ICIC Express Letters
Volume **16**, Number **12**, December **2022**
 ISSN 1881-803X
pp. 1309–1314

GENERATION OF MOIRE-LIKE IMAGES USING BEZIER SURFACES

Toru Hiraoka[1] and Yoshihisa Tsurunari[2]

[1]Department of Information Systems
University of Nagasaki
1-1-1, Manabino, Nagayo-chou, Nishisonogi-gun, Nagasaki-ken 851-2195, Japan
hiraoka@sun.ac.jp

[2]Center for Education and Research of Disaster Risk Reduction and Redesign
Oita University
700, Dannoharu, Oita-shi, Oita-ken 870-1192, Japan
y-tsurunari@oita-u.ac.jp

Received May 2022; accepted July 2022

Abstract. *A non-photorealistic rendering method to automatically generate moire-like images from photographic images has been proposed. Moire-like patterns are expressed by smooth curve, and moire-like images are a composite of moire-like patterns into photographic images and have a fantastic impression. Moire-like images emphasize the staircasing effect of bilateral filter, and it is conceivable to generate moire-like images by using another filter that the staircasing effect occurs. Therefore, methods have also been proposed to generate moire-like images by emphasizing the staircasing effect of Gaussian filter or trilateral filter. In this paper, we develop a method to automatically generate moire-like patterns that are different from the conventional methods. The proposed method generates moire-like images by using the staircasing effect of smoothed photographic images using Bezier surfaces. Since there are several parameters in the proposed method, we investigated through experiments how moire-like patterns are generated by changing the value of each parameter change. The proposed method was also applied to various photographic images. Through the experiments, it was found that the proposed method can generate moire-like patterns different from the conventional methods.*
Keywords: Non-photorealistic rendering, Moire-like pattern, Bezier surface, Automatic generation

1. **Introduction.** A non-photorealistic rendering [1, 2, 3, 4] method by image processing [5] has been proposed to automatically generate moire-like images [6] from photographic images by using the staircasing effect [7, 8] (stair-step shading) of bilateral filter [9, 10], which preserves and smoothes the edges of the images. Moire-like images generated by the conventional method [6] are a kind of op art [11], in which moire-like patterns are generated in photographic images, and have a fantastic impression. Op art is a genre of painting that gives a special visual effect based on the perceptual psychological mechanism of optical illusions. Moire-like images can be used as special effects for TV, magazines, SNS (social networking service) and websites. By changing the expression of moire-like patterns, it is thought that moire-like images with different impressions can be generated and the range of utilization of moire-like images will expand. Therefore, methods [12, 13] have been proposed to generate moire-like images by using other filters that cause the staircasing effect. In [12, 13], Gaussian filter and trilateral filter were respectively used to generate moire-like patterns with different textures from the conventional method [6]. The intervals of moire-like patterns generated by the conventional methods [6, 12, 13] vary depending on the shade of photographic images.

DOI: 10.24507/icicel.16.12.1309

In this paper, we develop a method to automatically generate moire-like patterns that is different from the conventional methods. The proposed method uses the staircasing effect smoothed photographic images using Bezier surfaces to generate moire-like images. Moire-like patterns of the proposed method are expressed by curves at equal intervals as compared with those of the conventional methods [6, 12, 13]. An experiment with various photographic images was conducted to visually confirm moire-like patterns generated by the proposed method. Additionally, an experiment was conducted to visually confirm the changes in moire-like patterns generated by changing the values of the parameters in the proposed method.

This paper is organized as follows: the second section describes the proposed method for generating moire-like images from photographic images using Bezier surfaces, 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 implemented in three steps: in Step 1, a photographic image is smoothed using Bezier surfaces; in Step 2, pseudo contour lines generated by the staircasing effect are emphasized from the smoothed image; and in Step 3, a moire-like image is generated by combining the photographic image and the pseudo contour lines. A flow chart of the proposed method is shown in Figure 1.

