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GENERATION OF STREAMLINE IMAGES USING CORRELATION COEFFICIENTS BETWEEN RGB

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Abstract. *We propose a non-photorealistic rendering method for automatically generating streamline images from photographic images. Streamline images are represented by streamlines that trace photographic images and are preserved the edges in photographic images. The proposed method is executed by an iterative calculation using correlation coefficients between RGB. An experiment was conducted to visually confirm streamline images from various photographic images. Additionally, an experiment was also conducted to visually confirm streamline patterns generated by changing the values of parameters in the proposed method. The experiments show that the proposed method can generate streamline patterns on the entire image with various photographic images and can adjust the size and density of streamline patterns.*

Keywords: Non-photorealistic rendering, Streamline, Correlation coefficient, RGB, Automatic generation

1. **Introduction.** Non-photorealistic rendering (NPR) [1, 2, 3, 4, 5] generates images with artistic styles such as sketches, oil paintings, illustrations and cartoons from photographic images, videos and three-dimensional data with computers. Since NPR is widely used in television, magazines and websites due to its ability to significantly reduce manual work and improve appearance. Since the appropriate NPR method differs depending on the purpose and target of expression, various NPR methods have been developed so far, and various NPR methods are still required.

This paper proposes an NPR method that can generate streamline images with an unprecedented artistic style from photographic images. Streamline images are represented by streamlines that trace photographic images and preserve the edges in photographic images. The proposed method is executed by an iterative calculation using correlation coefficients between RGB. An experiment was conducted to visually confirm streamline images from various photographic images. Additionally, an experiment was also conducted to visually confirm streamline patterns generated by changing the values of parameters in the proposed method.

Similar to the proposed method, many NPRs using the relationship between RGB have been developed [6, 7, 8]: [6] generates interference-streak images by bilateral filter with operation between RGB, [7] generates thermographic images by smoothing filter with swapping between RGB, and [8] generates colorful stripe patchwork images by smoothing filter based on ratio between RGB. Additionally, similar to the proposed method, many NPRs using correlation coefficient have been developed [9, 10, 11, 12]: [9], [10], [11] and

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[12] generate concrete-wall-texture-like images, ribbed-pattern images, crepe-paper-like images and parallel-fine-curve-line images, respectively. The NPR images generated by [6] to [12] have different expressions from streamline images. Therefore, in the current situation where various expressions of NPR images are required, the proposed method to generate streamline images with the unprecedented artistic style will significantly contribute to the field and utilization of NPR. It is worth noting that combining the relationship between RGB and correlation coefficient enables the generation of streamline images with the unprecedented artistic style.

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

2. **Proposed Method.** The proposed method is largely executed in two steps: Step 1 calculates correlation coefficients between RGB, and Step 2 converts photographic images using the correlation coefficients. Streamline images are generated by iterating Steps 1 and 2. A flow chart of the proposed method is shown in Figure 1.

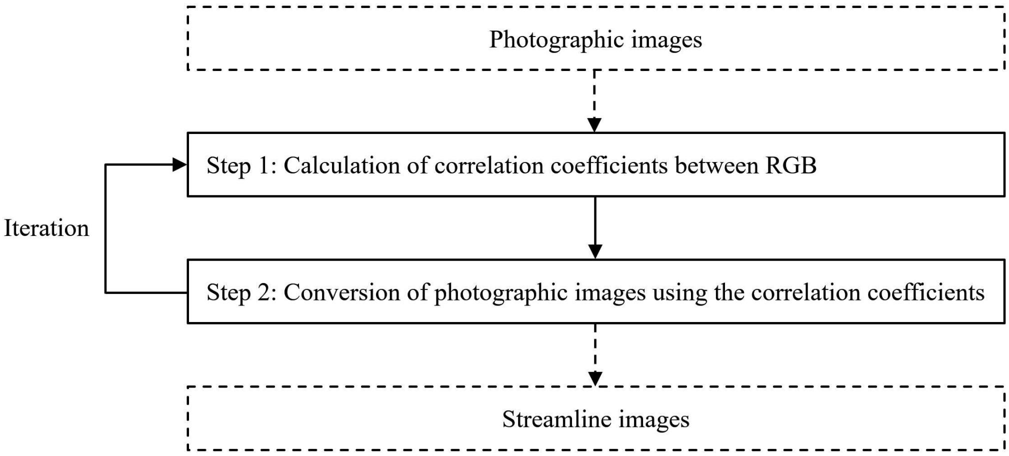


FIGURE 1. Flow chart of our method

The details of the steps in Figure 1 are explained below.

Step 0: The input pixel values of RGB for spatial coordinates (i, j) $(i = 1, 2, \ldots, I;$ $j = 1, 2, \ldots, J)$ of a photographic image are defined as $f_{R,i,j}$, $f_{G,i,j}$ and $f_{B,i,j}$. The pixel values of the image at the t-th iteration number are defined as $f^{(t)}_{R,i,j}$, $f^{(t)}_{G,i,j}$ and $f^{(t)}_{B,i,j}$, where $f^{(1)}_{R,i,j} = f_{R,i,j}$, $f^{(1)}_{G,i,j} = f_{G,i,j}$ and $f^{(1)}_{B,i,j} = f_{B,i,j}$. The pixel values $f^{(t)}_{R,i,j}$, $f^{(t)}_{G,i,j}$ and $f^{(t)}_{B,i,j}$ have U gradation values from 0 to $U-1$.

