ICIC Express Letters
Volume 11, Number 11, November 2017
 ISSN 1881-803X
pp. 1685–1690

MOIRE-LIKE IMAGES USING BINARIZED-WEIGHT BILATERAL FILTER FOR HIGHER QUALITY AND SPEED

Toru Hiraoka[1] and Kiichi Urahama[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]Department of Communication Design Science
Kyushu University
4-9-1, Shiobaru, Minami-ku, Fukuoka-shi, Fukuoka-ken 815-8540, Japan
urahama@design.kyushu-u.ac.jp

Received June 2017; accepted August 2017

Abstract. *A non-photorealistic rendering method using a bilateral filter (BF) to generate moire-like images from photographic images has previously been proposed. The standard method has two problems. First, its processing requires much time because iterative calculations using the computationally heavy BF are performed. Second, moire patterns are difficult to generate in regions of a photographic image with only small variation in brightness. In the present study, a method using a binarized-weight BF is proposed to achieve, relative to the standard method, faster image rendering by reducing the amount of computation and higher quality by generating moire patterns in regions of the photographic image with only small variation in brightness. To verify the effectiveness of the proposed method, a test is conducted using the Lenna image. A test of computational time shows that the proposed method can process images faster than the standard method, and a quality test shows that the proposed method can generate moire patterns in regions where the standard method cannot. The proposed method is also applied to a variety of other photographic images in addition to the Lenna image, and confirmed to give good results, as when applied to the Lenna image.*
Keywords: Non-photorealistic rendering (NPR), Moire, Binarized-weight bilateral filter, Higher speed, Higher quality

1. **Introduction.** A bilateral filter (BF) [1, 2], which smoothes images while preserving contours, has been receiving attention in recent years and is used in a wide range of applications such as image processing, computer vision, and computer graphics [3, 4, 5, 6, 7]. The BF is known to produce a staircase effect with stepwise shading changes. Since false contours are created as part of the staircase effect, a method to correct the occurrence of the false contours has been proposed [8, 9]. On the other hand, a non-photorealistic rendering (NPR) method [10, 11] has also been proposed for emphasizing the false contours from the BF to generate moire-like images (see Figure 1(b)) from photographic images. The NPR is a technique for generating non-photorealistic images such as oil paintings, pencil sketches, and charcoal drawings by a computer [12, 13, 14, 15, 16]. Moire-like images are a type of an op-art with moire patterns generated on photographic images, and can be used as special effects for television, magazines, and the Internet. The op-art is a style of pictorial art work that is calculated to present to its viewers a special visual effect based on perceptual psychological mechanisms of optical illusions.

The standard method for generating moire-like images has two problems. First, its processing requires much time because iterative calculations using the computationally heavy BF are performed. Second, moire patterns are difficult to generate in regions of

(a) Lenna (b) Moire-like image

FIGURE 1. The Lenna image and its moire-like image using the standard method

a photographic image with only small variation in brightness. In the moire-like image in Figure 1(b), for example, the difficulty of producing moire patterns can be seen in the light-gray cylindrical region on the left, the region above the hat, and the black arch region on the right.

Herein is proposed a method using a binarized-weight BF to achieve, relative to the standard method, both faster image rendering by reducing the amount of computation and higher quality by generating moire patterns in regions of the photographic image with only small variation in brightness. The binarized-weight BF binarizes the weight coefficients of the BF to 0 and 1, and enables a reduction of computationally heavy exponential function calculations. Moreover, compared with the standard BF using exponential function weights with values between 0 and 1, the use of binarized weights can potentially generate moire patterns more easily because it emphasizes the false contours caused by the staircase effect. Similar to the BF, the binarized-weight BF can smooth images while preserving contours. To verify the effectiveness of the proposed method, a test is conducted using the Lenna image shown in Figure 1(a). The proposed method is also applied to a variety of photographic images in addition to the Lenna image.

The rest of this paper is organized as follows. Section 2 describes the proposed method using the binarized-weight BF. Section 3 shows experimental results, and reveals that the proposed method can process images faster than the standard method and generate moire patterns in regions where the standard method cannot. Finally, Section 4 concludes this paper.

