Generation of Moire-Picture-Like Color Images by Bilateral Filter

Toru HIRAOKA†(a) and Kiichi URAHAMA††, Members

SUMMARY We propose a non-photorealistic rendering method for generating moire-picture-like color images from color photographs. The proposed method is performed in two steps. First, images with a staircasing effect are generated by a bilateral filter. Second, moire patterns are generated with an improved bilateral filter called an anti-bilateral filter. The characteristic of the anti-bilateral filter is to emphasize gradual boundaries.

key words: non-photorealistic rendering, moire, bilateral filter

1. Introduction

A bilateral filter [1] which is an edge-aware smoothing filter is receiving a lot of attention and is being used in many fields [2] such as image processing and computer graphics. A staircasing effect of stepwise changes in shading is known to occur in the bilateral filter. The staircasing effect generates pseudo contours, thus studies to eliminate the occurrence of pseudo contours have been carried out [3].

In this letter, by exploiting the staircasing effect instead of avoiding it, we propose a non-photorealistic rendering method for generating moire-picture-like color images from color photographs. These moire-picture-like color images are a kind of op art as shown in Fig. 1 (cited under permission from the copyright holders of these pictures). Op art is a genre of painting based on psychological mechanisms of perceptual illusion. The proposed method has characteristics emphasizing gradual boundaries and generating images with multiple overlapping moire patterns such as the right image of Fig. 1. In addition, the proposed method has characteristic that the spacing and the orientation of moire patterns can be automatically generated in accordance with the shading and the edge of color photographs. These moire-picture-like color images can be considered as a use of special effects such as movies and TV. To the authors’ best knowledge, there has been no study on generating moire-picture-like color images. As a result of the experiments, we show impressive moire patterns which are emphasized gradual boundaries and generated with overlapping moire patterns.

2. Method

The proposed method is performed in two steps. First, images with the staircasing effect are generated with the bilateral filter. Second, images with moire patterns are generated with an improved bilateral filter called an anti-bilateral filter.

2.1 Bilateral Filter

Let input pixel values of RGB on image coordinates \((i, j)\) be \(r_{i,j}^{(0)}, s_{i,j}^{(0)}\) and \(b_{i,j}^{(0)}\), and let output pixel values after processing with the bilateral filter be \(r_{i,j}^{(r)}, s_{i,j}^{(r)}\) and \(b_{i,j}^{(r)}\) where \(r\) is the number of iterations.

The bilateral filter of \(r_{i,j}^{(r)}\) is given by

\[
I_{k,t}^{(r)} = \frac{\sum_{k=-w}^{w} \sum_{l=-w}^{w} e^{-\alpha((i-k)^2+(j-l)^2)} - \beta((i-k)^2+(j-l)^2)^2} {\sum_{k=-w}^{w} \sum_{l=-w}^{w} e^{-\alpha((i-k)^2+(j-l)^2)} - \beta((i-k)^2+(j-l)^2)^2}} \tag{1}
\]

where \(\alpha\) and \(\beta\) are positive constants and \(w\) is window size. \(\alpha\) is a parameter for adjusting the influence of the distance from the pixel coordinates \((i, j)\). As the value of \(\alpha\) is greater, the pixels away from the pixel coordinates \((i, j)\) will be less affected. \(\beta\) is a parameter for adjusting the influence of the absolute value of the difference between the pixel coordinates \((i, j)\). As the value of \(\beta\) is greater, the pixels with a value away from the value of the pixel coordinates \((i, j)\) will be less affected. It is possible to reduce the value of \(w\), as the value of \(\alpha\) is smaller. The bilateral filters of \(g_{i,j}^{(r)}\) and \(\hat{b}_{i,j}^{(r)}\) are obtained in the same manner as the bilateral filter of \(r_{i,j}^{(r)}\).
2.2 Anti-Bilateral Filter

Let pixel values after processing with the bilateral filter of $T_i$ times iteration be $r_{i,j}^{T_i(0)} = r_{i,j}^{(0)}$, $g_{i,j}^{T_i(0)} = g_{i,j}^{(0)}$, and $b_{i,j}^{T_i(0)} = b_{i,j}^{(0)}$, and let output pixel values after processing with the anti-bilateral filter be $r_{i,j}^{(0)}$, $g_{i,j}^{(0)}$, and $b_{i,j}^{(0)}$ where $t$ is the number of iterations.

The anti-bilateral filter of $r_{i,j}^{(0)}$ is given by

$$
r_{i,j}^{(t)} = 2r_{i,j}^{(t-1)} - \sum_{k=-w}^{w} \sum_{l=-w}^{w} e^{-\alpha((i-k)^2+(j-l)^2)} \beta (r_{i,j}^{(t-1)} - r_{i,j}^{(t-1)})^2 \frac{r_{i,j}^{(t-1)} - r_{i,j}^{(t-1)}}{k,l} \quad (2)
$$

where $\alpha$ and $\beta$ are positive constants and $w$ is window size.

Equation (2) is intended to add sequentially the variation of the pixel values by the bilateral filter of Eq. (1). The anti-bilateral filters of $g_{i,j}^{(0)}$, and $b_{i,j}^{(0)}$ are obtained in the same manner as the anti-bilateral filter of $r_{i,j}^{(0)}$. Note the difference between Eq. (1) and Eq. (2). Equation (1) is a low-pass filter, while Eq. (2) is a high-pass filter. The staircasing effect initially produced by Eq. (1) is amplified by Eq. (2) to produce the moire effect. This amplification plays a central role in the proposed method.

