ICIC Express Letters
Volume **12**, Number **6**, June **2018**

ICIC International ©2018 ISSN 1881-803X
pp. 511–517

GENERATION OF LINE-PATTERN IMAGE BY JOINT SINGULAR VALUE DECOMPOSITION AND UNSHARP MASK

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Received November 2017; accepted February 2018

Abstract. *This paper proposes a visual effect method for generating a line-pattern image from a photographic image. The proposed method is executed by an iterative calculation using joint singular value decomposition and unsharp mask. The feature of the proposed method is that the line-pattern images with various line patterns can be automatically generated by varying the singular number of joint singular value decomposition and the shape of window of unsharp mask. To verify the visual effects of the line-pattern image, experiments with varying parameters of the proposed method are conducted. Also, experiments using various photographic images are conducted.*

Keywords: Visual effect, Joint singular value decomposition, Unsharp mask, Line pattern

1. **Introduction.** Visual effects have been receiving attention in television, movies, and social networking services as a technology to create images that are not in reality. Art work using visual effects is completely generated by a computer using fractal and chaos, is generated from a photographic image and video, and is drawn by a person using a mouse. This paper focuses on visual effects generated from the photographic image. Many researches have been conducted to generate such visual effects. For example, there are researches to convert artistic images such as pointillism [1], charcoal drawing [2], oil painting [3], and pencil drawing [4, 5, 6] from the photographic images. Recently, many researches also have been conducted to generate not only existing painting expressions but also unprecedented painting expressions such as labyrinthine image [7], cell image [8], moire image [9], and stripe-patchwork image [10]. The labyrinthine image is generated using a method based on a random generation of gray tones and competing statistical requirements. The cell image, the moire image, and the stripe-patchwork image are generated by inverse iris filter, filter combining bilateral filter and unsharp mask, and inverse filter using k-means clustering, respectively.

This paper focuses on an unprecedented painting expression to develop a variety of visual effects, and proposes a line-pattern image which is a novel unprecedented painting expression consisting of lines. The line-pattern image is generated by an iterative calculation using joint singular value decomposition [11, 12] and unsharp mask from the photographic image. The feature of the proposed method is that the line-pattern images with various line patterns can be automatically generated by varying the singular number of joint singular value decomposition and the shape of window of unsharp mask. The labyrinthine image and the stripe-patchwork image also consist of various line patterns. However, the proposed method can generate different line patterns, and control how the line patterns are generated to some extent by varying the shape of window of unsharp mask. To verify the performance of the proposed method, the visual effects of the line-pattern image are investigated with varying the singular number of joint singular value decomposition and the shape of window of unsharp mask. Also, experiments using various photographic images are verified.

The rest of this paper is organized as follows. Section 2 describes the proposed method using joint singular value decomposition and unsharp mask. Section 3 shows experimental results, and reveals the appearance of the line-pattern images generated by varying the singular number of joint singular value decomposition and the shape of window of unsharp mask. Finally, Section 4 concludes this paper.

2. **Proposed Method.** The line-pattern image is generated by performing two main processes. The first process uses joint singular value decomposition to convert the photographic image. Joint singular value decomposition is an extension of singular value decomposition in order to compress the redundancy in images and between images of multiple image. In joint singular value decomposition, M number of matrix of I columns and J rows are expressed by the sum of K number of the products of transpose vectors of J elements and vectors of I elements. The second process uses unsharp mask to convert the image after the first process. Unsharp mask emphasizes the contour lines of the image. The line-pattern image is generated by repeating the first and second processes. A flow chart of the proposed method is shown in Figure 1.

