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GENERATION OF MOIRE-LIKE IMAGES USING TRILATERAL FILTER

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Abstract. *We propose a non-photorealistic rendering method for automatically generating moire-like images from photographic images using trilateral filter. The proposed method is implemented by enhancing the staircasing effect of trilateral filter with unsharp mask. A conventional method for generating moire-like images using bilateral filter has been proposed. Trilateral filter of the proposed method adds the weight of the gradient direction to the weights of bilateral filter of the conventional method, and then the proposed method can generate more curved moire-like patterns and moire-like patterns that are finer near the edges in photographic images. In order to verify the effectiveness of the proposed method, an experiment to visually confirm moire-like patterns generated by changing the value of the newly added parameter in trilateral filter was performed using Lenna image, and an experiment was performed using various photographic images. As a result of the experiments, it was found that the proposed method can generate finer moire-like patterns near the edges and smoother moire-like patterns than the conventional method.*

Keywords: Moire-like image, Trilateral filter, Unsharp mask, Gradient direction

1. **Introduction.** A method for generating moire-like images from automatically photographic images using bilateral filter [1, 2] has been proposed in [3, 4]. Bilateral filter preserves edges in images and smooths images, and is used in the fields of image processing [5, 6], computer graphics [7] and computer vision [8]. In bilateral filter, a staircasing effect with stepwise changes in shading occurs [9, 10]. Moire-like patterns are patterns that pseudo contour lines by the staircasing effect are emphasized with unsharp mask. An example of moire-like image generated from Lenna image (Figure 1(a)) by the conventional method is shown in Figure 1(b). For example, the white column on the left side of moire-like image in Figure 1(b) has linear moire-like patterns. If linear moire-like patterns can be expressed by smoother curves, it is considered that the appearance of moire-like images will be improved.

Therefore, we propose a method for generating moire-like patterns with smoother curves using trilateral filter that is an extension of bilateral filter. Trilateral filter of the proposed method adds the weight of the gradient direction to the weights of bilateral filter. In addition to having more curved moire-like patterns than the conventional method, the proposed method can also have finer moire-like patterns near the edges in photographic images. A method for stretching moire-like patterns vertically and horizontally has been proposed [11]. In the conventional method, a parameter related to the aspect ratio was

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(a) Lenna image (b) Moire-like image (c) Moire-like image stretched in vertical direction

Figure 1. Lenna image, an example of moire-like image and an example of moire-like image stretched in vertical direction

introduced into bilateral filter. An example of moire-like image stretched in vertical direction is shown in Figure 1(c). Moire-like image in Figure 1(c) has the drawback that moire-like patterns are stretched in the vertical direction as a whole. The same is true for moire-like images stretched in horizontal direction. In other words, the conventional method cannot partially distort moire-like patterns. On the other hand, the proposed method has the advantage that moire-like patterns can be partially distorted. In order to verify the effectiveness of the proposed method, an experiment to visually confirm moire-like patterns generated by changing the value of the newly added parameter in trilateral filter was performed using Lenna image, and an experiment was performed using various photographic images.

This paper is organized as follows: the second section describes the proposed method for generating moire-like images from photographic images using trilateral filter, 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 is executed in two steps: the first step is to process iteratively with trilateral filter, and the second step is to process iteratively with unsharp mask using trilateral filter. Trilateral filter is a value computed by adding a weight of the gradient direction to bilateral filter. Bilateral filter is an isotropic filter, while trilateral filter is an anisotropic filter that is influenced by the direction of the edges. Anisotropic bilateral filter, which is an anisotropic expansion of bilateral filter, has been proposed [12]. Anisotropic bilateral filter changes the Euclidean distance between pixels in the weight of bilateral filter to the quadratic form distance. That is, trilateral filter and anisotropic bilateral filter are different. The flow chart of the proposed method is shown in Figure 2.

Details of the procedure in Figure 2 are explained below.

Step 0: The input pixel values for spatial coordinates (i, j) of a photographic image are defined as $f_{i,j}$. The pixel values $f_{i,j}^{(t)}$ of the image at the t-th iteration number have value of U gradation from 0 to $U-1$, where $f_{i,j}^{(0)} = f_{i,j}$.