Step 1: The correlation coefficients $c^{(t)}_{RG,i,j}$, $c^{(t)}_{GB,i,j}$ and $c^{(t)}_{BR,i,j}$ between RGB are calculated as the following equations, respectively.

$$a^{(t)}_R = \frac{\sum_{k=-W}^{W} \sum_{l=-W}^{W} f^{(t)}_{R,i+k,j+l}}{(2W+1)^2} \tag{1}$$

$$a^{(t)}_G = \frac{\sum_{k=-W}^{W} \sum_{l=-W}^{W} f^{(t)}_{G,i+k,j+l}}{(2W+1)^2} \tag{2}$$

$$a^{(t)}_B = \frac{\sum_{k=-W}^{W} \sum_{l=-W}^{W} f^{(t)}_{B,i+k,j+l}}{(2W+1)^2} \tag{3}$$

$$c_{RG,i,j}^{(t)} = \frac{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{R,i+k,j+l}^{(t)} - a_R^{(t)}\right)\left(f_{G,i+k,j+l}^{(t)} - a_G^{(t)}\right)}{\sqrt{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{R,i+k,j+l}^{(t)} - a_R^{(t)}\right)^2}\sqrt{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{G,i+k,j+l}^{(t)} - a_G^{(t)}\right)^2}} \tag{4}$$

$$c_{GB,i,j}^{(t)} = \frac{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{G,i+k,j+l}^{(t)} - a_G^{(t)}\right)\left(f_{B,i+k,j+l}^{(t)} - a_B^{(t)}\right)}{\sqrt{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{G,i+k,j+l}^{(t)} - a_G^{(t)}\right)^2}\sqrt{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{B,i+k,j+l}^{(t)} - a_B^{(t)}\right)^2}} \tag{5}$$

$$c_{BR,i,j}^{(t)} = \frac{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{B,i+k,j+l}^{(t)} - a_B^{(t)}\right)\left(f_{R,i+k,j+l}^{(t)} - a_R^{(t)}\right)}{\sqrt{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{B,i+k,j+l}^{(t)} - a_B^{(t)}\right)^2}\sqrt{\sum_{k=-W}^{W}\sum_{l=-W}^{W}\left(f_{R,i+k,j+l}^{(t)} - a_R^{(t)}\right)^2}} \tag{6}$$

where W is the window size, and k and l are the positions in the window. In Equation (4), it is necessary to pay attention to the order of the pixels of R and G in the window when calculating the correlation coefficients $c_{RG,i,j}^{(t)}$. The same applies to Equations (5) and (6).

Step 2: The pixel values $f_{R,i,j}^{(t+1)}$, $f_{G,i,j}^{(t+1)}$ and $f_{B,i,j}^{(t+1)}$ are calculated using the correlation coefficients $c_{RG,i,j}^{(t)}$, $c_{GB,i,j}^{(t)}$ and $c_{BR,i,j}^{(t)}$ as the following equations, respectively.

$$f_{R,i,j}^{(t+1)} = f_{R,i,j} + \alpha c_{RG,i,j}^{(t)} \tag{7}$$

$$f_{G,i,j}^{(t+1)} = f_{G,i,j} + \alpha c_{GB,i,j}^{(t)} \tag{8}$$

$$f_{B,i,j}^{(t+1)} = f_{B,i,j} + \alpha c_{BR,i,j}^{(t)} \tag{9}$$

where α is a positive constant. In case $f_{R,i,j}^{(t+1)}$, $f_{G,i,j}^{(t+1)}$ and $f_{B,i,j}^{(t+1)}$ are less than 0, then $f_{R,i,j}^{(t+1)}$, $f_{G,i,j}^{(t+1)}$ and $f_{B,i,j}^{(t+1)}$ must be set to 0, respectively. In case $f_{R,i,j}^{(t+1)}$, $f_{G,i,j}^{(t+1)}$ and $f_{B,i,j}^{(t+1)}$ are greater than $U-1$, then $f_{R,i,j}^{(t+1)}$, $f_{G,i,j}^{(t+1)}$ and $f_{B,i,j}^{(t+1)}$ must be set to $U-1$, respectively.

Steps 1 and 2 described above are repeated T times. An image composed of the pixel values $f_{R,i,j}^{(T)}$, $f_{G,i,j}^{(T)}$ and $f_{B,i,j}^{(T)}$ is the streamline image.

3. **Experiments.** Two experiments were conducted: the first experiment was conducted using Parrots image shown in Figure 2 and visually confirmed the change in streamline patterns generated by changing the values of the parameters in the proposed method, and the second experiment applied the proposed method to various photographic images shown in Figure 3. All photographic images used in the experiments were $512 * 512$ pixels and 256 gradations.