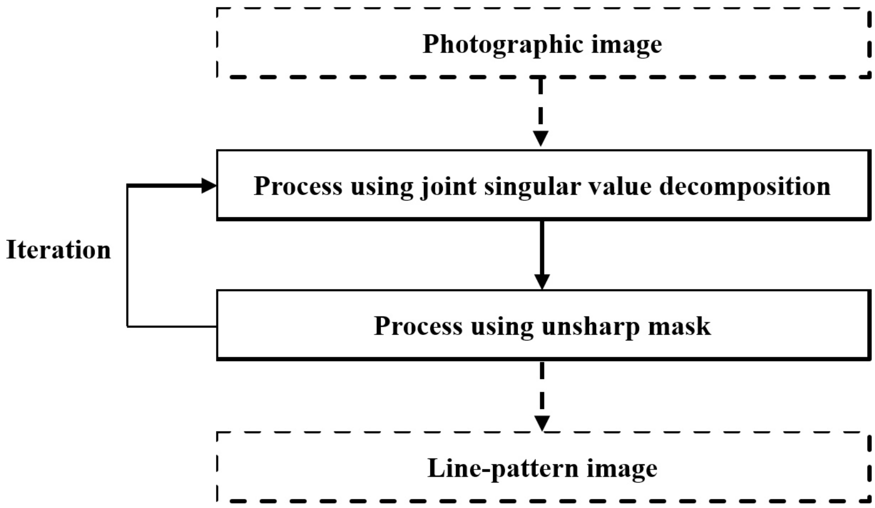


FIGURE 1. Flow chart of the proposed method

2.1. **Process using joint singular value decomposition.** This process uses joint singular value decomposition to convert the photographic image. Let input pixel values (Red, Green, and Blue) on coordinates (i, j) of the color photographic image be $f_{R,i,j}$, $f_{G,i,j}$, and $f_{B,i,j}$ $(i = 1, 2, \ldots, I; j = 1, 2, \ldots, J)$, respectively. The pixel values $f_{R,i,j}$, $f_{G,i,j}$, and $f_{B,i,j}$ have value of 256 gradation from 0 to 255.

Joint singular value decomposition of $f_{R,i,j}$, $f_{G,i,j}$, and $f_{B,i,j}$ is computed. Let the k-th joint singular values and vectors be $\lambda_{R,k}$, $\lambda_{G,k}$, $\lambda_{B,k}$, $u_k = [u_{k,1}, u_{k,2}, \ldots, u_{k,I}]$, 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.

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

$$f_{G,i,j} = \sum_{k=1}^{\infty} \lambda_{G,k} v_k^T u_k \tag{2}$$

$$f_{B,i,j} = \sum_{k=1}^{\infty} \lambda_{B,k} v_k^T u_k \tag{3}$$

Let output pixel values of the reconstructed images using from the first to K-th joint singular values and vectors be $JSVD_{R,K}(f_{R,i,j})$, $JSVD_{G,K}(f_{G,i,j})$, and $JSVD_{B,K}(f_{B,i,j})$, respectively.

$$JSVD_{R,K}(f_{R,i,j}) = \sum_{k=1}^{K} \lambda_{R,k} v_k^T u_k \tag{4}$$

$$JSVD_{G,K}(f_{G,i,j}) = \sum_{k=1}^{K} \lambda_{G,k} v_k^T u_k \tag{5}$$

$$JSVD_{B,K}(f_{B,i,j}) = \sum_{k=1}^{K} \lambda_{B,k} v_k^T u_k \tag{6}$$

The pixel values $g_{R,i,j}^{(c)}$, $g_{G,i,j}^{(c)}$, and $g_{B,i,j}^{(c)}$ are computed as

$$g_{R,i,j}^{(c)} = 2f_{R,i,j}^{(1)} - JSVD_{R,K}\left(f_{R,i,j}^{(c)}\right) \tag{7}$$

$$g_{G,i,j}^{(c)} = 2f_{G,i,j}^{(1)} - JSVD_{G,K}\left(f_{G,i,j}^{(c)}\right) \tag{8}$$

$$g_{B,i,j}^{(c)} = 2f_{B,i,j}^{(1)} - JSVD_{B,K}\left(f_{B,i,j}^{(c)}\right) \tag{9}$$