Step 1: The output pixel values $f_{i,j}^{(t)}$ in trilateral filter are calculated by the following equations.

$$f_{i,j}^{(t)} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} w_{1,i,j,k,l} w_{2,i,j,k,l}^{(t-1)} w_{3,i,j,k,l}^{(t-1)} f_{k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} w_{1,i,j,k,l} w_{2,i,j,k,l}^{(t-1)} w_{3,i,j,k,l}^{(t-1)}} \tag{1}$$

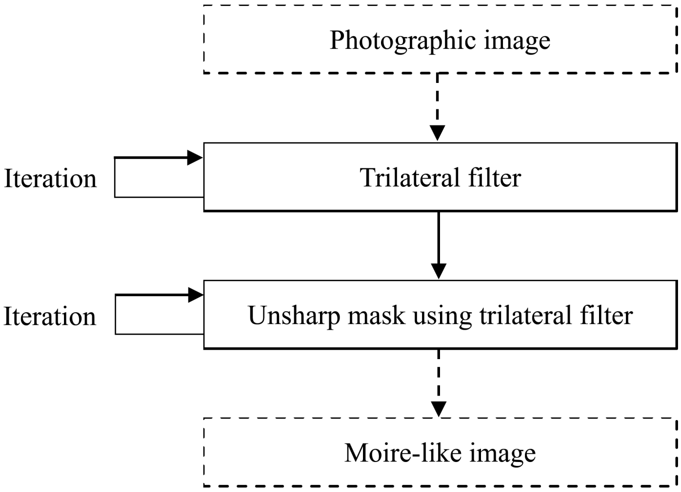

FIGURE 2. Flow chart of the proposed method

$$w_{1,i,j,k,l} = e^{-\alpha\left((i-k)^2+(j-l)^2\right)} \tag{2}$$

$$w_{2,i,j,k,l}^{(t-1)} = e^{-\beta\left(f_{i,j}^{(t-1)}-f_{k,l}^{(t-1)}\right)^2} \tag{3}$$

$$w_{3,i,j,k,l}^{(t-1)} = e^{-\gamma\left(\left(d_{x,i,j}^{(t-1)}-d_{x,k,l}^{(t-1)}\right)^2+\left(d_{y,i,j}^{(t-1)}-d_{y,k,l}^{(t-1)}\right)^2\right)} \tag{4}$$

where W is the window size, α, β and γ are positive constants, k and l are the positions in the window, and $d_{x,i,j}^{(t-1)}$ and $d_{y,i,j}^{(t-1)}$ are the horizontal and vertical gradient directions. And, $w_{1,i,j,k,l}$ is the weight related to spatial coordinates, $w_{2,i,j,k,l}$ is the weight related to the pixel values, and $w_{3,i,j,k,l}$ is the weight related to the gradient directions added to bilateral filter. When the value of the parameter γ in the weight $w_{3,i,j,k,l}$ is 0, trilateral filter becomes bilateral filter. The gradient directions $d_{x,i,j}^{(t-1)}$ and $d_{y,i,j}^{(t-1)}$ in the weight $w_{3,i,j,k,l}$ are calculated by the following equations.

$$d_{x,i,j}^{(t-1)} = \frac{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} w_{1,i,j,k,l} d_{x',k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} w_{1,i,j,k,l}} \tag{5}$$

$$d_{x',k,l}^{(t-1)} = f_{k-1,l-1}^{(t-1)} + 2f_{k-1,l}^{(t-1)} + f_{k-1,l+1}^{(t-1)} - f_{k+1,l-1}^{(t-1)} - 2f_{k+1,l}^{(t-1)} - f_{k+1,l+1}^{(t-1)} \tag{6}$$

$$d_{y,i,j}^{(t-1)} = \frac{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} w_{1,i,j,k,l} d_{y',k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} w_{1,i,j,k,l}} \tag{7}$$

$$d_{y',k,l}^{(t-1)} = f_{k-1,l-1}^{(t-1)} + 2f_{k,l-1}^{(t-1)} + f_{k+1,l-1}^{(t-1)} - f_{k-1,l+1}^{(t-1)} - 2f_{k,l+1}^{(t-1)} - f_{k+1,l+1}^{(t-1)} \tag{8}$$

The processing of Step 1 is repeated T_1 times.

Step 2: Let the pixel values $f_{i,j}^{(T_1)}$ be $g_{i,j}^{(0)}$, and let the pixel values after applying trilateral filter (Equation (1)) to the pixel values $g_{i,j}^{(t)}$ be $TF\left(g_{i,j}^{(t)}\right)$. The output pixel values $g_{i,j}^{(t)}$ in unsharp mask using trilateral filter are calculated by the following equation.

$$g_{i,j}^{(t)} = a\left(g_{i,j}^{(t-1)} - TF\left(g_{i,j}^{(t-1)}\right)\right) + g_{i,j}^{(t-1)} \tag{9}$$

where a is a positive constant. As the value of a is larger, moire patterns are more emphasized. If $g_{i,j}^{(t)}$ is less than 0, then $g_{i,j}^{(t)}$ must be set to 0. If $g_{i,j}^{(t)}$ is greater than

$U - 1$, then $g_{i,j}^{(t)}$ must be set to $U - 1$. The processing of Step 2 is repeated T_2 times, and then an image composed of the pixel values $g_{i,j}^{(T_2)}$ is the moire-like image.