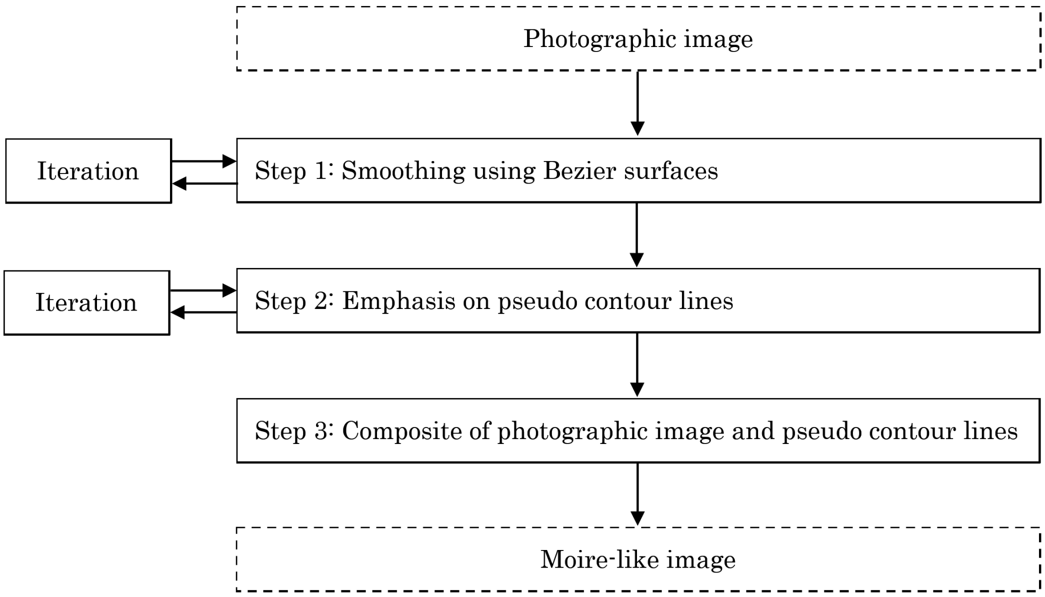

FIGURE 1. Flow chart of the proposed method

Details of the procedure in Figure 1 are explained below.

Step 0: The input pixel values for spatial coordinates (i, j) $(i = 0, 1, 2, \ldots, I-1;$ $j = 0, 1, 2, \ldots, J-1)$ of a gray-scale photographic image are defined as $f_{i,j}$. The pixel values $f_{i,j}$ have value of U gradation from 0 to $U-1$.

Step 1: The pixel values $f_{i,j}^{(t-1)}$ are smoothed to the pixel values $f_{i,j}^{(t)}$ using Bezier surfaces. The pixel values of the image at the t-th iteration number are defined as $f_{i,j}^{(t)}$, where $f_{i,j}^{(0)} = f_{i,j}$. The pixel values $f_{i,j}^{(t)}$ are of floating point type, and are calculated by the following equations:

$$f_{i,j}^{(t)} = \sum_{k=0}^{2W} \sum_{l=0}^{2W} f_{i+k-W,j+l-W}^{(t-1)} B_k B_l \tag{1}$$

$$B_k = \frac{(2W)!}{k!(2W-k)!} 0.5^{2W} \tag{2}$$

$$B_l = \frac{(2W)!}{l!(2W-l)!}0.5^{2W} \tag{3}$$

where W is the window size, and k and l are the positions in the window. This iterative calculation is repeated T_1 times.

Step 2: The pixel values $f_{i,j}^{(T_1)}$ are defined as $s_{i,j}^{(0)}$, where $s_{i,j}^{(0)}$ are of integer type. The pixel values that emphasize the pseudo contour line from the smoothed pixel values $s_{i,j}^{(t-1)}$ are defined as $g_{i,j}^{(t)}$. The pixel values $g_{i,j}^{(t)}$ are calculated by the following equations:

$$g_{i,j}^{(t)} = \sum_{k=0}^{2W}\sum_{l=0}^{2W} s_{i+k-W,j+l-W}^{(t-1)} B_k B_l \tag{4}$$

$$B_k = \frac{(2W)!}{k!(2W-k)!}0.5^{2W} \tag{5}$$

$$B_l = \frac{(2W)!}{l!(2W-l)!}0.5^{2W} \tag{6}$$

The pixel values $s_{i,j}^{(t)}$ are calculated by the following equation,

$$s_{i,j}^{(t)} = a\left(s_{i,j}^{(t-1)} - g_{i,j}^{(t)}\right) + s_{i,j}^{(t-1)} \tag{7}$$

