ICIC Express Letters
Volume **17**, Number **8**, August **2023**

ICIC International ©2023 ISSN 1881-803X
pp. **857–863**

GENERATION OF WIDTH-CHANGING RIPPLE IMAGES USING REGION-DIVIDED SMOOTHING FILTER

Toru Hiraoka and Jia-Lin Zhang

Division of Computer Science
Graduate School of Regional Design and Creation
University of Nagasaki
1-1-1, Manabino, Nagayo-chou, Nishisonogi-gun, Nagasaki-ken 851-2195, Japan
{ hiraoka; mc221002 }@sun.ac.jp

Received December 2022; accepted February 2023

Abstract. *A non-photorealistic rendering method for automatically generating ripple images from photographic images using region-division smoothing filter has been proposed. Ripple patterns are composed of continuous lines with fluctuations, and ripple images are expressed by superimposing ripple patterns on photographic images. The conventional method has the features that the width of ripple patterns is constant. Therefore, the visual effect of ripple images is improved by changing the width of ripple patterns according to the change in the pixel values of photographic images. To change the width of ripple patterns, we proposed a method for making the window size variable in the conventional method. The image generated by our method is referred to as width-changing ripple image. To verify the effectiveness of our method, we applied our method to various photographic images and visually evaluated the appearance of those width-changing ripple images. Additionally, we investigate the changes in width-changing ripple images by changing the values of the parameters in our method.*

Keywords: Non-photorealistic rendering, Ripple pattern, Smoothing filter, Changing width, Automatic generation

1. **Introduction.**

The technology for generating photorealistic CG (Computer Graphics) [1] images is called photorealistic rendering, while the technology for generating non-photorealistic CG images is called NPR (Non-Photorealistic Rendering). NPR imitates human art expressions [2, 3] such as paintings and illustrations, and has computer-specific expressions [4, 5] such as moire-like images and reaction-diffusion-pattern-like images. In this paper, we focus on ripple images [6, 7, 8], which are NPR of computer-specific expressions. Ripple patterns are composed of continuous lines with fluctuations, and ripple images are expressed by superimposing ripple patterns on photographic images. The conventional method [6] is executed by an iterative process with intensity gradient and can generate vertical and horizontal ripple patterns. The conventional method [7] is executed by an iterative process with two smoothing filters using different regions in the window (hereinafter referred to as region-divided smoothing filter) and can generate ripple patterns in any orientation. The conventional method [8] is executed by an iterative process using inverse filter [9] and circular-sector-type smoothing filter and can generate ripple patterns in any orientation. However, ripple images generated by the conventional method [6, 7, 8] have the disadvantage of low preservation of photographic images because the width of ripple patterns is constant over the entire image. To improve the visual effect of ripple images, a method of extending the conventional method [7] to generate ripple patterns in two orientations has been proposed [10].

In this paper, we propose a method to improve the visual effect of ripple images by changing the width of ripple patterns. Hereinafter, the image generated by our method

DOI: 10.24507/icicel.17.08.857

is referred to as width-changing ripple image. Our method is executed by changing the window size in the conventional method [7] according to the pixel values of photographic images. To verify the effectiveness of our method, experiments are conducted using various photographic images, and it is clarified that the width of ripple patterns can be changed according to the pixel values.

The rest of this paper is organized as follows. Section 2 describes our method for generating width-changing ripple images. Section 3 shows experimental results and reveals the effectiveness of our method. Finally, Section 4 concludes this paper.

2. **Our Method.**

Our method is executed in three steps. In Step 1, the window sizes are determined according to the position in photographic images. In Step 2, region-divided smoothing filter with the window sizes obtained in Step 1 is applied. In Step 3, photographic images are converted using the values obtained in Step 2. By repeating Steps 2 and 3, width-changing ripple images are generated. A flow chart of our method is shown in Figure 1.

