GENERATING WATERCOLOR PAINTING-LIKE IMAGES BY USING BILATERAL FILTER

Toru HIRAOKA[1]

[1]Department of Information Engineering, National Institute of Technology, Oita College

We propose a non-photorealistic rendering method for generating watercolor-like images from color photographs. The proposed method is performed in two steps. First, images with flow patterns created by tracing with a brush are generated with an anisotropic filter. Second, watercolor-like images are generated by coloring that corresponds to the absolute values of the color differences between the image processed by the bilateral filter and the original image. To evaluate performance of the proposed method for generating watercolor-like images, we conduct experiments using example images.

***Key Words* :** watercolor, non-photorealistic rendering, bilateral filter, anisotropic filter

1. INTORODUCTION

Non-photorealistic rendering (NPR) for transformation of photographic images to pager mosaic, oil painting, pencil drawing, watercolor, and other modes of imagery has been the subject of many studies[1)2)3)]. Here we focus on NPR transformation to watercolor paintings, which are generally characterized by brush strokes and blurring of paint in pale tones. Many methods have been proposed for NPR transformation to watercolors, including the use of three-dimensional geometrical models[4)5)], incorporation of artists' techniques in the form of painting rules[6)] , application of color diffusion processing by cellular automaton modeling of color-partitioned regions[7)], rounding by dilation of extracted color regions, and coloring by variation in morphology and distance and by alpha blending[8)].

We propose an NPR technique incorporating a bilateral filter (BF) [9)], which is a type of nonlinear smoothing filter, to generate watercolor-like images from photographic images. In the first step of this two-step technique, the photographic image is transformed to a smooth, flowing image with an anisotropic filter [10)] which is then processed by the BF to obtain enhanced strokes that appear to have been drawn by brush together with the blurring of pale tones. In the second step, coloring is implemented in accordance with the absolute value of differences found between the image obtained by the BF processing and the original image. In this coloring process, the regions of image edge contours are colored with less coloring than the regions having smaller changes in intensity. As an effect of the BF, moreover, textures resembling impulse noise tend to resist coloring. The end result is an image that conveys an impression distinct from those of watercolor-like images obtained by existing methods.

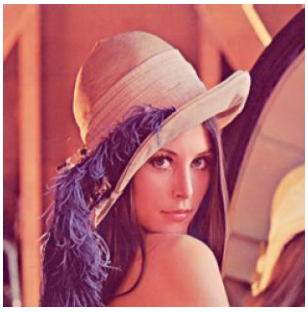

Fig.1 Lena Image.

The effectiveness of the proposed method was investigated experimentally. Variations in the watercolor-like image generated from the Lena image shown in Fig.1 were obtained by varying the BF parameters, and watercolor-like images were also generated from several other photographic images to assess their visual effects.

2. METHOD

The proposed method is implemented by using

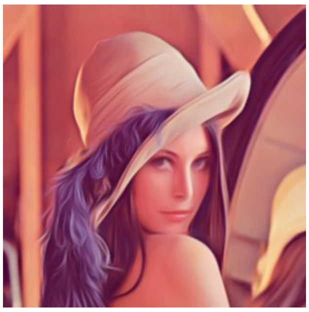

Fig.2 Image after anisotropic filter processing.

two main processes. The photographic image is first transformed by anisotropic filtering, and the resulting image is then transformed by the BF. The processing is essentially the same for red, green, and blue images of the colored image, and the watercolor-like image is obtained by merging these three.

(1) Anisotropic Filter Processing

In the first process, the anisotropic filter imparts smoothing perpendicular to gradients rendered anisotropic by BF spatial weighting based on pixel-value gradients. It preserves the edges and generates enhanced striping. (For details on this process, see Reference 10)). The image in Fig.2, obtained by the anisotropic filtering of the 512*512 pixel 256-tone Lena image, illustrates its effective transformation to smooth, flowing images, as evident particularly in the hair and hat plume regions.

(2) Bilateral Filter Processing

In the second process, the absolute values of the color differences between the image obtained with the BF and the original image are determined, and coloring is then implemented in correspondence with these values. The procedure in the proposed method is as follows.

(1) For coordinates (i, j) in the color image obtained in the first process, $d^{(t)}_{R,i,j}$, $d^{(t)}_{G,i,j}$ and $d^{(t)}_{B,i,j}$ are the values of the red, green, and blue pixel values, respectively. The term $t(=0,1,2,\cdots)$ is the iteration number and $d^{(0)}_{R,i,j}$, $d^{(0)}_{G,i,j}$ and $d^{(0)}_{B,i,j}$ are the initial iteration values of the pixels in the color image obtained in the first process. In this paper, we describe the red image pixel processing, which is essentially the same for the green and blue images.