2. **Proposed Method.**

A moire-like image is generated by performing two main processes. In the first process, an image with a staircase effect is generated using a binarized-weight BF. By binarizing the weight coefficients of a BF to 0 and 1, the binarized-weight BF can reduce heavy exponential function calculations. In the second process, the image obtained from the first process is filtered with a new filter that combines the binarized-weight BF and unsharp masking (unsharp binarized-weight BF) to generate a moire-like image that magnifies the staircase effect. The unsharp binarized-weight BF can emphasize the false contours caused by the staircase effect than the BF, and generate moire patterns more easily. A flow chart of the proposed method is shown in Figure 2.

2.1. **Binarized-weight BF.**

Let $f_{1,i,j}^{(0)}$ be the input pixel value of the coordinates (i, j) for a photographic image. At iteration t, calculate the output pixel value $f_{1,i,j}^{(t)}$ of the BF as follows:

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

$$w^{(t)}_{1,i,j,k,l} = e^{-\alpha\left((i-k)^2+(j-l)^2\right)-\beta\left(f^{(t)}_{1,i,j}-f^{(t)}_{1,k,l}\right)^2} \quad (2)$$

where α and β are positive constants and W is the window size.

For the binarized-weight BF, the following equation is used instead of Equation (2):

$$w^{(t)}_{1,i,j,k,l} = \begin{cases} 1 & \alpha\left((i-k)^2+(j-l)^2\right)+\beta\left(f^{(t)}_{1,i,j}-f^{(t)}_{1,k,l}\right)^2 < C \\ 0 & \text{otherwise} \end{cases} \quad (3)$$

where C is a positive constant. If $\alpha\left((i-k)^2+(j-l)^2\right)+\beta\left(f^{(t)}_{1,i,j}-f^{(t)}_{1,k,l}\right)^2$ in Equation (3) is less than C, then the weight coefficient $w^{(t)}_{1,i,j,k,l}$ of the BF is 0; otherwise, it is 1.

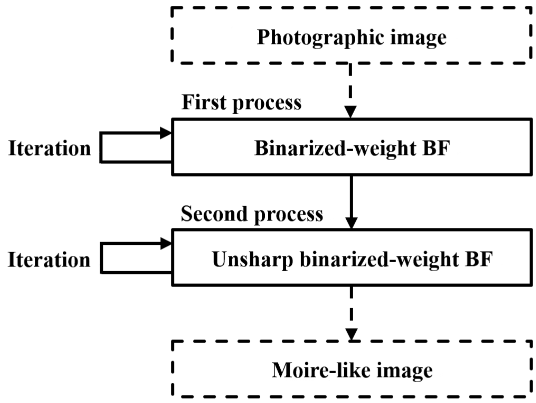


Figure 2. Flow chart of the proposed method

2.2. **Unsharp binarized-weight BF.** Let $f^{(0)}_{2,i,j}$ be the image $f^{(T_1)}_{1,i,j}$ after filtering T_1 times with the binarized-weight BF. At iteration t, calculate the output pixel value for the iterated $f^{(t)}_{2,i,j}$ as follows:

$$f^{(t)}_{2,i,j} = 2f^{(t-1)}_{2,i,j} - \frac{\displaystyle\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} w^{(t-1)}_{2,i,j,k,l} f^{(t-1)}_{2,k,l}}{\displaystyle\sum_{k=i-W}^{i+W}\sum_{l=j-W}^{j+W} w^{(t-1)}_{2,i,j,k,l}} \quad (4)$$

$$w^{(t)}_{2,i,j,k,l} = \begin{cases} 1 & \alpha\left((i-k)^2+(j-l)^2\right)+\beta\left(f^{(t)}_{2,i,j}-f^{(t)}_{2,k,l}\right)^2 < C \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

where the values of α, β, W, and C are the same as those used for the binarized-weight BF in Section 2.1.