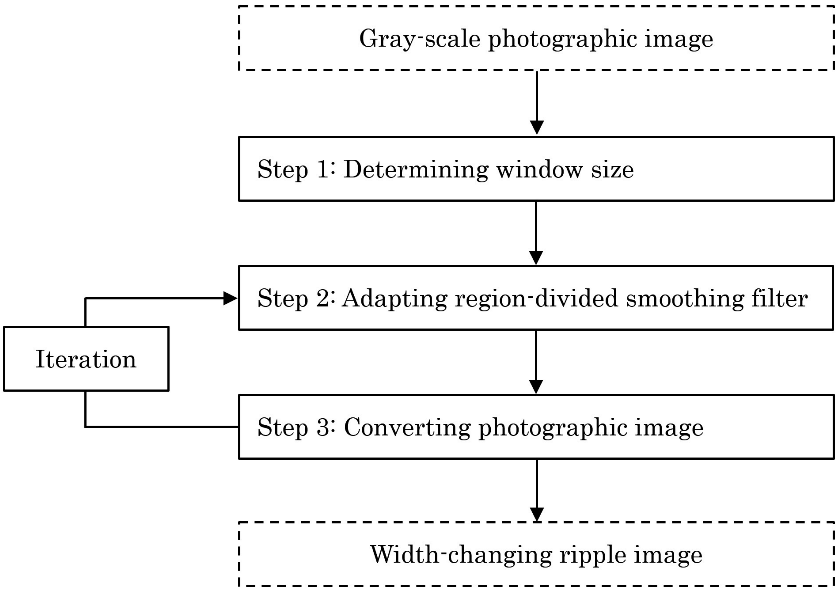

Gray-scale photographic image
Step 1: Determining window size
Step 2: Adapting region-divided smoothing filter
Iteration
Step 3: Converting photographic image
Width-changing ripple image

Figure 1. Flow chart of our method

The detailed procedure in Figure 1 is shown as follows.

Step 0: The input pixel values for spatial coordinates (i, j) of a gray-scale photographic image are defined as $g_{i,j}$, where $i = 1, 2, \ldots, I$ and $j = 1, 2, \ldots, J$. The pixel values $g_{i,j}$ have value of U gradations from 0 to $U - 1$. Two window sizes for determining the width of ripple patterns are defined as W_1 and W_2, where $W_1 < W_2$.

Step 1: The pixel values $f_{i,j}$ obtained by applying smoothing filter to the gray-scale photographic image are calculated as the following equation.

$$f_{i,j} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} g_{k,l}}{(2W+1)^2} \tag{1}$$

where k and l are the positions in the window and $W = [(W_1 + W_2)/2]$, where $[\,]$ represents an operation for rounding to the nearest whole number. The average $a_{i,j}$ of the pixel values $f_{i,j}$ in the window are calculated as the following equation.

$$a_{i,j} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} f_{k,l}}{(2W+1)^2} \tag{2}$$

The variances $v_{i,j}$ of the pixel values $f_{i,j}$ in the window are calculated as the following equation.

$$v_{i,j} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} (f_{k,l} - a_{i,j})^2}{(2W+1)^2} \tag{3}$$

The variances $v_{i,j}$ are sorted in descending order, and the sorted orders of the variances $v_{i,j}$ are $s_{i,j}$. The window sizes $W_{i,j}$ at spatial coordinates (i, j) are calculated as the following equation.

$$W_{i,j} = W_1 + \left\lfloor \frac{s_{i,j}(W_2 - W_1 + 1)}{IJ} \right\rfloor \tag{4}$$

where $\lfloor\ \rfloor$ represents a decimal point truncation operator.

