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REDUCTION OF ITERATIVE CALCULATION AND QUALITY IMPROVEMENT FOR GENERATION OF MOIRE-LIKE IMAGES USING BILATERAL FILTER

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Abstract. *A method for generating moire-like images using bilateral filter from photographic images has been proposed. The problems with the conventional method are that it takes much calculation time and there are areas where it is difficult to generate moire patterns in photographic images. Therefore, in this paper, a method to solve the above two problems is developed by improving an iterative processing of unsharp mask using bilateral filter in the conventional method. The proposed method can reduce the number of the iterative calculations, and can generate the emphasized moire patterns on the whole image. To verify the effectiveness of the proposed method, experiments were conducted by comparing the number of the iterative calculations between the conventional method and the proposed method, and were done by visually confirming moire-like images generated from various photographic images. Experimental results revealed that the desired results of achieving the reduction of iterative calculation and the quality improvement can be obtained by using the proposed method.*
Keywords: Moire-like image, Bilateral filter, Reduction of iterative calculation, Quality improvement

1. **Introduction.** Bilateral filter [1, 2] which preserves contours in images and smooths images has attracted attention in recent years. When images are processed with bilateral filter, images with a staircase effect in which stepwise changes in brightness appear are generated. Many researches have been conducted to eliminate false contours caused by the staircase effect [3, 4]. On the other hand, some researches have focused on emphasizing pseudo contours to generate moire-like images [5, 6]. Moire-like images are generated by an iterative calculation using bilateral filter and unsharp mask. The conventional method [5, 6] has two problems: the first problem is that the calculation time is long, and the second problem is that there are areas where it is difficult to generate moire patterns. The cause of the first problem is that bilateral filter with large computation cost is used in the iterative calculation. The specific areas in the second problem have small changes in brightness. For example, in moire image shown in Figure 1(b), there are the light-gray pillar on the left and the black arch on the right as areas where moire patterns hardly occur.

In generating moire images from photographic images, we develop a method to reduce the number of the iterative calculations and to generate the emphasized moire patterns on the whole image. The proposed method improves an iterative processing of unsharp mask

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(a) Lenna (b) Moire-like image

FIGURE 1. Lenna image and moire-like image by the conventional method [5, 6]

using bilateral filter in the conventional method [5, 6]. As a related research, a method to reduce the calculation time and to improve the quality of moire-like images has been proposed [7]. In the conventional method [7], binarized-weight bilateral filter is used instead of bilateral filter. Binarized-weight bilateral filter binarizes the weight coefficients of bilateral filter to 0 and 1, and enables a reduction of calculation of exponential function with large amount of calculation. Although the conventional method [7] mainly reduces the calculation time of the bilateral filter, the proposed method can reduce the number of the iterative calculations. Therefore, by combining the conventional method [7] and the proposed method (the combined method), faster processing can be expected.

In order to verify the effectiveness of the proposed method, an experiment using Lenna image was conducted by comparing the number of the iterative calculations between the conventional method [5, 6] and the proposed method. Then, through an experiment applying the proposed method to various photographic images, it was visually confirmed that moire patterns can be generated in areas with small changes in brightness. Furthermore, an experiment by the combined method was conducted.

This paper is organized as follows: the second section describes the proposed method for generating moire-like 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 moire-like images at high speed and with high quality from photographic images. The proposed method is executed in two steps: in the first step, it is processed iteratively with bilateral filter, and in the second step, it is done iteratively with unsharp mask using bilateral filter. The proposed method is an improvement of the iterative processing of unsharp mask using bilateral filter in the conventional method [5, 6]. Specifically, by increasing the strength of unsharp mask, moire patterns can be more clearly expressed in one iterative calculation, and as a result, moire-like images can be generated with a smaller iterative number. 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 256 gradation from 0 to 255, where $f_{i,j}^{(0)} = f_{i,j}$.

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

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

where W is the window size, α and β are positive constants, and k and l are the positions in the window. 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.

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

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. As the value of a is larger, moire patterns are more emphasized and are generated with fewer iteration number T_2.

