LETTER

Generation of Oil-Film-Like Images by Bilateral Infra-Envelope Filter

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SUMMARY A non-photorealistic rendering method creates oil-film-like images, expressed with colorful, smooth curves similar to the oil films generated on the surface of glass or water, from color photo images. The proposed method generates oil-film-like images through iterative processing between a bilateral infra-envelope filter and an unsharp mask. In order to verify the effectiveness of the proposed method, tests using a Lena image were performed, and visual assessment of oil-film-like images was conducted for changes in appearance as the parameter values of the proposed method were varied. As a result of tests, the optimal value of parameters was found for generating oil-film patterns.

key words: non-photorealistic rendering, oil film, bilateral infra-envelope filter, unsharp mask

1. Introduction

In recent years, non-photorealistic rendering\(^{(1)}\), computer generation of images that is not faithful to photorealism, has gathered interest as a technology. Applications of non-photorealistic rendering include technical illustrations in manufacturing and industry; water-color-like, oil-painting-like, and India-ink-like rendering in the field of fine arts\(^{(2)}\)–\(^{(6)}\); and extended computer-graphics expressions or three-dimensional (3D) animation-cell-like conversions in the visual entertainment domain. Non-photorealistic rendering can be classified among methods that exploit 3D geometry data, methods that exploit two-dimensional (2D) images such as photographs, and methods that exploit pointing devices such as computer mice. This paper focuses on a method that exploits the 2D images such as photographs in an application to the fine arts.

This paper specifically proposes a non-photorealistic rendering method in which oil-film-like images expressed with colorful, smooth curves similar to oil films generated on the surface of glass or water (see Fig. 1) are created from color photo images. Oil-film-like images are represented by overlapping oil-film patterns on color photo images. According to our search of the literature, no previous research has studied the generation of oil-film-like images in non-photorealistic rendering. The proposed method generates oil-film-like images through iterative processing between a bilateral infra-envelope filter\(^{(7)}\) and an unsharp mask. The bilateral infra-envelope filter derives an image that envelopes the lower parts of unevenness in brightness values of images, while the unsharp mask emphasizes the edge zones to perform sharpening.

The characteristics of the oil-film-like images generated under the proposed method can be described as follows. For a circular zone of pixels with similar value levels (below circle zone), the orientation and interval of curves are automatically generated according to the edges and gradation gradient, such that oil-film patterns of colorful, smooth curves can be formed along the circumference of the circle zone. Oil-film-like images mimic colorful patterns which are generated by reflecting the light in oil films. In order to verify the effectiveness of the proposed method, we examined the way that oil-film patterns form in the proposed method when parameters are varied through tests with a Lena color image (see Fig. 2). The results of the tests offer guidelines for generating oil-film-like images from various color photo images.

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2. Proposed Method

The proposed method is executed largely via two processes. In the first process, a bilateral infra-envelope filter is employed to prepare the image with a staircasing effect [8] (stair-stepped variation in gradation). In the second process, a bilateral infra-envelope filter and an unsharp mask are employed to produce an oil-film-like image.

For the first process, the input pixel values (R, G, B) for spatial coordinates (i, j) are established as $d_{R,i,j}^{(0)}$, $d_{G,i,j}^{(0)}$, and $d_{B,i,j}^{(0)}$, and the output pixel values (R, G, B) from the bilateral infra-envelope filter are computed as $d_{R,i,j}^{(t)}$, $d_{G,i,j}^{(t)}$, and $d_{B,i,j}^{(t)}$ (where $t$ is the iteration number). Red, green, and blue are computed in the same manner, and so only the calculation for red is provided in Eqs. (1) to (3) below.

\[
d_{R,i,j}^{(t)} = \frac{\sum_{k=i-w}^{i+w} \sum_{l=j-w}^{j+w} D_{i,l,k,l}^{(t-1)} d_{R,k,l}^{(t-1)}}{\sum_{k=i-w}^{i+w} \sum_{l=j-w}^{j+w} D_{i,k,l}^{(t-1)}}
\]

