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GENERATION OF MOIRE-LIKE IMAGES USING EUCLIDEAN DISTANCE FROM EDGE

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Abstract. *A non-photorealistic rendering method has been proposed to generate moire-like images from photographic images using bilateral filter. Moire-like patterns are expressed by smooth curve, and moire-like images have a fantastic impression. By changing the expression of moire-like patterns, it is thought that moire-like patterns with a different impression will be generated. We propose a method for changing the complexity of moire-like patterns using Euclidean distance from the edge of photographic images. We conducted experiments using various photographic images, and visually confirmed the shape of moire-like patterns. The experimental results show that our method can generate more complicated moire-like patterns than the conventional method.*

Keywords: Moire-like image, Euclidean distance from edge, Bilateral filter, Automatic generation

1. **Introduction.** Many studies [1, 2, 3, 4] have been conducted on non-photorealistic rendering using image processing [5]. Among them, a non-photorealistic rendering method has been proposed to generate moire-like images [6, 7, 8] from photographic images using the staircase effect [9, 10] of bilateral filter [11, 12]. Moire-like images are a kind of op art. Op art is a genre of paintings calculated to give special visual effects based on the perceptual psychological mechanism of optical illusion. The conventional methods are characterized in that the direction and interval of moire-like patterns can be automatically adapted according to the edge and gradation of photographic images. Moire-like patterns generated by the conventional methods are expressed by smooth curve, and moire-like images have a fantastic impression. Furthermore, by changing the shape of moire-like patterns, the impression of moire-like images can be changed, and the application of moire-like images can be expanded.

In this paper, we propose a method for changing the shape of moire-like patterns using Euclidean distance from the edge of photographic images. Moire-like patterns of our method become more complicated than those of the conventional methods, and then moire-like images of our method have an impression different from those of the conventional methods. In order to verify the effectiveness of our method, experiments using Lenna image were conducted to visually investigate how moire-like patterns change by changing the values of the parameters of our method. In addition, experiments using various photographic images were conducted to examine moire-like images. As a result of the experiments, it is clarified that our method can generate more complicated moire-like patterns than the conventional methods.

A method [13] for generating moire-like patterns close to those of our method has been proposed by a method similar to our method. Since the conventional method [13] uses RGB-D images, a camera capable of acquiring depth such as a stereo camera is

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required. On the other hand, our method does not require a special camera that can acquire depth. And, a method [14] for generating moire-like patterns different from those of the conventional methods [6, 7, 8] has also been proposed, but our method can generate moire-like patterns different from those of the conventional method [14]. In addition, although our method adds the Euclidean distance coefficient to bilateral filter, a study [15] is also being conducted to generate moire-like images by adding the gradients to bilateral filter. However, the conventional method [15] generates moire-like patterns similar to those of the conventional methods [6, 7, 8].

This paper is organized as follows: the second section describes our method for generating moire-like images different from the conventional method, the third section shows experimental results and reveals the effectiveness of our method, and the conclusion of this paper is given in the fourth section.

2. **Our Method.** The conventional methods [6, 7, 8] are executed in two steps: the first step is processing using bilateral filter, and the second step is processing using unsharp mask. Our method adds Euclidean distance from the edge of photographic images to the coefficient of bilateral filter in the first step of the conventional methods. A flow chart of our method is shown in Figure 1.

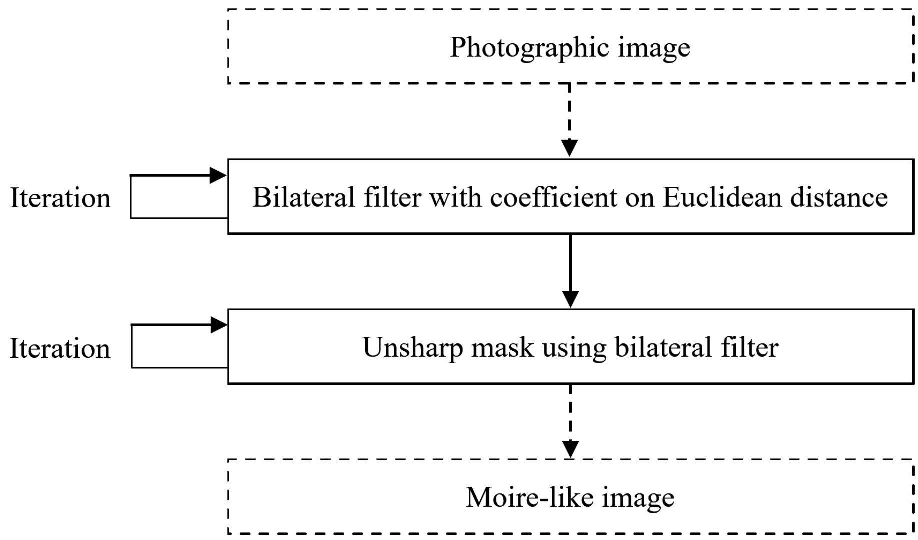


FIGURE 1. Flow chart of our method

Details of the procedure of our method 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 256 gradation from 0 to 255, where $f_{i,j}^{(0)} = f_{i,j}$.