Step 2: The pixel values of the image at the t-th iteration number are defined as $f_{i,j}^{(t)}$, where $f_{i,j}^{(1)} = f_{i,j}$. The image $f_{i,j}^{(t)}$ is smoothed using two different regions in the window of $W_{i,j}$ pixels. Smoothing is calculated as the average of the pixel values included in each region. The two regions shown in Figure 2 are windows separated by a straight line with a slope of θ radian passing through the center of the window. The pixels on the straight line are included in the two regions. The pixel values of the two smoothed images are defined as $s_{1,i,j}^{(t)}$ and $s_{2,i,j}^{(t)}$, respectively. The differences $d_{i,j}^{(t)}$ between the pixel values of the smoothed images $s_{1,i,j}^{(t)}$ and $s_{2,i,j}^{(t)}$ is calculated as the following equation.

$$d_{i,j}^{(t)} = s_{2,i,j}^{(t)} - s_{1,i,j}^{(t)} \tag{5}$$

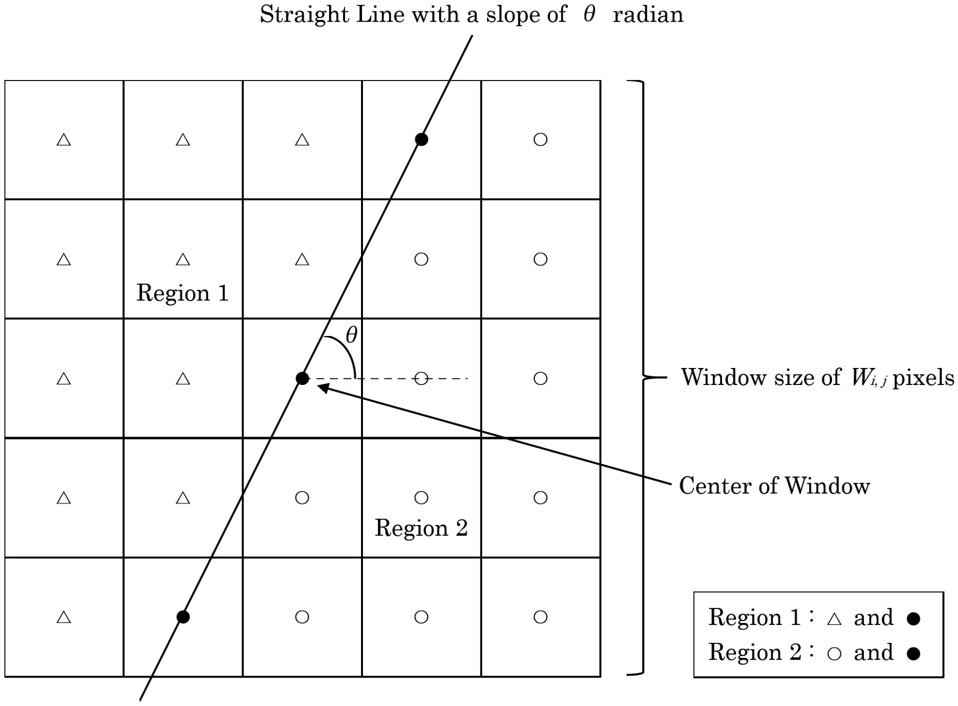

Straight Line with a slope of θ radian
Region 1
θ
Window size of $W_{i,j}$ pixels
Center of Window
Region 2
Region 1 : △ and ●
Region 2 : ○ and ●

FIGURE 2. Conceptual diagram of two regions in the window

Step 3: The differences $d_{i,j}^{(t)}$ are added to the pixel values $g_{i,j}$ of the photographic image, and the pixel values $f_{i,j}^{(t)}$ are updated to $f_{i,j}^{(t+1)}$ as the following equation.

$$f_{i,j}^{(t+1)} = g_{i,j} + d_{i,j}^{(t)} \tag{6}$$

In case $f_{i,j}^{(t+1)}$ is less than 0, then $f_{i,j}^{(t+1)}$ must be set to 0. In case $f_{i,j}^{(t+1)}$ is greater than 255, then $f_{i,j}^{(t+1)}$ must be set to 255. A width-changing ripple image is obtained after Steps 2 and 3 of T times iteration.