(1)

\[
D_{i,j,k,l}^{(t)} = \begin{cases} 
\frac{e^{-\alpha((i-k)^2+(j-l)^2)-\beta d_{R,i,j}^{(t)}-d_{R,k,l}^{(t)}}}{(d_{RGB,i,j}^{(t)} \geq d_{RGB,k,l}^{(t)})} & (\text{otherwise}) \\
0 & (\text{otherwise})
\end{cases}
\]

(2)

\[
d_{RGB,i,j}^{(0)} = d_{R,i,j}^{(0)} + d_{G,i,j}^{(0)} + d_{B,i,j}^{(0)}
\]

(3)

Here, $\alpha$ and $\beta$ are positive constants, and $w$ is the window size. Parameter $\alpha$ adjusts the influence of distance from coordinates (i, j); as $\alpha$ becomes larger, the influence of pixels away from coordinates (i, j) decreases. Parameter $\beta$ adjusts the influence of the absolute value of the difference between coordinates (i, j) and pixel value $d_{R,i,j}^{(t)}$; as $\beta$ becomes larger, the influence of pixels with large absolute values of differences from pixel value $d_{R,i,j}^{(t)}$ decreases. Finally, a larger value of $w$ corresponds to a larger computation volume. The bilateral infra-envelope filter is applied $T_1$ times. In the calculation, the bilateral infra-envelope filter employs only the pixels (k, l) with pixel values $f_{RGB,k,l}^{(t)}$ no greater than pixel value $f_{RGB,i,j}^{(t)}$.

In the second process, pixel values (R, G, B) of $d_{R,i,j}^{(T_1)}$, $d_{G,i,j}^{(T_1)}$, and $d_{B,i,j}^{(T_1)}$ after application of the bilateral infra-envelope filter $T_1$ times are established as $f_{R,i,j}^{(0)}$, $f_{G,i,j}^{(0)}$, and $f_{B,i,j}^{(0)}$, for which output pixel values (R, G, B) of $f_{R,i,j}^{(0)}$, $f_{G,i,j}^{(0)}$, and $f_{B,i,j}^{(0)}$ (where $t$ is the iteration number) are computed in a process combining the bilateral infra-envelope filter and the unsharp mask. Red, green, and blue are computed in the same manner, and so only the calculation for red is provided in Eqs. (4) to (6) below.

\[
f_{R,i,j}^{(t)} = 2f_{i,j}^{(t-1)} - \frac{\sum_{k=i-w}^{i+w} \sum_{l=j-w}^{j+w} f_{i,k,l}^{(t-1)} f_{k,l}^{(t-1)}}{\sum_{k=i-w}^{i+w} \sum_{l=j-w}^{j+w} f_{i,k,l}^{(t-1)}}
\]

(4)

\[
F_{i,j,k,l}^{(t)} = \begin{cases} 
e^{-\alpha((i-k)^2+(j-l)^2)-\beta (d_{R,i,j}^{(t)}-f_{R,k,l}^{(0)})^2} & (f_{RGB,i,j}^{(t)} \geq f_{RGB,k,l}^{(t)}) \\
0 & (\text{otherwise})
\end{cases}
\]

(5)

\[
f_{RGB,i,j}^{(t)} = f_{R,i,j}^{(t)} + f_{G,i,j}^{(t)} + f_{B,i,j}^{(t)}
\]

(6)

Here, positive constants $\alpha$ and $\beta$ and window size $w$ have the same values as in Eqs. (1) and (2). The image after applying the combined process of the bilateral infra-envelope filter and the unsharp mask $T_2$ times is an oil-film-like image.

3. Experiments

The proposed method was applied to a 256-gradation Lena color image, size 512 * 512 pixels. The change in appearance of the oil-film-like image was visually assessed as the parameters $T_1$, $T_2$, $w$, $\alpha$, and $\beta$ of the proposed method were varied. For the tests, the base reference values of the parameters were set as 10, 40, 10, 0.01, and 0.01, respectively, and each parameter was varied separately.