where c ($c = 1, 2, \ldots$) is the number of iterations, $f_{R,i,j}^{(1)} = f_{R,i,j}$, $f_{G,i,j}^{(1)} = f_{G,i,j}$, and $f_{B,i,j}^{(1)} = f_{B,i,j}$. If $g_{R,i,j}^{(c)}$, $g_{G,i,j}^{(c)}$, and $g_{B,i,j}^{(c)}$ are less than 0, they are set to 0, respectively. If $g_{R,i,j}^{(c)}$, $g_{G,i,j}^{(c)}$, and $g_{B,i,j}^{(c)}$ are greater than 255, they are set to 255, respectively.

2.2. **Process using unsharp mask.** This process emphasizes the line patterns by unsharp mask. Let pixel values obtained by smoothing the pixel values $g_{R,i,j}^{(c)}$, $g_{G,i,j}^{(c)}$, and $g_{B,i,j}^{(c)}$ be $h_{R,i,j}^{(c)}$, $h_{G,i,j}^{(c)}$, and $h_{B,i,j}^{(c)}$, respectively. The smoothing is the average of the pixel values contained in a window centered on the pixel (i, j). In the following experiments, the shapes of the window are set to $3 * 3$, $5 * 5$, $3 * 5$, and $5 * 3$. It is possible to generate different line patterns depending on the shape of window.

The pixel values $o_{R,i,j}^{(c)}$, $o_{G,i,j}^{(c)}$, and $o_{B,i,j}^{(c)}$ converted by unsharp mask are computed as follows.

$$o_{R,i,j}^{(c)} = 2g_{R,i,j}^{(c)} - h_{R,i,j}^{(c)} \tag{10}$$

$$o_{G,i,j}^{(c)} = 2g_{G,i,j}^{(c)} - h_{G,i,j}^{(c)} \tag{11}$$

$$o_{B,i,j}^{(c)} = 2g_{B,i,j}^{(c)} - h_{B,i,j}^{(c)} \tag{12}$$

If $o_{R,i,j}^{(c)}$, $o_{G,i,j}^{(c)}$, and $o_{B,i,j}^{(c)}$ are less than 0, they are set to 0, respectively. If $o_{R,i,j}^{(c)}$, $o_{G,i,j}^{(c)}$, and $o_{B,i,j}^{(c)}$ are greater than 255, they are set to 255, respectively.

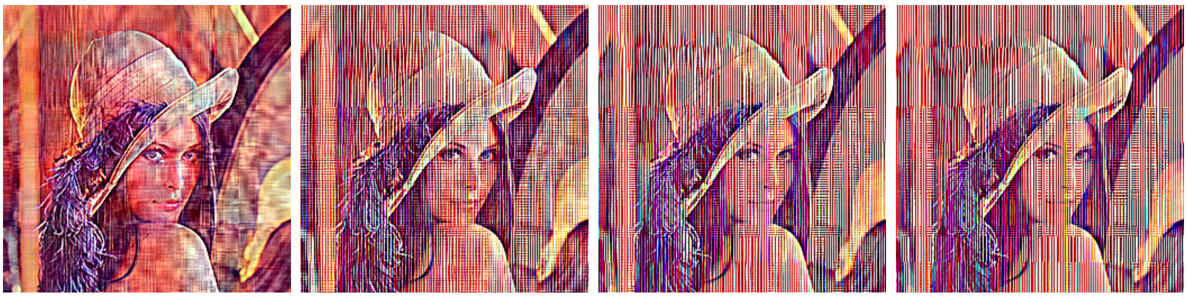
2.3. **Iterative calculation.** This iterative calculation gradually forms the line patterns. Let the pixel values $o^{(c)}_{R,i,j}$, $o^{(c)}_{G,i,j}$, and $o^{(c)}_{B,i,j}$ be $f^{(c+1)}_{R,i,j}$, $f^{(c+1)}_{G,i,j}$, and $f^{(c+1)}_{B,i,j}$, respectively. It returns to the process using joint singular value decomposition.