Step 1: The edge is extracted from the photographic image using EDISON [16] that is a feature extraction tool that integrates edge detection and image segmentation. The shortest Euclidean distances $d_{i,j}$ to the edge pixels are calculated at each pixel.

The output pixel values $f_{i,j}^{(t)}$ in bilateral filter with the coefficient on the shortest Euclidean distances $d_{i,j}$ are calculated by the following equation.

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

where W is the window size, α, β and γ are positive constants, and k and l are the positions in the window. In Equation (1), the term of $-\gamma(d_{i,j} - d_{k,l})^2$ is added to the coefficient of exponential function in our method. The larger the value of γ, the more different moire-like patterns from the conventional method are generated. As the value of γ is 0, the same moire-like patterns as the conventional methods are generated. The processing of Step 1 is repeated T_1 times.

Step 2: Let pixel values $f_{i,j}^{(T_1)}$ be $g_{i,j}^{(0)}$. The output pixel values $g_{i,j}^{(t)}$ in unsharp mask using bilateral filter are calculated by the following equation.

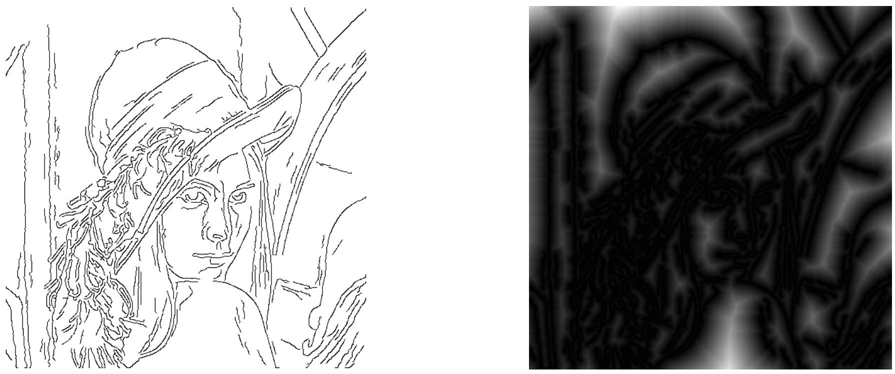
$$g_{i,j}^{(t)} = a\left(g_{i,j}^{(t-1)} - \frac{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(g_{i,j}^{(t-1)}-g_{k,l}^{(t-1)}\right)^2} g_{k,l}^{(t-1)}}{\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} e^{-\alpha((i-k)^2+(j-l)^2)-\beta\left(g_{i,j}^{(t-1)}-g_{k,l}^{(t-1)}\right)^2}}\right)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

where a is a positive constant. 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 255, then $g_{i,j}^{(t)}$ must be set to 255.

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 of our method.

3. **Experiments.** Two experiments were conducted to verify the effectiveness of our method. In the first experiment, the value of the parameter γ was changed to visually confirm moire-like patterns using Lenna image shown in Figure 2. In the second experiment, our method was applied to various photographic images. All images used in the experiments were $512 * 512$ pixels and 256 gradation. In reference to [6, 7, 8], the values of the parameters a, α, β, W, T_1 and T_2 used in all experiments were set to 2.0, 0.01, 0.01, 20, 20 and 10, respectively. For reference, the image that extracted the edge from

Figure 2. Lenna image



(a) Edge-extracted image (b) Distance-calculated image

Figure 3. Edge-extracted image and distance-calculated image

Lenna image is shown in Figure 3(a), and the image that Euclidean distance is calculated from the edge is shown in Figure 3(b).