3. Experiments.

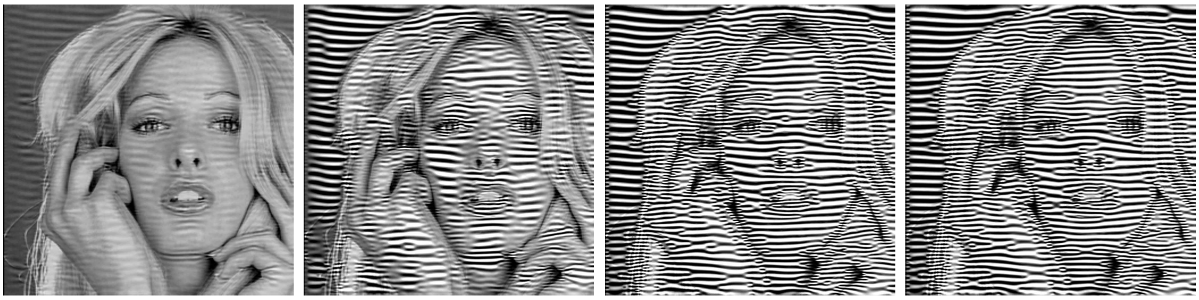
We mainly conducted two experiments. First, the experiment with changing the values of the parameters in our method was conducted using Woman image shown in Figure 3. Second, the experiment with various photographic images shown in Figure 4 was conducted. All photographic images used in the experiments are $1024 * 1024$ pixels and 256 gradations.

FIGURE 3. Woman image

FIGURE 4. Various photographic images

3.1. Experiment with changing parameters.

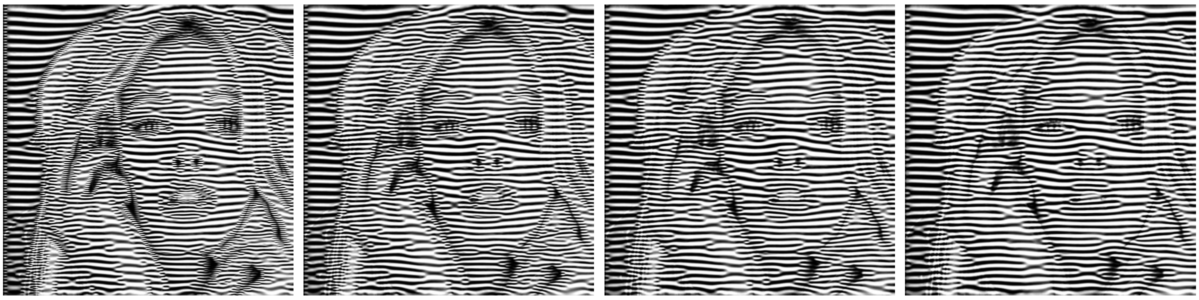
Width-changing ripple images by changing the iteration number T were visually confirmed using Woman image. The iteration number T was set to 10, 20, 50, and 100. Other parameters W_1, W_2, and θ were set to 3, 11, and 0, respectively. The results of the experiment are shown in Figure 5. As the value of the iteration number T was larger, width-changing ripple patterns became clear and converged.



(a) $T = 10$ (b) $T = 20$ (c) $T = 50$ (d) $T = 100$

FIGURE 5. Width-changing ripple images in the case of the iteration number $T = 10$, 20, 50, and 100

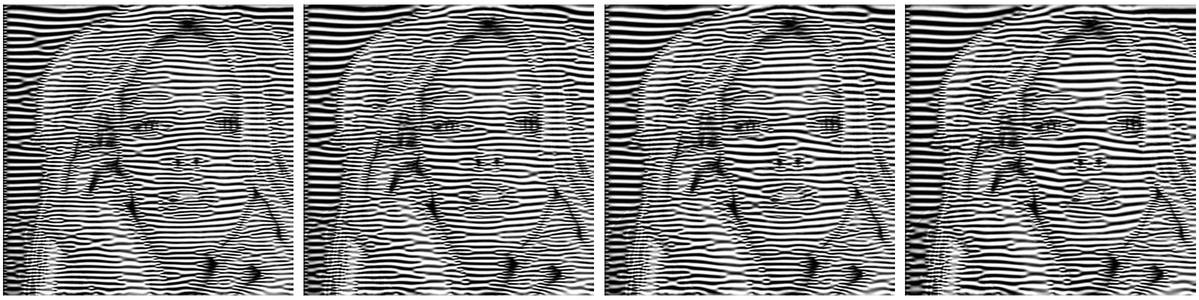
Width-changing ripple images by changing the window size W_1 were visually confirmed using Woman image. The window size W_1 was set to 2, 3, 4, and 5. Other parameters T, W_2, and θ were set to 100, 11, and 0, respectively. The results of the experiment are shown in Figure 6. As the value of the window size W_1 was smaller, the width of ripple patterns in the region where the change of pixel values was large became narrower.