Compute the pixel value $d^{(t+1)}_{R,i,j}$ by using the BF as

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

where α and β are positive constants. Parameter α regulates the effect of the distance from coordinates (i, j), so that the influence of pixels at a given distance decreases with increasing values α. Parameter β regulates the effect of the absolute value of the difference from the pixel value $d^{(t)}_{R,i,j}$ at coordinates (i, j), so that the influence of a given pixel having a substantial difference in the absolute value decreases with increasing values of β. The value of w, representing the window size, was set at $w=10$ throughout the following experiments.

The term $d^{(T)}_{R,i,j}$ represents the pixel value in the image obtained by T iterations of the BF.

(2) For each pixel in the image, determine $\left|d^{(T)}_{R,i,j} - d^{(0)}_{R,i,j}\right|$ and denote it as $f_{R,i,j}$. With the minimum and maximum values of $f_{R,i,j}$, denoted as min_R and max_R respectively, transform $f_{R,i,j}$ to $g_{R,i,j}$ and thus to the pixel values of a 255-tone image having values from 0 to 255 by

$$g_{R,i,j} = 255\left(1 - \frac{g_{R,i,j} - min_R}{max_R - min_R}\right) \quad (2)$$

(3) Merge images $g_{R,i,j}$, $g_{G,i,j}$ and $g_{B,i,j}$ to obtain the watercolor-like image.

3. EXPERIMENTS

We first applied the proposed method to the 512*512 pixel 255-tone Lena image and assessed the variations induced in the generated watercolor-like image by changes in the process parameters. We next applied the method to several other 512*512 pixel 255-tone images and assessed the watercolor-like images generated.

(1) Effect of Parameters on the Lena Image

We first assessed the variation in the watercolor-like images created by changing the number of BF iterations T with values of 0.01 for

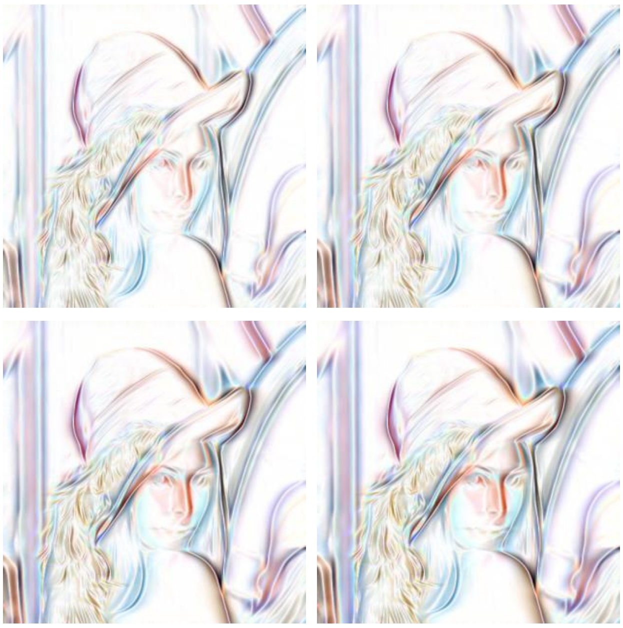

Fig.3 Variation in water color-like images with iteration.
（$T = 10,20,30,40$）

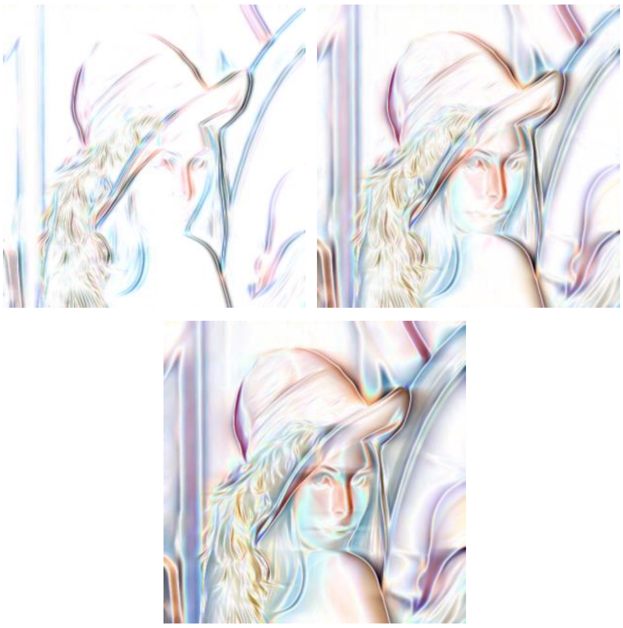

Fig.5 Variation in water color-like images with β.
（$\alpha = 0.01$, $\beta = 0.1, 0.01, 0.001$）