where a is a positive constant. In case $s_{i,j}^{(t)}$ is less than 0, then $s_{i,j}^{(t)}$ must be set to 0. In case $s_{i,j}^{(t)}$ is greater than $U-1$, then $s_{i,j}^{(t)}$ must be set to $U-1$. The difference $d^{(t)}$ is calculated by the following equation,

$$d^{(t)} = \frac{\sum_{i=0}^{I-1}\sum_{j=0}^{J-1}\left|s_{i,j}^{(t)} - s_{i,j}^{(t-1)}\right|}{IJ} \tag{8}$$

This iterative calculation is performed until the difference $d^{(t)}$ is small. The difference $d^{(t)}$ becomes smaller as the iteration number increases. When the difference $d^{(t)}$ becomes smaller than D, this process ends, and the iteration number when this process ends is T_2. When the value of D is increased, the iteration number T_2 is reduced and the calculation cost is reduced. On the other hand, if the value of D is increased, moire-like patterns are not generated in the entire image.

Step 3: The pixel values $f_{i,j}$ of the photographic image and the pixel values $s_{i,j}^{(T_2)}$ of the images obtained in Step 2 are combined by the following equation. The combined pixel values are defined as $h_{i,j}$.

$$h_{i,j} = \frac{f_{i,j} + s_{i,j}^{(T_2)}}{2} \tag{9}$$

The image composed of the pixel values $h_{i,j}$ is the moire-like image of the proposed method.

3. Experiments.

We conducted two experiments: in the first experiment, the changes in moire-like patterns generated when the values of the parameters in the proposed method were changed were visually confirmed, and in the second experiment, the proposed method was applied to various photographic images. The first experiment used Woman image shown in Figure 2, 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, the parameter D was set to 5. The reason for setting D to 5 is that moire-like patterns could be generated in the entire image throughout the experiments.

Figure 2. Woman image

Figure 3. Various photographic images

3.1. **Experiment with changing parameters.** Moire-like images by changing the iteration number T_1 were visually confirmed using Woman image. The iteration number T_1 was set to 10, 40, 70 and 100. The other parameters W and a were set to 7 and 7, respectively. The results of the experiment are shown in Figure 4. The larger the value of T_1, the less the curvature of the moire-like patterns and the smoother the moire-like patterns.

(a) $T_1 = 10$ (b) $T_1 = 40$ (c) $T_1 = 70$ (d) $T_1 = 100$

Figure 4. Moire-like images for $T_1 = 10$, 40, 70 and 100

Moire-like images by changing the window size W were visually confirmed using Woman image. The window size W was set to 1, 4, 7 and 10. The other parameters T_1 and a were set to 70 and 7, respectively. The results of the experiment are shown in Figure 5. The larger the value of W, the larger the interval between the moire-like patterns.

Moire-like images by changing the parameter a were visually confirmed using Woman image. The parameter a was set to 1, 4, 7 and 10. The other parameters T_1 and W were set to 70 and 7, respectively. The results of the experiment are shown in Figure 6. There was no significant change in the moire-like patterns depending on the value of a. However, The values of T_2 were 10, 6, 5 and 4 when the values of a were 1, 4, 7 and 10, respectively, and it was found that the larger the value of a, the smaller the value of the iteration number T_2.

(a) $W = 1$ (b) $W = 4$ (c) $W = 7$ (d) $W = 10$

FIGURE 5. Moire-like images for $W = 1$, 4, 7 and 10

(a) $a = 1$ (b) $a = 4$ (c) $a = 7$ (d) $a = 10$

FIGURE 6. Moire-like images for $a = 1$, 4, 7 and 10

3.2. **Experiment using various photographic images.** The proposed method was applied to four photographic images shown in Figure 3. Since it was easy to see moire-like patterns in the privious experiments using Woman image with $512 * 512$ pixels, the parameters T_1, W and a were set to 70, 7 and 7, respectively. The results of the experiment are shown in Figure 7. All moire-like images could be automatically generated according to the change of the edges and the shading in photographic images. Additionally, moire-like patterns of the proposed method could be expressed by curves at equal intervals as compared with those of the conventional methods, and the proposed method could generate moire-like patterns with different textures from the conventional methods.