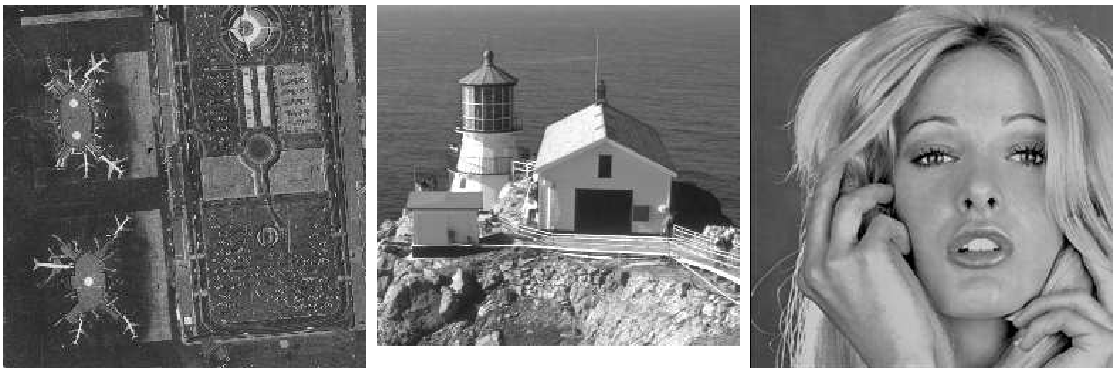
Moire-like images by changing the parameter γ were visually confirmed using Lenna image. The value of the parameter γ was set to 0.1, 1.0 and 10.0. The results of the experiment are shown in Figure 4. Observing Figure 4 and [6, 7, 8], our method could generate finer moire-like patterns than the conventional method. And, as the value of γ was larger, moire-like patterns were generated along the edge. The value of γ may be set according to the usage.

(a) $\gamma = 0.1$ (b) $\gamma = 1.0$ (c) $\gamma = 10.0$

FIGURE 4. Moire-like images in the case of $\gamma = 0.1$, 1.0 and 10.0

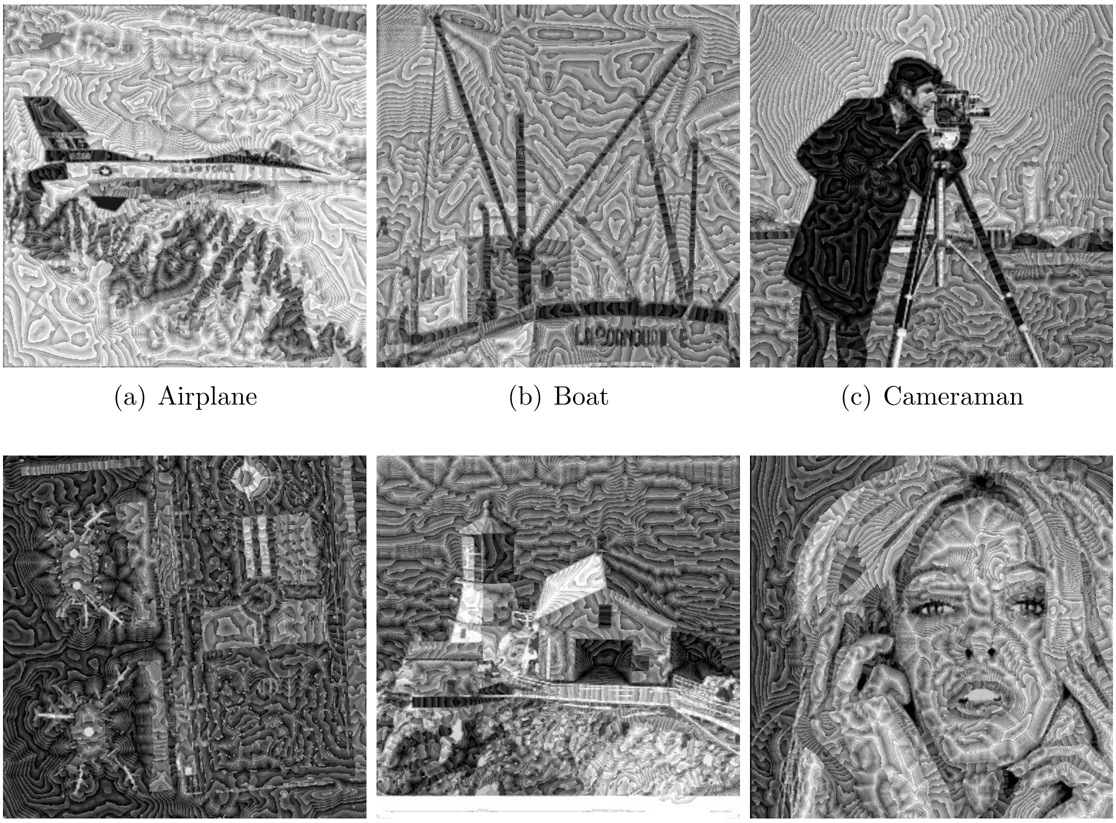
Our method was applied to six photographic images shown in Figure 5. The value of the parameter γ was set to 0.1. The results of the experiment are shown in Figure