As the first test, $T_1$ was varied between 5, 10, 15, and 20. The respective oil-film-like images are shown in the upper left, upper right, lower left, and lower right of Fig. 3. The proposed method was applied to a 256-gradation Lena color image, size 512 * 512 pixels. The change in appearance of the oil-film-like image was visually assessed as the parameters $T_1$, $T_2$, $w$, $\alpha$, and $\beta$ of the proposed method were varied. For the tests, the base reference values of the parameters were set as 10, 40, 10, 0.01, and 0.01, respectively, and each parameter was varied separately.

As the first test, $T_1$ was varied between 5, 10, 15, and 20. The respective oil-film-like images are shown in the upper left, upper right, lower left, and lower right of Fig. 3. As shown, as $T_1$ became smaller, the circle zones became smaller. Moreover, when $T_1$ was 5, the circle zones were so small as to sometimes be unrecognizable. Thus, appropriate
values for $T_1$ appear to be from 10 to 20.

Next, $T_2$ was varied between 10, 20, 30, and 40. The respective oil-film-like images are shown in the upper left, upper right, lower left, and lower right of Fig. 4. As shown, as $T_2$ became larger, the oil-film pattern formations became more pronounced. When $T_2$ was 40, oil-film patterns formed across the entire image, and the oil-film-like image converged. Thus, taking also the computation time for the proposed method into account, an appropriate value for $T_2$ appears to be approximately 40.

Third, $w$ was varied between 5, 10, 15, and 20. The respective oil-film-like images are shown in the upper left, upper right, lower left, and lower right of Fig. 5. As shown, as $w$ became smaller, the circle zones became smaller, although increasing $w$ beyond 10 did not greatly change the size of the circle zones. Thus, taking also the computation time for the proposed method into account, an appropriate value for $w$ appears to be from 5 to 10.

Fourth, $\alpha$ was varied between 0.001, 0.01, and 0.1. The respective oil-film-like images are shown in the upper left,
upper right, and bottom of Fig. 6. For these images, as \( \alpha \) became larger, it became more difficult for oil-film patterns to form, and as \( \alpha \) became smaller, the formed image became less like the original image. Thus, an appropriate value for \( \alpha \) appears to be approximately 0.01.

Fifth, \( \beta \) was varied between 0.001, 0.01, and 0.1. The oil-film-like images are respectively shown in the upper left, upper right, and bottom of Fig. 7. For these images, as the value of \( \beta \) became larger, the circle zones became smaller, although there was little difference in the sizes of the circle zones between \( \beta = 0.01 \) and \( \beta = 0.001 \). Thus, a value of approximately 0.01 appears to be appropriate for \( \beta \).

Lastly, the proposed method was applied to five 256-gradation color photo images sized 512 * 512 pixels besides the Lena color image. The results are shown in Fig. 8, in which the original image is shown on the left and the oil-film-like image is shown on the right. In all cases, the oil-film-like image had oil-film patterns of colorful, smooth curves formed along circle zones. However, oil-film pattern formation was found to be different in detailed texture zones.

As an additional test, we prepared a questionnaire survey in which oil film (see Fig. 1) and oil-film-like images (see the lower left of Fig. 3 and the right of Fig. 8) were collectively presented as a set. All images were then presented to a group of 26 students aged 17 or 18 (18 men, 8 women) who were asked to choose how similar in five stages evaluation: “very similar”, “similar”, “even”, “not very similar”, and “not similar”. It was found that the 4 subjects selected “very similar”, 9 selected “similar”, 9 selected “even”, 2 selected “not very similar”, and 2 selected “not similar”. Based on these survey results, we concluded that oil film and oil-film-like images are similar.

4. Conclusion

A method of non-photorealistic rendering is proposed in which oil-film-like images are generated from color photo images by iterative processing that employs a bilateral infrared envelope filter and an unsharp mask. In order to verify the effectiveness of the proposed method, tests using a Lena color image were conducted, and visual assessment of oil-film-like images was carried out to determine changes in appearance as values of the parameters for the proposed method were varied. The results of the tests offer guidelines for generating oil-film-like images from various color photo images.

A subject for future study is to expand the proposed method so that oil-film patterns form in detailed texture zones. Another task is to expand the proposed method for application to motion images.

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