Finally, the image obtained by repeating the iterative calculation C times is the line-pattern image.

3. **Experiments.** First, the line-pattern images generated by varying the singular number K of joint singular value decomposition are visually confirmed using Lenna image shown in Figure 2. Next, the line-pattern images generated by varying the shape of window of unsharp mask are visually confirmed using Lenna image. Finally, the line-pattern images generated from various photographic images are verified. All experiments are conducted using the photographic images with $256 * 256$ pixel size.

FIGURE 2. Lenna image

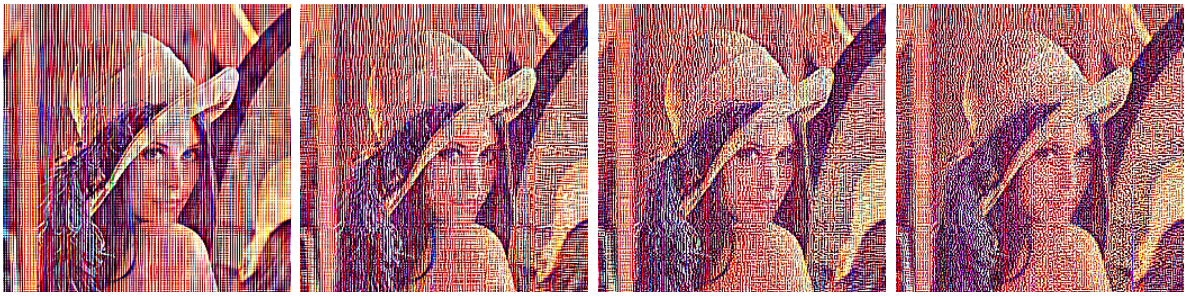
3.1. **Experiment with varying the iterative number.** The line-pattern images generated by varying the iterative number C of joint singular value decomposition are visually confirmed using Lenna image. The iterative number C is set to 5, 10, 15, and 20. The singular number K is set to 20, and the shape of window of unsharp mask is $3 * 3$. The results of the experiment are shown in Figure 3. As the value of the iterative number C is larger, the line patterns become clearer. On the other hand, as the value of the iterative number C is larger, the saturation of the line-pattern image decreases. Thus, the value of the iterative number C should be around 10.



(a) $C = 5$ (b) $C = 10$ (c) $C = 15$ (d) $C = 20$

FIGURE 3. Line-pattern images generated by varying the iterative number C

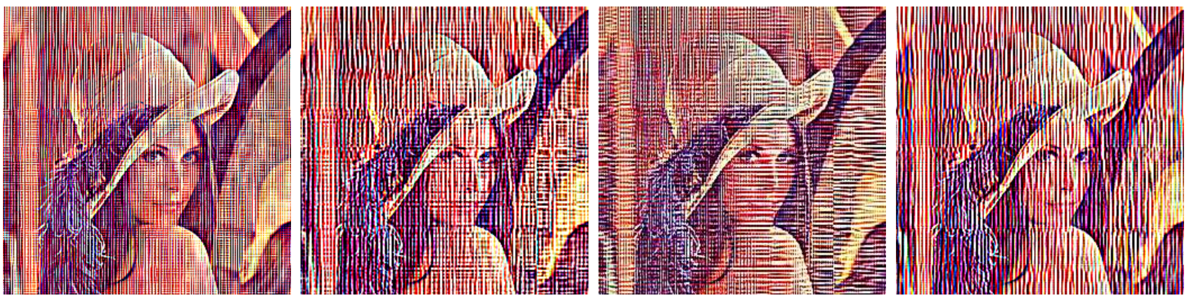
3.2. **Experiment with varying the singular number.** The line-pattern images generated by varying the singular number K of joint singular value decomposition are visually confirmed using Lenna image. The singular number K is set to 20, 40, 60, and 80. The iterative number C is set to 10, and the shape of window of unsharp mask is $3 * 3$. The results of the experiment are shown in Figure 4. As the value of the singular number K is smaller, the line patterns are more straight. In order to generate the straight line patterns, the value of the singular number K should be around 20.