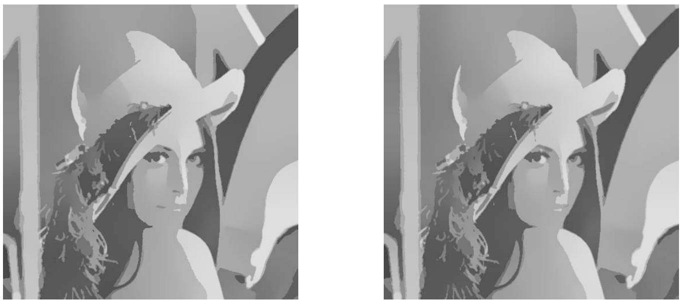
The image after filtering T_2 times with the unsharp binarized-weight BF is the moire-like image generated by the proposed method.

3. **Tests.** First, through the first process to create an image with the staircase effect, the computation times for the proposed and standard methods are compared in terms of speed using the Lenna image. Next, using the Lenna image, the moire-like image generated using the proposed method is checked visually to verify whether it has higher quality. Finally, to verify its usefulness in a more general set of photographic images, the proposed method is applied to a variety of photographic images in addition to the Lenna image. All tests were performed on 8-bit grayscale 512 × 512 pixel images. The parameters α, β, and W were set as 0.01, 0.01, and 20, respectively, based on previous

reports [10, 11]. For the standard method, the moire-like image (see Figure 1(b)) was generated with T_1 and T_2 set to 20 and 40, respectively. The computing environment for all tests is a Windows 10 Enterprise operating system on a computer with a 3.20 GHz CPU, a 8.00 GB of memory, and an Intel(R) HD Graphics 530 graphics board. The programming language used is VC++.

3.1. **Verification of higher speed.** The computation time was 16.661 and 3.329 seconds for one iteration of the BF and the binarized-weight BF, respectively. The proposed method can speed up processing fivefold relative to the standard method.

The image created using the BF with $T_1 = 20$ (BF image) is shown as Figure 3(a). The average absolute differences between pixel values (average error) of the BF image and the image created using the binarized-weight BF with varying T_1 and C combinations are listed in Table 1. The test was performed while varying T_1 from 1 to 20 in steps of 1 and C from 2.0 to 4.0 in steps of 0.5. The results in Table 1 show that as T_1 increases, the



(a) BF (b) Binarized-weight BF

FIGURE 3. Images using the BF ($T_1 = 20$) and binarized-weight BF ($T_1 = 12$, $C = 3.0$)

TABLE 1. Average error

		C				
		2.0	2.5	3.0	3.5	4.0
	1	6.211	5.978	5.765	5.571	5.388
	2	5.398	4.990	4.628	4.312	4.039
	3	4.786	4.242	3.772	3.396	3.120
	4	4.331	3.675	3.124	2.728	2.491
	5	3.994	3.243	2.628	2.221	2.046
	6	3.723	2.903	2.232	1.842	1.767
	7	3.489	2.616	1.908	1.573	1.633
	8	3.287	2.361	1.641	1.391	**1.627**
	9	3.113	2.138	1.418	**1.308**	1.745
T_1	10	2.956	1.933	1.244	1.332	1.935
	11	2.810	1.749	1.129	1.461	2.146
	12	2.677	1.590	**1.121**	1.631	2.350
	13	2.553	1.455	1.215	1.803	2.540
	14	2.440	1.352	1.358	1.962	2.714
	15	2.334	**1.302**	1.502	2.108	2.871
	16	2.238	1.314	1.643	2.246	3.012
	17	2.156	1.358	1.779	2.372	3.143
	18	2.094	1.424	1.910	2.491	3.260
	19	**2.063**	1.500	2.037	2.601	3.365
	20	2.064	1.584	2.154	2.706	3.461

average error decreases to some minimum value, after which it slowly increases. The bold faces in Table 1 indicate the minimum values of the average error along the change in T_1 with C being fixed to each value. Similarly, as C increases, the minimum of the average error decreases to some minimum value, after which it slowly increases. The underlines in Table 1 indicate the minimum values of the average error along the change in C with T_1 being fixed to each value. The results suggest that the most appropriate values for T_1 and C are approximately 12 and 3.0, respectively, and the image using the binarized-weight BF with these values is shown as Figure 3(b). Comparing Figures 3(a) and 3(b), little difference can be seen between the BF image and the image using the binarized-weight BF. Since T_1 is smaller in the proposed method ($T_1 = 12$) than the standard method ($T_1 = 20$), the proposed method can speed up processing than the standard method.

