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GENERATION OF INTERFERENCE-STREAK IMAGES BY BILATERAL FILTER WITH OPERATION BETWEEN RGB

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Abstract. *A non-photorealistic rendering method to generate interference-streak images from photographic images using bilateral envelope filter has been proposed. Interference-streak images are expressed by overlapping colorful streaks. However, in the conventional method, there are areas where interference-streak patterns do not occur in interference-streak images, so that it is necessary to finely adjust the parameter values according to photographic images. Therefore, this paper proposes a method for generating interference-streak patterns in the entire image without fine-tuning the parameter values. The proposed method is a process using bilateral filter with operation between RGB. Experiments were performed to apply the proposed method to various photographic images, and then the presence or absence of interference-streak patterns was visually confirmed.*
Keywords: Interference-streak pattern, Bilateral filter, Operation between RGB, Non-photorealistic rendering

1. **Introduction.** Many studies [1-11] on non-photorealistic rendering that generates non-realistic images from photographic images, videos and three-dimensional data using image processing [12, 13] have been conducted. Among these non-realistic images are interference-streak images [4]. Interference patterns appear when red, green and blue waves overlap and strengthen or weaken each other. Interference-streak images represent interference patterns and are expressed by overlapping colorful streaks. The conventional method generates interference-streak images from photographic images by a process using bilateral filter [14, 15], bilateral envelope filter and unsharp mask. Interference-streak patterns are generated by emphasizing the stepwise pseudo contours [16] caused by bilateral filter, and the direction and interval of interference-streak patterns are automatically adapted according to the edges and gradients of photographic images. Interference-streak images are used as special effects in television, magazines, websites and social networking services. However, in the conventional method, there are areas where interference-streak patterns do not occur in interference-streak images, so that it is necessary to finely adjust the parameter values according to photographic images.

We in this paper develop a method for generating interference-streak patterns in the entire image without fine-tuning the parameter values. The proposed method generates interference-streak images from photographic images by a process using bilateral filter with operation between RGB and unsharp mask. Interference-streak patterns of the proposed method are generated by emphasizing the stepwise pseudo contours of bilateral filter as in the conventional method. In addition, the proposed method can change the appearance of interference-streak images by changing the parameter values. To verify the effectiveness of the proposed method, an experiment using various photographic images was performed, and then it was visually confirmed that interference-streak patterns are generated in

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the entire image. In addition, an experiment was conducted to visually confirm the appearance of interference-streak images that change by changing the parameter values.

This paper is organized as follows: the second section describes the proposed method for generating interference-streak images, the third section shows experimental results and reveals the effectiveness of the proposed method, and the conclusion of this paper is given in the fourth section.

2. Proposed Method.

The proposed method generates interference-streak images from photographic images. The proposed method is executed in two processes: the first process generates images with the stepwise pseudo contours by bilateral filter with operation between RGB, and the second process generates interference-streak images by bilateral filter with operation between RGB and unsharp mask. Bilateral filter can smooth images by preserving the edges. Unsharp mask can sharpen images by enhancing the edges. A flow chart of the proposed method is shown in Figure 1.

