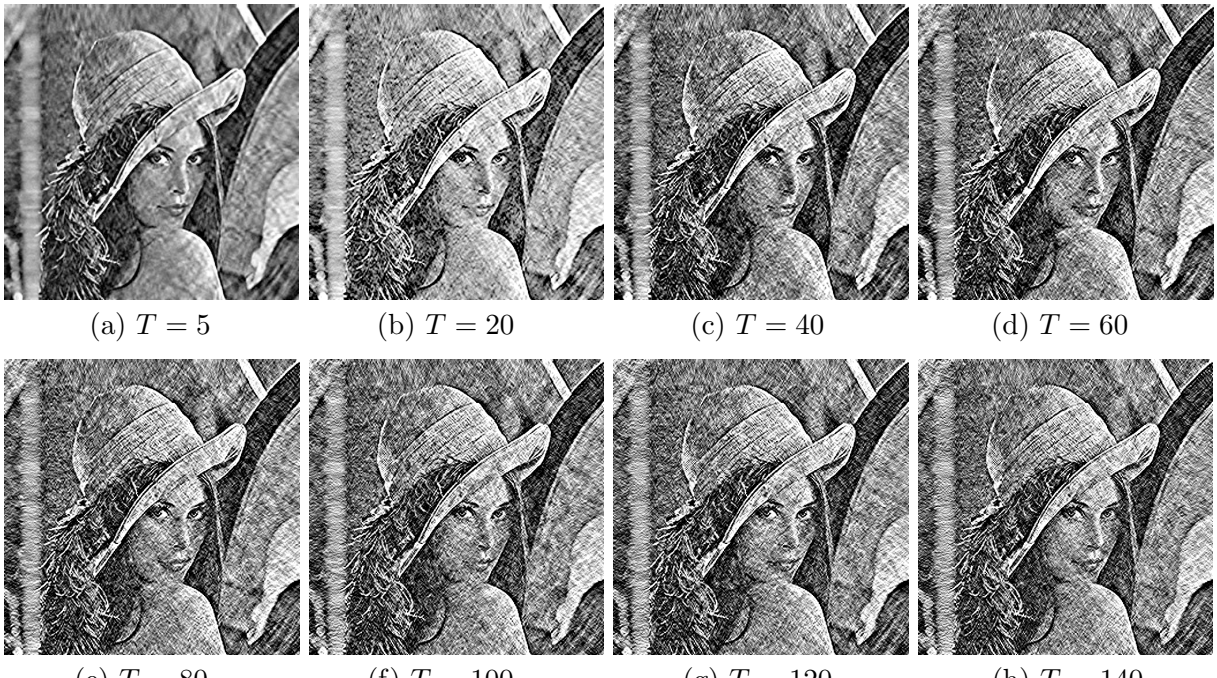
$$f_{i,j}^{(t)} = f_{i,j}^{(t-1)} - SVD_K\left(f_{i,j}^{(t-1)}\right)_{i,j} + f_{i,j} \tag{3}$$

where t is the number of iterations. Let the initial values $f_{i,j}^{(0)}$ be $f_{i,j}$. The pixel values $f_{i,j}^{(t)}$ are set to 0 if their values are less than 0, and set to 255 if their values are greater than 255.

Finally, charcoal-drawing-like images are obtained after the iterative processing using singular value decomposition and inverse filter of T times iteration.

3. **Experiments.** We first applied our method to the gray-scale image of $512 * 512$ size and 256 tone of Lena, and visually assessed the variations induced in charcoal-drawing-like images as the parameter values in our method are changed. We next applied our method to several photographic gray-scale images of $512 * 512$ size and 256 tone.

First, we assessed the variation in charcoal-drawing-like images generated as the number of iterations T is changed with $K = 20$. The results for $T = 5$, 20, 40, 60, 80, 100, 120, and 140 are shown in Figure 2. As the value of T is increased, charcoal-drawing-like patterns



(a) $T = 5$ (b) $T = 20$ (c) $T = 40$ (d) $T = 60$

(e) $T = 80$ (f) $T = 100$ (g) $T = 120$ (h) $T = 140$

FIGURE 2. Charcoal-drawing-like images using different T

(a) $K = 10$ (b) $K = 20$ (c) $K = 30$ (d) $K = 40$

FIGURE 3. Charcoal-drawing-like images using different K

FIGURE 4. The enlarged view of charcoal-drawing-like color image with $T = 100$ and $K = 20$

became clear and charcoal-drawing-like images were converged. In order to converge charcoal-drawing-like images, we judged that the optimal value of T was around 100.

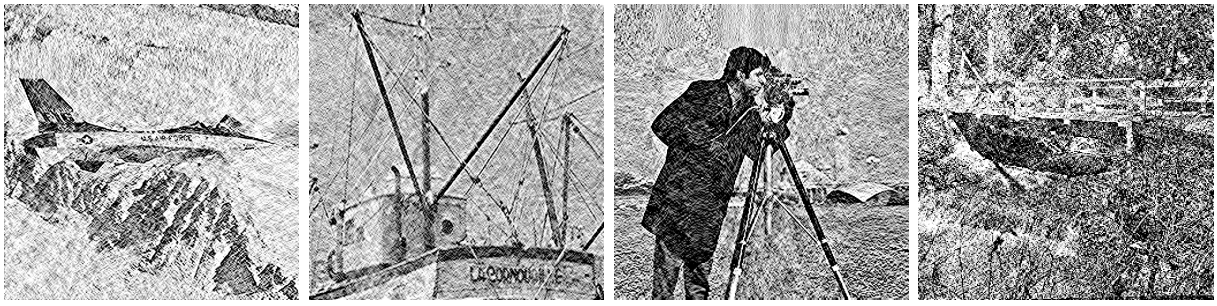
Next, we assessed the variation in charcoal-drawing-like images generated as the number of iterations K is changed with $T = 100$. The results for $K = 10$, 20, 30, and 40 are shown in Figure 3. As the value of K is increased, charcoal-drawing-like patterns became finer and the rubbing texture of the charcoal decreased. In order to express charcoal-drawing-like patterns, we judged that the optimal value of K was around 20.

For reference, Figure 4 shows the enlarged view of charcoal-drawing-like color image with $T = 100$ and $K = 20$. As shown, patterns such as cross hatching of charcoal drawing are expressed.

Finally, we applied our method to four photographic gray-scale images of $512 * 512$ size and 256 tone shown in Figure 5 with $T = 100$ and $K = 20$. The results are shown in Figure 6. In all four cases, charcoal-drawing-like patterns were automatically generated

(a) Airplane (b) Boat (c) Cameraman (d) Bridge

FIGURE 5. Photographic gray-scale images



(a) Airplane (b) Boat (c) Cameraman (d) Bridge

FIGURE 6. Charcoal-drawing-like images

in accordance with the luminance and the shading of photographic images. However, the cross-hatching-like patterns were less likely to appear in the small part of the texture of Figure 6(c).

4. **Conclusions.** We proposed a simple non-photorealistic rendering method for generating charcoal-drawing-like images from photographic gray-scale images. In order to evaluate the performance of our method, we conducted experiments using a gray-scale image of Lena as the parameter values in our method are changed, and applied to several photographic images. As a result, we confirmed that our method could generate charcoal-drawing-like images, and found the optimal value of parameters in our method for generating charcoal-drawing-like images.

The future task is to generate cross-hatching-like patterns in the small part of the texture. Another task is to expand our method for application to photographic color images and photographic movies.

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