Moiré-picture-like color images are obtained after processing of the anti-bilateral filter of $T_2$ times iteration.

3. Experiments

At first, for reference, the proposed method is applied to two simple gray scale images, we check how the occurrence of moire patterns. Next, we conduct experiments using a color image of Lena, and obtain moire patterns which are emphasized and generated by iterative calculations. In addition, we conduct experiments by changing the values of the parameters $\alpha$, $\beta$ and $w$ using the color image of Lena. Finally, we conduct experiments using several color images.

3.1 Experiments Using Simple Gray Scale Images

We apply the proposed method to two simple gray scale images (the size of $512 \times 512$ pixels) shown in Fig. 2.

Moiré-picture-like gray scale images generated by the proposed method where $T_1 = 20$, $T_2 = 100$, $w = 20$, $\alpha = 0.001$ and $\beta = 0.01$ are shown in Fig. 3. Observing Fig. 3, moire patterns are generated perpendicular to the luminance gradient, and also affected by the frame of the image.

3.2 Experiments Using Color Image of Lena

We apply the proposed method to the color image of Lena (the size of $512 \times 512$ pixels) shown in Fig. 4.

Moiré-picture-like color images generated by the proposed method in the case of $T_1 = \{10, 20, 30, 40\}$ where $T_2 = 40$, $w = 10$, $\alpha = 0.001$ and $\beta = 0.01$ are shown in Fig. 5. Upper left image of Fig. 5 is the case of $T_1 = 10$, $w = 10$, lower left image is the case of $w = 15$, and lower right image is the case of $w = 20$. Observing Fig. 5, as upper right image is the case of $T_1 = 10$, lower right image is the case of $T_1 = 30$, and lower right image is the case of $T_1 = 40$. Observing Fig. 7, as the number of iterations of $T_1$ is smaller, curves of moire patterns are fine.

Moiré-picture-like color images in the case of $T_2 = \{10, 20, 30, 40\}$ where $T_1 = 20$, $w = 10$, $\alpha = 0.001$ and $\beta = 0.01$ are shown in Fig. 6. Upper left image of Fig. 6 is the case of $T_1 = 10$, upper right image is the case of $T_2 = 20$, lower left image is the case of $T_2 = 30$, and lower right image is the case of $T_2 = 40$. Observing Fig. 6, as the number of iterations of $T_2$ becomes lager, moire patterns are gradually emphasized, for instance, in the part of fine hat textured region.

Moiré-picture-like color images in the case of $w =$
{5, 10, 15, 20} where $T_1 = 20$, $T_2 = 40$, $\alpha = 0.001$ and $\beta = 0.01$ are shown in Fig. 7. Upper left image of Fig. 7 is the case of $w = 5$, upper right image is the case of the value of $w$ becomes larger, spaces of moire patterns becomes wider gradually.

Moiré-picture-like color images in the case of $\alpha = \{0.1, 0.01, 0.001\}$ and $\beta = \{0.1, 0.01, 0.001\}$ where $T_1 = 20$, $T_2 = 40$ and $w = 10$ are shown in the figures from Fig. 8 to Fig. 10. Figure 8 is the case of $\alpha = 0.1$, Fig. 9 is the case of $\alpha = 0.01$, and Fig. 10 is the case of $\alpha = 0.001$. Upper left images of them are the case of $\beta = 0.1$, upper right images are the case of $\beta = 0.01$, and lower left image is the case of $\beta = 0.001$. Observing these images, as the values of $\alpha$ and $\beta$ are smaller, moire patterns are fine. On the other hand, as the value of $\beta$ is smaller, the saturation of moire-picture-like color images is degraded.

In order to generate visually clean moire-picture-like color images, the space of moire patterns is required to be some extent wide. Because the saturation of these images is reduced when the spaces of moire patterns are too small.
Therefore, in case of image size of 512 × 512 pixels, the optimal values of parameters $T_1$, $T_2$, $w$, $\alpha$ and $\beta$ for generating visually clean moire-picture-like color images are around 20, 30, 10, 0.01 and 0.01 respectively.

3.3 Experiments Using Several Color Images

Moire-picture-like color images generated by the proposed method from six color photographs (the size of 512 × 512 pixels) are shown in the figures from Fig. 11 to Fig. 16. We set $T_1 = 20$, $T_2 = 40$, $\alpha = 0.001$, $\beta = 0.01$ and $w = 10$. Left images in them are original images and right ones are moire-picture-like color images.

From the observation of these images, we can verify...
that moire patterns are emphasized in all of them and multiple overlapping moires are generated. However, fine textures in original image are smeared in the moire-picture-like color image of Fig. 12 and moire patterns are not cleanly produced in the regions of Mandrill’s hair of Fig. 13.

4. Conclusion

We have proposed a non-photorealistic rendering method for generating moire-picture-like color images from color photographs by exploiting the staircasing effect of the bilateral filter. The proposed method was found to generate impressive moire-picture-like color images which are generated using overlapping moire patterns to emphasize gradual boundaries.

References

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