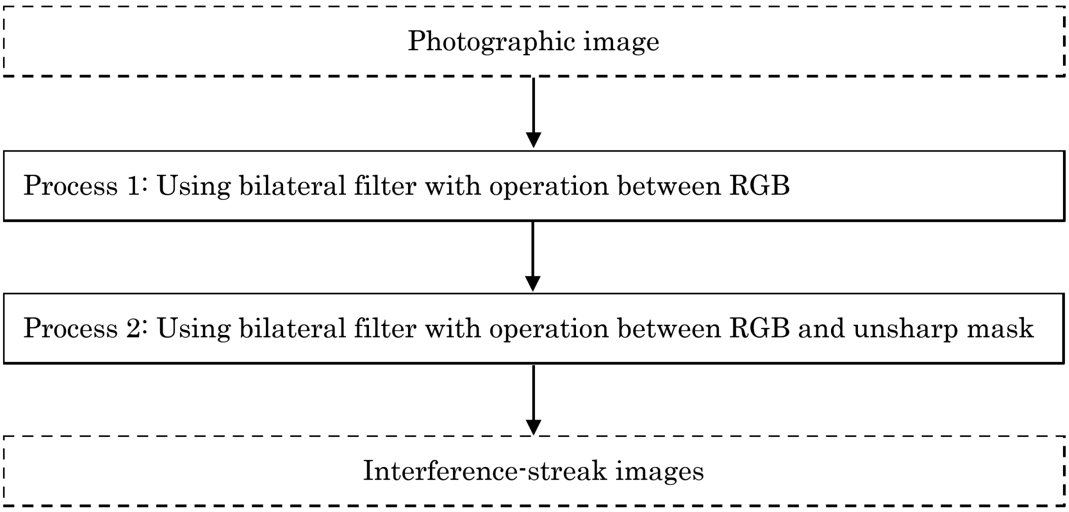


FIGURE 1. Flow chart of our method

Details of the procedure of the proposed method are explained below.

Process 1: The input pixel values (R, G, B) 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 $f_{B,i,j}$, respectively. The pixel values $f_{R,i,j}$, $f_{G,i,j}$ and $f_{B,i,j}$ have value of U gradation from 0 to $U-1$. The output pixel values $f_{R,i,j}^{(t)}$, $f_{G,i,j}^{(t)}$ and $f_{B,i,j}^{(t)}$ in bilateral filter with operation between RGB are calculated by the following equations.

$$f_{R,i,j}^{(t)} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(f_{G,i,j}^{(t-1)}-f_{G,k,l}^{(t-1)}\right)^2} f_{R,k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(f_{G,i,j}^{(t-1)}-f_{G,k,l}^{(t-1)}\right)^2}} \tag{1}$$

$$f_{G,i,j}^{(t)} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(f_{B,i,j}^{(t-1)}-f_{B,k,l}^{(t-1)}\right)^2} f_{G,k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(f_{B,i,j}^{(t-1)}-f_{B,k,l}^{(t-1)}\right)^2}} \tag{2}$$

$$f_{B,i,j}^{(t)} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(f_{R,i,j}^{(t-1)}-f_{R,k,l}^{(t-1)}\right)^2} f_{B,k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(f_{R,i,j}^{(t-1)}-f_{R,k,l}^{(t-1)}\right)^2}} \tag{3}$$

where t is an iteration number, $f_{R,i,j}^{(0)} = f_{R,i,j}$, $f_{G,i,j}^{(0)} = f_{G,i,j}$, $f_{B,i,j}^{(0)} = f_{B,i,j}$, W is the window size, α and β are positive constants, and k and l are the positions in the window. Process 1 is repeated T_1 times.

Process 2: The pixel values $f_{R,i,j}^{(T_1)}$, $f_{G,i,j}^{(T_1)}$ and $f_{B,i,j}^{(T_1)}$ are defined as $g_{R,i,j}^{(0)}$, $g_{G,i,j}^{(0)}$ and $g_{B,i,j}^{(0)}$, respectively. The output pixel values $g_{R,i,j}^{(t)}$, $g_{G,i,j}^{(t)}$ and $g_{B,i,j}^{(t)}$ in unsharp mask using bilateral filter with operation between RGB are calculated by the following equations.

$$g_{R,i,j}^{(t)} = a\left(g_{R,i,j}^{(t-1)} - \frac{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(g_{G,i,j}^{(t-1)}-g_{G,k,l}^{(t-1)}\right)^2} g_{R,k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(g_{G,i,j}^{(t-1)}-g_{G,k,l}^{(t-1)}\right)^2}}\right) + g_{R,i,j}^{(t-1)} \quad (4)$$

$$g_{G,i,j}^{(t)} = a\left(g_{G,i,j}^{(t-1)} - \frac{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(g_{B,i,j}^{(t-1)}-g_{B,k,l}^{(t-1)}\right)^2} g_{G,k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(g_{B,i,j}^{(t-1)}-g_{B,k,l}^{(t-1)}\right)^2}}\right) + g_{G,i,j}^{(t-1)} \quad (5)$$

$$g_{B,i,j}^{(t)} = a\left(g_{B,i,j}^{(t-1)} - \frac{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(g_{R,i,j}^{(t-1)}-g_{R,k,l}^{(t-1)}\right)^2} g_{B,k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(g_{R,i,j}^{(t-1)}-g_{R,k,l}^{(t-1)}\right)^2}}\right) + g_{B,i,j}^{(t-1)} \quad (6)$$