3.2. **Verification of higher quality.** Based on the results in Section 3.1, the quality test was performed with T_1 and C set as 12 and 3.0, respectively, and T_2 varied among 10, 20, 30, and 40. The moire-like images created using the proposed method are shown in Figure 4. As shown, more moire patterns are generated as T_2 increases. In the case of Figure 4(d) ($T_2 = 40$), moire patterns are generated in the regions where moire patterns were difficult to generate using the standard method (see Figure 1(b)), and they are generated throughout the entire moire-like image.

(a) $T_2 = 10$ (b) $T_2 = 20$ (c) $T_2 = 30$ (d) $T_2 = 40$

FIGURE 4. Moire-like images using the proposed method with varying T_2

FIGURE 5. Various photographic images

FIGURE 6. Moire-like images using the proposed method for various photographic images

3.3. **Test using various images.** The proposed method was next applied to four additional photographic images (see Figure 5). Based on the results in Sections 3.1 and 3.2, T_1, T_2, and C were set as 12, 40, and 3.0, respectively. The resulting moire-like images using the proposed method are shown in Figure 6. As shown, moire patterns are generated throughout entire regions for all moire-like images.

4. **Conclusions.** A method was proposed using a binarized-weight BF to achieve both faster image rendering by reducing the amount of computation relative to the standard method and higher quality by generating moire patterns in regions of the photographic image with only small variation in brightness. To verify the effectiveness of the proposed method, a test was first conducted using the Lenna image and it was shown that the proposed method can process images faster than the standard method. Next, a quality test showed that the proposed method can generate moire patterns in regions where the standard method cannot. Finally, the proposed method was also applied to the variety of photographic images, and confirmed to give good results, as when applied to the Lenna image.

Further studies are needed to apply the proposed method to color and moving images. Another future challenge is to enable the automatic setting of optimal parameter values depending on the photographic image used.

REFERENCES

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

[2] 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.

[3] K. Urahama, Extracting intrinsic structures in images: Noise reduction and generation of illustrations by using bilateral filters, *The Journal of the Institute of Image Information and Television Engineers*, vol.62, no.8, pp.1268-1273, 2008.

[4] K. Sugimoto, N. Fukushima and S. Kamata, Fast bilateral filter for multichannel images via soft-assignment coding, *Proc. of APSIPA*, 2016.

[5] J. Wang, J. Wu, Z. Wu, G. Jeon and J. Jeong, Bilateral filtering and directional differentiation for bayer demosaicking, *IEEE Sensors Journal*, vol.17, no.3, pp.726-734, 2017.

[6] Y. He, Y. Zheng, Y. Zhao, Y. Ren, J. Lian and J. Gee, Retinal image denoising via bilateral filter with a spatial kernel of optimally oriented line spread function, *Computational and Mathematical Methods in Medicine*, vol.2017, pp.1-13, 2017.

[7] H. H. Ali, H. Kolivand and M. S. Sunar, Soft bilateral filtering shadows using multiple image-based algorithms, *Multimedia Tools and Applications*, vol.76, no.2, pp.2591-2608, 2017.

[8] 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.

[9] 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.

[10] T. Hiraoka and G. 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.

[11] 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.

[12] B. J. Meier, Painterly rendering for animation, *Proc. of ACM SIGGRAPH 1996*, pp.477-484, 1996.

[13] S. X. Man, A multi-parameter generating method for colored pencil rendering, *American Journal of Information Science and Computer Engineering*, vol.2, no.5, pp.53-57, 2016.

[14] N. Ji, S. Shan, Z. Ma and X. Chen, Artist-drawing inspired automatic sketch portrait rendering, *Conference of 2016 Nicograph International*, pp.1-8, 2016.

[15] F. Huang and B. Huang, Generation of stereo oil paintings from RGBD images, *International Conference on CMVIT*, pp.64-68, 2017.

[16] T. Hiraoka and H. Nonaka, Generation of charcoal-drawing-like images by singular value decomposition and inverse filter, *ICIC Express Letters*, vol.11, no.7, pp.1215-1220, 2017.