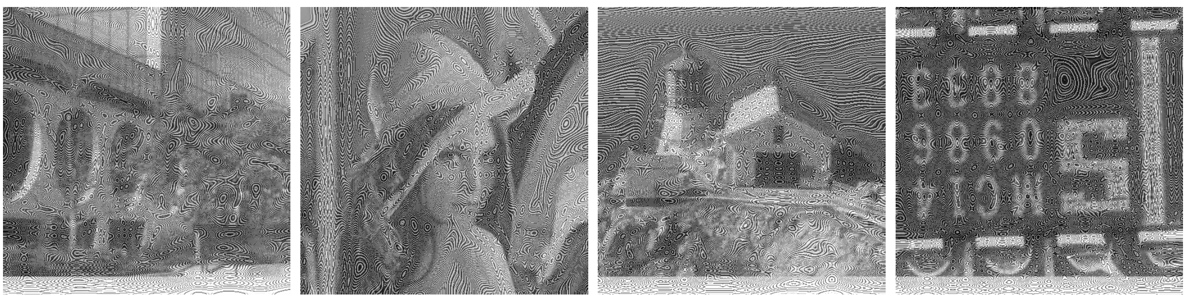

FIGURE 7. Various moire-like images

4. **Conclusions.** We developed a non-photorealistic rendering method to automatically generate moire-like patterns that are different from the conventional methods. The proposed method generated moire-like images by using the staircasing effect of smoothed photographic images using Bezier surfaces. Through experiments using Woman image and other photographic images, the proposed method could automatically generate moire-like images according to the change of the edges and the shading in photographic images. And,

the proposed method could change the interval and smoothness of moire-like patterns by adjusting the values of the parameters. And, in the proposed method, the intervals between moire-like patterns were relatively equal compared to the conventional methods.

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

Acknowledgment. This work was supported by JSPS KAKENHI Grant Number JP19K 12664.

REFERENCES

[1] 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.

[2] D. Martin, G. Arroyo, A. Rodriguez and T. Isenberg, A survey of digital stippling, *Computers & Graphics*, vol.67, pp.24-44, 2017.

[3] I. Ilinkin, Designing a course on non-photorealistic rendering, *Eurographics 2020*, pp.9-16, 2020.

[4] P. L. Rosin, Y. K. Lai, D. Mould, R. Yi, I. Berger, L. Doyle, S. Lee, C. Li, Y. J. Liu, A. Semmo, A. Shamir, M. Son and H. Winnemoller, NPRportrait 1.0: A three-level benchmark for non-photorealistic rendering of portraits, *Computational Visual Media*, vol.8, no.3, pp.445-465, 2022.

[5] D. Wang, Y. Ma, Z. Pan and N. Zhang, Enhancement for low-contrast images with FitzHugh-Nagumo nonlinearity and adaptive stochastic resonance, *International Journal of Innovative Computing, Information and Control*, vol.18, no.3, pp.941-955, 2022.

[6] T. Hiraoka and K. Urahama, Generation of moire-picture-like color images by bilateral filter, *IEICE Transactions on Information and Systems*, vol.E96-D, no.8, pp.1862-1866, 2013.

[7] A. Buades, B. Coll and J. M. Morel, The staircasing effect in neighborhood filters and its solution, *IEEE Transactions on Image Processing*, vol.15, no.6, pp.1499-1505, 2006.

[8] 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.

[9] C. Tomasi and R. Manduchi, Bilateral filtering for gray and color images, *Proceedings of ICCV*, pp.839-846, 1998.

[10] 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, 2008.

[11] J. M. Zanker, Looking at op art from a computational viewpoint, *Spatial Vision*, vol.17, nos.1-2, pp.75-94, 2004.

[12] 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.

[13] T. Hiraoka and Y. Tsurunari, Generation of moire-like images using trilateral filter, *ICIC Express Letters*, vol.15, no.5, pp.475-480, 2021.