where a is a positive constant. In case $g_{R,i,j}^{(t)}$, $g_{G,i,j}^{(t)}$ and $g_{B,i,j}^{(t)}$ are less than 0, then $g_{R,i,j}^{(t)}$, $g_{G,i,j}^{(t)}$ and $g_{B,i,j}^{(t)}$ must be set to 0, respectively. In case $g_{R,i,j}^{(t)}$, $g_{G,i,j}^{(t)}$ and $g_{B,i,j}^{(t)}$ are greater than $U-1$, then $g_{R,i,j}^{(t)}$, $g_{G,i,j}^{(t)}$ and $g_{B,i,j}^{(t)}$ must be set to $U-1$, respectively. Process 2 is repeated T_2 times, and then an image composed of the pixel values $g_{R,i,j}^{(T_2)}$, $g_{G,i,j}^{(T_2)}$ and $g_{B,i,j}^{(T_2)}$ is the interference-streak image.

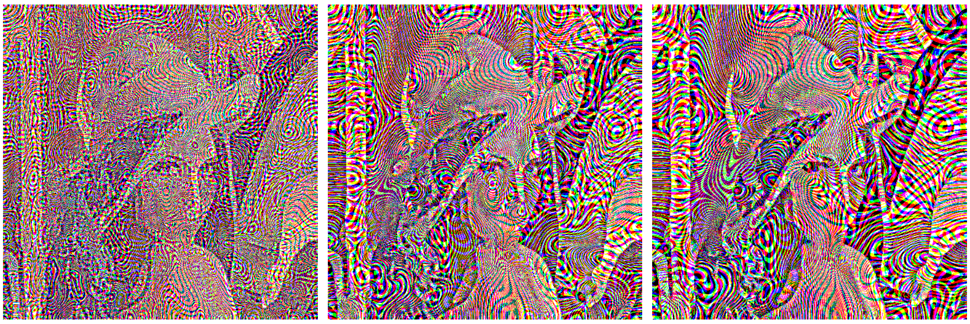
3. **Experiments.** Two experiments were conducted to verify the effectiveness of the proposed method: the first experiment changed the values of the parameters W, α and β to visually confirm interference-streak patterns using Lenna image shown in Figure 2, and the second experiment applied the proposed method to various photographic images shown in Figure 3 to visually confirm that interference-streak patterns are generated in the entire image. All images used in the experiments were $512*512$ pixels and 256 gradation. In reference to the literature [4, 10], the values of the parameters a, T_1 and T_2 used in all experiments were set to 2.0, 20 and 20, respectively.

FIGURE 2. Lenna image

FIGURE 3. Various photographic images

For reference, the properties of the parameters a, T_1 and T_2 are described. As the value of the parameter a was larger, interference-streak patterns became more saturated. As the value of the parameter T_1 was larger, interference-streak patterns were expressed more smoothly and it became difficult to visually recognize the original image. As the value of the parameter T_2 was larger, interference-streak patterns became clearer.

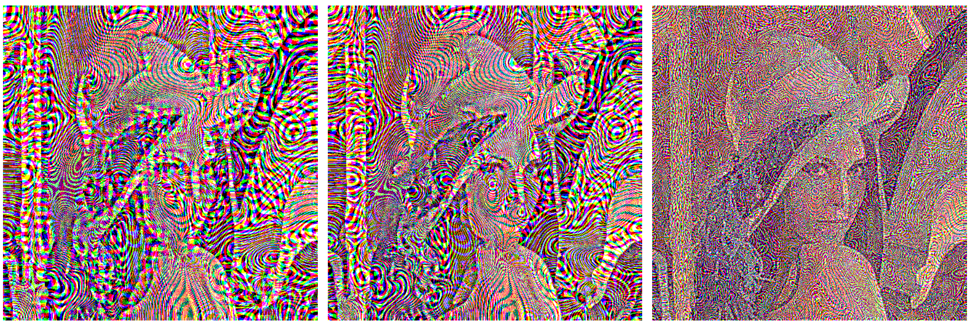
3.1. **Experiment with changing parameter values.** Interference-streak images by changing the value of the parameter W were visually confirmed using Lenna image. The value of the parameter W was set to 5, 10 and 20. The values of the parameters α and β were set to 0.01 and 0.01, respectively. The interference-streak images generated by changing the value of the parameter W are shown in Figure 4. Observing Figure 4, as the value of the parameter W was smaller, interference-streak patterns were expressed more finely.