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



(d) Lax (e) Lighthouse (f) Woman

FIGURE 5. Various photographic images



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

(d) Lax (e) Lighthouse (f) Woman

FIGURE 6. Moire-like images generated from various photographic images

6. Observing Figure 6 and [6, 7, 8], in all moire-like images, moire-like patterns of our method were more complicated than those of the conventional method. However, moire-like patterns could not be generated in the white region in the lower part of Figure 6(e). Even in the conventional method, moire-like patterns were not generated in the white area. It is necessary to devise to add some noise to the white region.

4. **Conclusions.** We proposed a method for changing the shape of moire-like patterns of moire-like images. Our method added Euclidean distance from the edge of photographic images to the coefficient of bilateral filter. We conducted two experiments to verify the effectiveness of our method. In the first experiment, the value of the parameter γ added to the coefficient of bilateral filter was changed to visually confirm moire-like patterns using Lenna image. In the second experiment, our method was applied to various photographic images. As a result of the experiments, it was clarified how to change moire-like patterns by changing the value of γ. Also, it was clarified that our method can generate more complicated moire-like patterns than the conventional methods.

The future task is to express more impressively by moving moire-like patterns.

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REFERENCES

[1] P. Haeberli, Paint by numbers: Abstract image representations, *ACM SIGGRAPH Computer Graphics*, vol.24, no.4, pp.207-214, 1990.

[2] J. Lansdown and S. Schofield, Expressive rendering: A review of nonphotorealistic techniques, *IEEE Computer Graphics and Applications*, vol.15, no.3, pp.29-37, 1995.

[3] D. Martin, G. Arroyo, A. Rodriguez and T. Isenberg, A survey of digital stippling, *Computers & Graphics*, vol.67, pp.24-44, 2017.
[4] I. Ilinkin, Designing a course on non-photorealistic rendering, *Eurographics 2020*, pp.9-16, 2020.
[5] R. Matsumura and A. Hanazawa, Human detection using color contrast-based histograms of oriented gradients, *International Journal of Innovative Computing, Information and Control*, vol.15, no.4, pp.1211-1222, 2019.
[6] T. Hiraoka and K. Urahama, Generation of moire picture-like images by bilateral filter, *The Journal of the Institute of Television Engineers of Japan*, vol.67, no.2, pp.J74-J77, 2013.
[7] K. Miyashita, T. Hiraoka and K. Urahama, Verification of parameters of bilateral filter for moire picture-like images, *The Journal of the Institute of Television Engineers of Japan*, vol.67, no.9, pp.J356-J358, 2013.
[8] T. Hiraoka, H. Nonaka and E. C. A. Carreon, Reduction of iterative calculation and quality improvement for generation of moire-like images using bilateral filter, *ICIC Express Letters*, vol.13, no.10, pp.949-954, 2019.
[9] A. Buades, B. Coll and J.-M. Morel, The staircasing effect in neighborhood filters and its solution, *IEEE Trans. Image Processing*, vol.15, no.6, pp.1499-1505, 2006.
[10] N. Pierazzo and G. Facciolo, Data adaptive dual domain denoising: A method to boost state of the art denoising algorithms, *Image Processing on Line*, vol.7, pp.93-114, 2017.
[11] C. Tomasi and R. Manduchi, Bilateral filtering for gray and color images, *Proc. of ICCV*, pp.839-846, 1998.
[12] S. Paris, P. Kornprobst, J. Tumblin and F. Durand, Bilateral filtering: Theory and applications, *Foundations and Trends® in Computer Graphics and Vision*, vol.4, no.1, pp.1-73, 2009.
[13] R. Takaki and T. Hiraoka, Generation of moire-like images from RGB-D images, *ICIC Express Letters*, vol.15, no.1, pp.37-42, 2021.
[14] T. Hiraoka, Generation of moire-like images using Gaussian filter, *Journal of the Institute of Industrial Applications Engineers*, vol.9, no.1, pp.21-25, 2021.
[15] T. Hiraoka and Y. Tsurunari, Generation of moire-like images using trilateral filter, *ICIC Express Letters*, vol.15, no.5, pp.475-480, 2021.
[16] The Robust Image Understanding Laboratory at Rutgers University, *Edge Detection and Image Segmentation (EDISON) System*, http://rci.rutgers.edu/meer/RIUL/research/code/EDISON/doc/help.html, 2002.