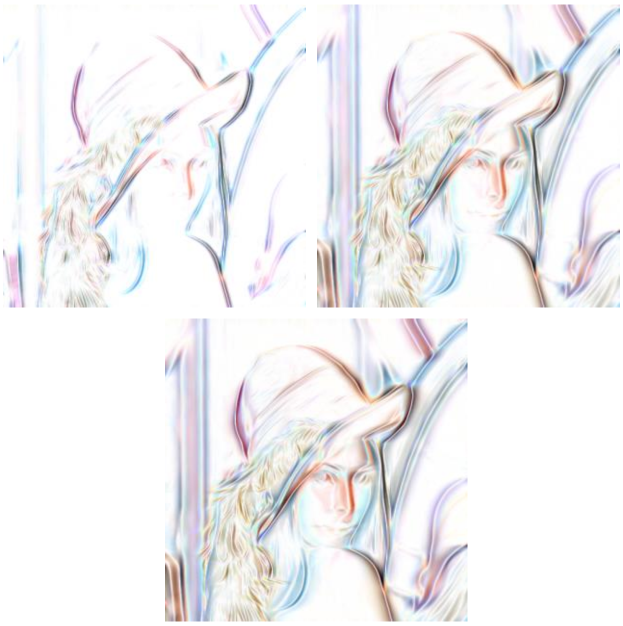

Fig.4 Variation in water color-like images with β.
（$\alpha = 0.1$, $\beta = 0.1, 0.01, 0.001$）

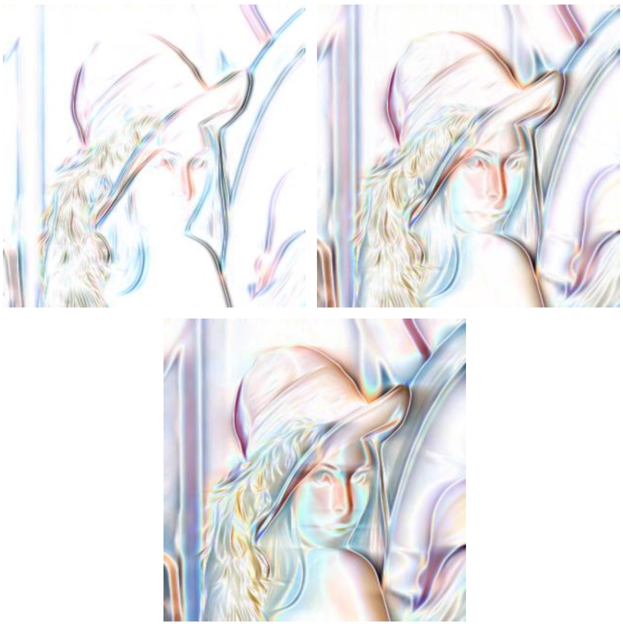

Fig.6 Variation in water color-like images with β.
（$\alpha = 0.001$, $\beta = 0.1, 0.01, 0.001$）

α and 0.01 for β in all cases. Fig.3 shows the results for $T = 10$, 20, 30, and 40 in the upper left, upper right, lower left, and lower right panels, respectively. The generated images show that increasing the value of T deepens the colors in the watercolor-like image and increases the colored regions. The results indicate that approximately 30 iterations (thus, $T = 30$) is appropriate, though the number also depends on the photographic image to be transformed.

We next varied the values of α and β with the T set at 30 in all cases and assessed the variation in the generated watercolor-like images. The results for α at 0.1, 0.01, and 0.001 are shown

Fig.7 Water color-like images (Airplane).

Fig.8 Water color-like images (Mandrill).

Fig.9 Water color-like images (Pepper).

Fig.10 Water color-like images (Sailboat).

in Fig.4 to Fig.6, respectively. In each of these three figures, the upper left, upper right, and lower panels show the images obtained for β at 0.1, 0.01, and 0.001, respectively. Taken together, these images show that the colors are deepened and the colored regions are increased by lowering the values of α and β. The results indicate that values of 0.01 to 0.001 are appropriate for both α and β.

(2) Assessment with Other Images

We next applied the proposed method to four other mages for $\alpha = 0.01$, $\beta = 0.01$, and $T = 30$. The results are shown in Fig.7 to Fig.10. In each of these three figures, the left panel shows the input image and the right panel shows the generated watercolor-like image. In all three cases, the watercolor-like image is characterized by enhanced strokes that appear to be drawn by brush together with the expression of blurring in pale tones. They also indicate that watercolor-like images generated by the proposed method convey a distinctive impression that is unlike those generated by other methods.

4. CONCLUSION

We proposed a method of generating watercolor-like images from photographic images by NPR with the incorporation of BF and described experiments that verified the effectiveness of the method. The first set of experiments, performed with the Lena image, showed the variations that can be created in the generated watercolor-like images by changing the BF parameter values. In the second set, the proposed method was applied to several other photographic images and confirmed the visual effects of the generated watercolor-like images.

The results show that the proposed method can create the enhanced brush strokes and paint blurring in pale tones that are characteristic expressions of watercolor painting, and that the generated images convey an impression that is different from those obtained by previously existing methods of watercolor-like image generation.

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