3. **Experiments.** Two experiments were conducted: the first experiment was to check the changes in moire-like patterns generated by changing the value of the new parameter γ in the proposed method, and the second experiment was to apply the proposed method to various photographic images. The first experiment used Lenna image shown in Figure 1(a), and the second experiment used four photographic images shown in Figure 3. All photographic images used in the experiments were $512 * 512$ pixels and 256 gradation. Unless otherwise noted in the following experiments, referring to [3, 4], the parameter values T_1, T_2, W, α, β and a were set to 20, 10, 20, 0.01, 0.01 and 2.0, respectively.

FIGURE 3. Various photographic images

For reference, the properties of the parameters T_1, T_2, W, α, β and a are shown below. As the value of T_1 becomes larger, the original images are expressed more smoothly and moire-like patterns are smoother. As the value of T_2 becomes larger, moire-like patterns become clearer. As the value of W becomes larger, the spacing between moire-like patterns becomes wider. As the value of α becomes larger, the spacing between moire-like patterns becomes smaller. As the value of β becomes smaller, the original images are less visible and moire-like patterns are clearer. As the value of a becomes larger, moire-like patterns are expressed more deeply.

3.1. **Experiment with changing parameter γ.** Moire-like images by changing the value of the parameter γ were visually confirmed using Lenna images. The value of the parameter γ was set to 0.001, 0.005, 0.01 and 0.1. The results of the experiment are shown in Figure 4. As the value of the parameter γ became larger, more curved moire-like patterns were generated and finer moire-like patterns were generated mainly around the edges in Lenna image.

(a) $\gamma = 0.001$ (b) $\gamma = 0.005$ (c) $\gamma = 0.01$ (d) $\gamma = 0.1$

FIGURE 4. Moire-like images in the case of the parameter $\gamma = 0.001$, 0.005, 0.01 and 0.1

In order to compare the proposed method with the conventional method [3, 4], looking at the white columns on the left side of moire-like images in Figure 1(b) and Figures 4(b), 4(c) and 4(d), although moire-like patterns of the conventional method were linear, those of the proposed method were more curved. Thus, the proposed method could express moire-like patterns with smoother curves than the conventional method.

In order to compare the proposed method with the conventional method [11], looking at the white columns on the left side of moire-like images in Figure 1(c) and Figures 4(b), 4(c) and 4(d), both the proposed and conventional methods could distort moire-like patterns. However, although moire-like patterns of the conventional method were stretched in the vertical direction as a whole, those of the proposed method were partially distorted. Thus, the proposed method could partially distort moire-like patterns.

3.2. **Experiment using various photographic images.** The proposed method was applied to four photographic images shown in Figure 3. Since moire-like patterns were visually recognized well in the previous experiment, the value of the parameter γ was set to 0.01. The results of the experiment are shown in Figure 5. All moire-like images could be automatically generated according to the change of the edges and the shading in photographic images.

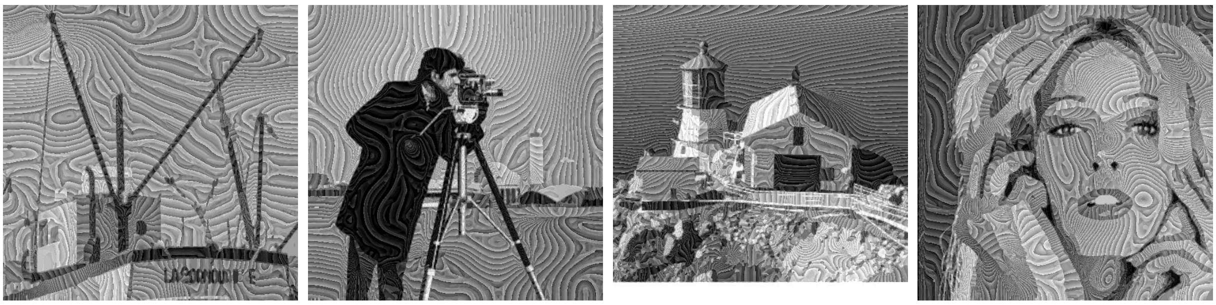

FIGURE 5. Moire-like images

4. **Conclusions.** We proposed a non-photorealistic rendering method for automatically generating moire-like images from photographic images using trilateral filter. Trilateral filter was bilateral filter with weights add the weight of the gradient direction. The proposed method was implemented by enhancing the staircasing effect of trilateral filter with unsharp mask. In order to verify the effectiveness of the proposed method, an experiment to visually confirm moire-like patterns generated by changing the value of the newly added parameter in trilateral filter was performed using Lenna image, and an experiment was performed using various photographic images. As a result of the experiments, the proposed method could automatically generate moire-like images according to the change of the edges and the shading in photographic images. In addition, the proposed method could generate finer moire-like patterns mainly around the edges in photographic images and more curved moire-like patterns than the conventional method using bilateral filter.

A subject for future study is to expand the proposed method for application to color photographic images and videos.

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