FIGURE 2. Parrots image

FIGURE 3. Various photographic images

3.1. **Experiment with changing parameter values.** Streamline images generated by changing the iteration number T were visually confirmed using Parrots image. The value of T was set to 5, 10, 20 and 40. The values of the other parameters W and α were set 7 and 20, respectively. The results of the experiment are shown in Figure 4. As the value of T was larger, streamline patterns became clearer and were expressed finely. Since streamline patterns were clearly visible when $T = 40$, the value of T was set to 40 in the other experiments.

(a) $T = 5$ (b) $T = 10$ (c) $T = 20$ (d) $T = 40$

FIGURE 4. Streamline images in the case of the iteration number $T = 5$, 10, 20 and 40

Streamline images generated by changing the window size W were visually confirmed using Parrots image. The window size W was set to 3, 5, 7 and 9. The values of the other parameters T and α were set 40 and 20, respectively. The results of the experiment are shown in Figure 5. As the value of W was larger, the size of streamline patterns became larger. The value of W was set to 7 in the other experiments because it was thought that streamline patterns were easier to see with $W = 7$.

Streamline images generated by changing the value of the parameter α were visually confirmed using Parrots image. The value of α was set to 10, 15, 20 and 25. The values of the other parameters T and W were set 40 and 7, respectively. The results of the experiment are shown in Figure 6. As the value of α was larger, the density of streamline patterns became clearer. On the other hand, as the value of α was larger, streamline images were less likely to recall Parrots image. The value of α was set to 20 in the other

(a) $W = 3$ (b) $W = 5$ (c) $W = 7$ (d) $W = 9$

FIGURE 5. Streamline images in the case of the window size $W = 3$, 5, 7 and 9

(a) $\alpha = 10$ (b) $\alpha = 15$ (c) $\alpha = 20$ (d) $\alpha = 25$

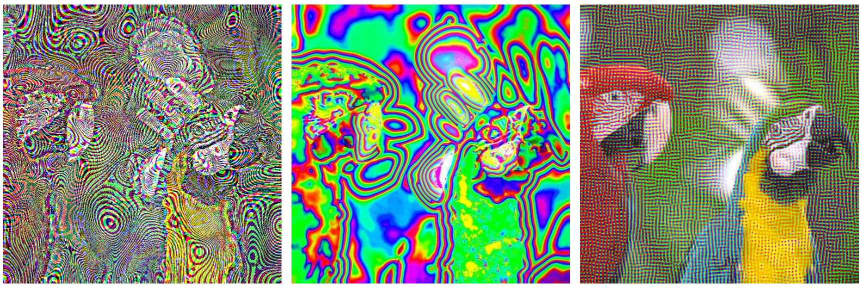
FIGURE 6. Streamline images in the case of the parameter value $\alpha = 10$, 15, 20 and 25

experiments because it was thought that streamline patterns were easier to see and Parrots image could be somewhat recalled when $\alpha = 20$.

According to the above experiments, the combination of the parameters T, W and α affected the changes in streamline images. Therefore, it is necessary to set the values of the parameters T, W and α according to the purpose of utilization of streamline images in actual use. Regarding the setting of the value of T, it is conceivable that the value of T should be increased until the change in streamline images becomes small, regardless of the values of W and α. To make streamline patterns easier to see and to somewhat recall the original images, the value of α should not be too large since a larger value of W results in a larger expression of streamline images. On the other hand, a larger value of α is acceptable since a smaller value of W results in a finer expressions of streamline patterns.

For reference, NPR images generated by the conventional methods [6, 7, 8, 9, 10, 11, 12] from Parrots image are shown in Figure 7. Note that (d), (e), (f) and (g) in Figure 7 use images obtained by converting Parrots image into grayscale. Streamline images of the proposed method were composed of different NPR patterns from all the NPR images of the conventional methods [6, 7, 8, 9, 10, 11, 12].

3.2. **Experiment using various photographic images.** The proposed method was applied to eight photographic images shown in Figure 3. With reference to the results of the experiment in Section 3.1, the values of the parameters T, W and α were set to 40, 7 and 20, respectively. The results of the experiment are shown in Figure 8. All streamline images were represented by streamline patterns that trace photographic images and preserve the edges in photographic images, and could be automatically generated with streamline patterns on the entire image.



(a) [6] (b) [7] (c) [8]

(d) [9] (e) [10] (f) [11] (g) [12]

FIGURE 7. NPR images of the conventional methods [6, 7, 8, 9, 10, 11, 12]

FIGURE 8. Streamline images

4. **Conclusions.** We proposed an NPR method that can generate streamline images with an unprecedented artistic style from photographic images. The proposed method was executed by an iterative calculation using correlation coefficients between RGB. Through an experiment that the values of the parameters in the proposed method were changed, it was found that the size and density of streamline patterns can be adjusted. Additionally, through an experiment using various photographic images, it was found that the proposed method can automatically generate streamline patterns on the entire images.

A subject for future study is to expand the proposed method for application to videos and three-dimensional data.

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