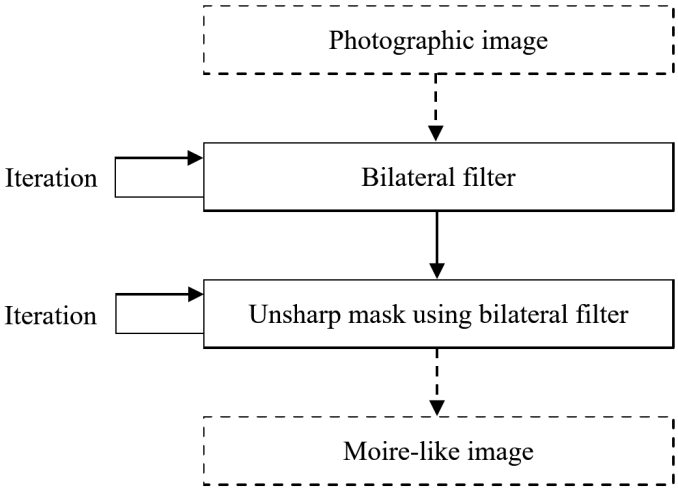

FIGURE 2. Flow chart of our method

3. **Experiments.** Three experiments were conducted. The first experiment compared the number of the iterative calculations between the conventional method [5, 6] and the proposed method using Lenna image shown in Figure 1(a). The second experiment applied the proposed method to various photographic images. In order to show that processing can be made faster by combining the proposed method and conventional method [7], the third experiment was performed by the combined method using Lenna image. All images used in the experiments were $512 * 512$ pixels and 256 gradation. The parameters α, β, W, and T_1 used in all experiments were set to 0.01, 0.01, 20, and 20, respectively. In the conventional method [7], T_1 was set to 12. The computing environment for all experiments was a Windows 10 Enterprise 2016 LTSB operating system on a computer with a 3.20 GHz CPU and a 8.00 GB of memory. The programming language used in all experiments was VC++.

First, moire-like images by varying the parameters a and T_2 were confirmed visually using Lenna image. The parameter a was set to 2, 4, 6, and 8, and the iteration number T_2 was set to 3, 6, 9, 12, and 15. The results of the experiment are shown in Figure 3. As the value of a was larger, moire patterns were emphasized and moire-like images converge with fewer iteration number T_2. For example, in case of $a = 6$ and $a = 8$, the moire-like images converged with $T_2 = 9$ and $T_2 = 6$, respectively. On the other hand, when the moire-like image of Figure 1(b) was generated by the conventional method [5, 6], the iteration number T_2 was required 40 times. Thus, the proposed method can generate moire-like images with fewer iteration number T_2 than the conventional method [5, 6]. In addition, in the conventional method [5, 6], there were areas where it was difficult to generate moire patterns shown in Figure 1(b), but the proposed method could generate moire patterns on the entire image.

FIGURE 3. Moire-like images by varying the parameters a and T_2

Next, the proposed method was applied to five photographic images shown in Figure 4. The parameters a and T_2 were set to 6 and 9, respectively. The results of the experiment are shown in Figure 5. Observing moire-like images of the literature [5] generated from the same photographic images as Figures 4(a), 4(c) and 4(d), there were areas where moire patterns were not generated, but the proposed method did not have such areas.

(a) Airplane (b) Boat (c) Cameraman (d) Lighthouse (e) Woman

FIGURE 4. Various photographic images

(a) Airplane (b) Boat (c) Cameraman (d) Lighthouse (e) Woman

FIGURE 5. Moire-like images

TABLE 1. Calculation times by four methods [second]

The conventional method [5, 6]	936.206
The conventional method [7]	170.799
The proposed method	455.625
The combined method	69.201

In the proposed method, moire patterns were generated throughout entire areas for all moire-like images.

Finally, the experiment by the combined method was conducted. The calculation times were compared by four methods: the conventional method [5, 6], the conventional method [7], the proposed method, and the combined method. The parameters a and T_2 in the proposed and the combined methods were respectively set to 6 and 9, and the parameter T_2 in the conventional method [5, 6] and the conventional method [7] was set to 40. The results of the experiment are shown in Table 1. The computation times were 936.206, 170.799, 455.625, and 69.201 seconds for the conventional method [5, 6], the conventional method [7], the proposed method, and the combined method, respectively. Although the proposed method had much longer calculation time than the conventional method [7], the proposed method reduces the number of the iterative calculations and the conventional method [7] reduces the calculation time of one iteration. Thus, by combining the proposed method and the conventional method [7], processing was performed faster. For reference, a moire-like image generated by the combined method is shown in Figure 6. Although there was a region where moire patterns were not generated slightly on the upper left corner, moire patterns could be generated almost in the whole image. However, the quality of the moire-like image by the combined method was deteriorated by including fine noise. The combined method can be used when processing is desired to be performed at high speed without much requesting the quality of moire-like images.

4. **Conclusions.** This paper proposed a method for generating moire-like images at high speed and with high quality from photographic images. The proposed method improved

FIGURE 6. Moire-like images by the combined method

an iterative processing of unsharp mask using bilateral filter in the conventional method [5, 6]. The proposed method could reduce the number of the iterative calculations, and could generate the emphasized moire patterns on the whole image. First, an experiment using Lenna image was conducted by comparing the number of the iterative calculations between the conventional method [5, 6] and the proposed method. Next, through an experiment applying the proposed method to various photographic images, it was visually confirmed that moire patterns can be generated in areas with small changes in brightness. Finally, an experiment that combines the conventional method [7] and the proposed method was conducted. Experimental results revealed that the proposed method works effectively.

A subject for future study is to express moire-like images more impressively by deforming the shape of moire patterns. Another task is to be able to generate more impressive moire patterns suitable for color photographic images and videos.

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