(a) $W = 5$ (b) $W = 10$ (c) $W = 20$

FIGURE 4. Interference-streak images in the case of $W = 5$, 10 and 20

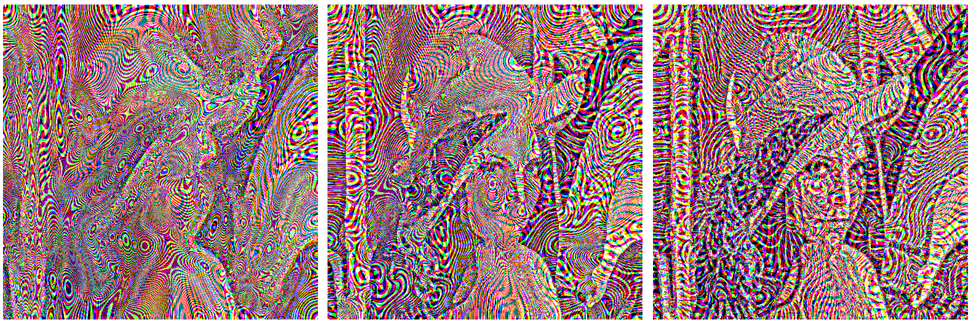
Interference-streak images by changing the value of the parameter α were visually confirmed using Lenna image. The value of the parameter α was set to 0.001, 0.01 and 0.1. The values of the parameters W and β were set to 10 and 0.01, respectively. The interference-streak images generated by changing the value of the parameter α are shown in Figure 5. Observing Figure 5, as the value of the parameter α was larger, interference-streak patterns were expressed more finely.



(a) $\alpha = 0.001$ (b) $\alpha = 0.01$ (c) $\alpha = 0.1$

FIGURE 5. Interference-streak images in the case of $\alpha = 0.001$, 0.01 and 0.1

Interference-streak images by changing the value of the parameter β were visually confirmed using Lenna image. The value of the parameter β was set to 0.001, 0.01 and 0.1. The values of the parameters W and α were set to 10 and 0.01, respectively. The interference-streak images generated by changing the value of the parameter β are shown in Figure 6. Observing Figure 6, as the value of the parameter β was smaller, interference-streak patterns were expressed more finely. And, as the value of the parameter β was too small, it became difficult to visually recognize the original image.



(a) $\beta = 0.001$ (b) $\beta = 0.01$ (c) $\beta = 0.1$

FIGURE 6. Interference-streak images in the case of $\beta = 0.001$, 0.01 and 0.1

From the above, in setting the parameter values when actually generating interference-streak images, the saturation, smoothness and fineness of interference-streak patterns adjust by a, T_1 and W, α or β, respectively. In the iteration number T_2, the value is set until interference-streak patterns becomes clear. On the other hand, if the values of the parameters are made too large or too small, it may be difficult to visually recognize the original image, so care must be taken.

3.2. **Experiment using various photographic images.** The proposed method was applied to six photographic images. Since interference-streak patterns were relatively easy to recognize in the previous experiment, the values of the parameters W, α and β were set to 10, 0.01 and 0.01, respectively. The six interference-streak images generated by the proposed method are shown in Figure 7. Observing Figure 7, interference-streak patterns were generated in the entire image. The interference-streak images of the conventional method [4] had areas where interference-streak patterns do not occur, but those of the proposed method did not have the areas. In addition, in the conventional method [4], it was necessary to adjust the parameter values in order to generate interference-streak

FIGURE 7. Interference-streak images generated from various photographic images

patterns in the entire image, but as can be seen from Figures 4 to 6, the proposed method could generate without fine-tuning the parameter values.

4. **Conclusions.** We proposed a new method for generating interference-streak images from photographic images by a process using bilateral filter with operation between RGB and unsharp mask. We conducted two experiments to verify the effectiveness of the proposed method: the first experiment changed the parameter values of the parameters to visually confirm interference-streak patterns using Lenna image, and the second experiment applied the proposed method to various photographic images to visually confirm that interference-streak patterns are generated in the entire image. As a result of the experiments, it was clarified how to change interference-streak patterns by changing the parameter values. Also, it was clarified that the proposed method can generate interference-streak patterns in the entire image without fine-tuning the parameter values.

A subject for future study is to be able to generate more impressive interference-streak patterns suitable for videos and three-dimensional data.

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