(a) $K = 20$ (b) $K = 40$ (c) $K = 60$ (d) $K = 80$

FIGURE 4. Line-pattern images generated by varying the singular number K

3.3. **Experiment with varying the shape of window of unsharp mask.** The line-pattern images generated by varying the shape of window of unsharp mask are visually confirmed using Lenna image. The shape of window is $3 * 3$, $5 * 5$, $3 * 5$, and $5 * 3$. The iterative number C and the singular number K are set to 10 and 20, respectively. The results of the experiment are shown in Figure 5. From Figures 5(a) and 5(b), as the window size increases, the line patterns become thick. From Figures 5(a) and 5(c), as the shape of window is long vertically, the horizontal line patterns are more likely to occur. From Figures 5(a) and 5(d), as the shape of window is long horizontally, the vertical line patterns are more likely to occur.



(a) $3 * 3$ (b) $5 * 5$ (c) $3 * 5$ (d) $5 * 3$

FIGURE 5. Line-pattern images generated by varying the shape of window

3.4. **Experiment using various images.** The proposed method was applied to eight additional photographic images shown in Figure 6. The iterative number C and the singular number K are set to 10 and 20 respectively, and the shape of window of unsharp mask is $3 * 3$. The results of the experiment are shown in Figure 7. From Figure 7, the line patterns are generated throughout entire regions for all line-pattern images. From Figure 7(d), however, the line patterns are less likely to occur in lower brightness regions. From Figure 7(e), also, the line patterns are less likely to occur in fine texture regions.

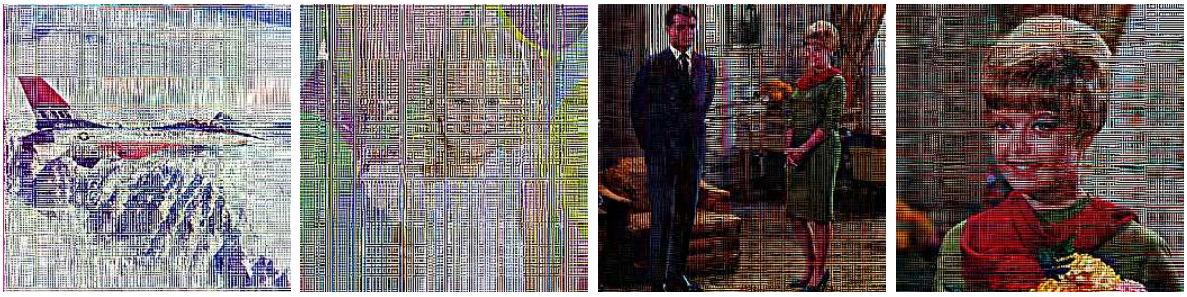
4. **Conclusions.** This paper proposed a line-pattern image which was a novel unprecedented painting expression consisting of lines. To verify the performance of the proposed method, the visual effects of the line-pattern image were investigated with varying the singular number of joint singular value decomposition and the shape of window of unsharp mask. Also, experiments using various photographic images were verified. As a result, by using the proposed method, we found that the line-pattern images with various line patterns could be automatically generated by varying the singular number of joint singular value decomposition and the shape of window of unsharp mask.

A further task is to generate the line patterns in lower brightness and fine texture regions. Another future task is to apply the proposed method to video.

(a) Airplane (b) Balloon (c) Couple (d) Girl

(e) Mandrill (f) Parrots (g) Pepper (h) Sailboat

FIGURE 6. Various photographic images



(a) Airplane (b) Balloon (c) Couple (d) Girl

(e) Mandrill (f) Parrots (g) Pepper (h) Sailboat

FIGURE 7. Line-pattern images generated from various photographic images

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