(a) $W_1 = 2$ (b) $W_1 = 3$ (c) $W_1 = 4$ (d) $W_1 = 5$

FIGURE 6. Width-changing ripple images in the case of the window size $W_1 = 2$, 3, 4, and 5

Width-changing ripple images by changing the window size W_2 were visually confirmed using Woman image. The window size W_2 was set to 9, 10, 11, and 12. Other parameters T, W_1, and θ were set to 100, 3, and 0, respectively. The results of the experiment are shown in Figure 7. As the value of the window size W_2 was larger, the width of ripple patterns in the region where the change of pixel values was small became wider.



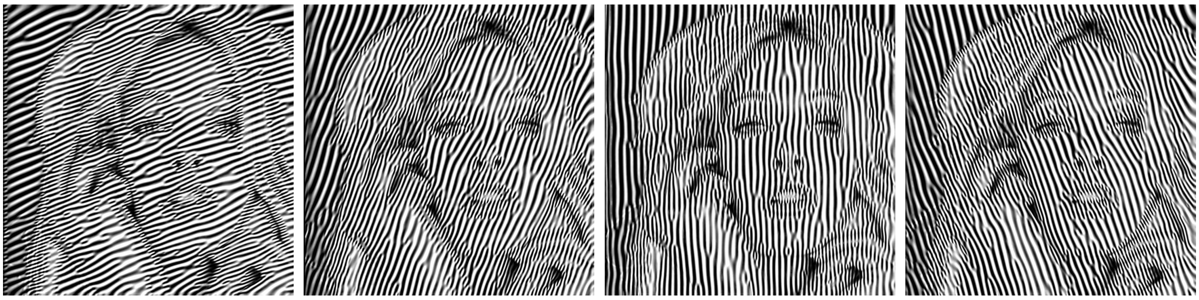
(a) $W_2 = 9$ (b) $W_2 = 10$ (c) $W_2 = 11$ (d) $W_2 = 12$

FIGURE 7. Width-changing ripple images in the case of the window size $W_2 = 9$, 10, 11, and 12

Width-changing ripple images by changing the orientation θ were visually confirmed using Woman image. The orientation θ was set to $(1/6)\pi$, $(1/3)\pi$, $(1/2)\pi$, and $(2/3)\pi$. Other parameters T, W_1, and W_2 were set to 100, 3, and 11, respectively. The results of the experiment are shown in Figure 8. Depending on the value of the orientation θ, the orientation of width-changing ripple patterns was changing.

3.2. **Experiment using various photographic images.** Our method was applied to four photographic images shown in Figure 4. The parameters T, W_1, W_2, and θ were set to 100, 3, 11, and 0, respectively. The results of the experiment are shown in Figure 9. In all cases, our method can automatically generate width-changing ripple patterns on the whole image. In other words, width-changing ripple patterns were expressed finely in the areas such as the edges of photographic images where the pixel values changed greatly, and were expressed larger in the areas where the pixel values changed little.

The average of the absolute differences in pixel values between the photographic images and the ripple image (hereinafter referred to as average difference) was calculated. The



(a) $\theta = (1/6)\pi$ (b) $\theta = (1/3)\pi$ (c) $\theta = (1/2)\pi$ (d) $\theta = (2/3)\pi$

Figure 8. Width-changing ripple images in the case of the orientation $\theta = (1/6)\pi$, $(1/3)\pi$, $(1/2)\pi$, and $(2/3)\pi$

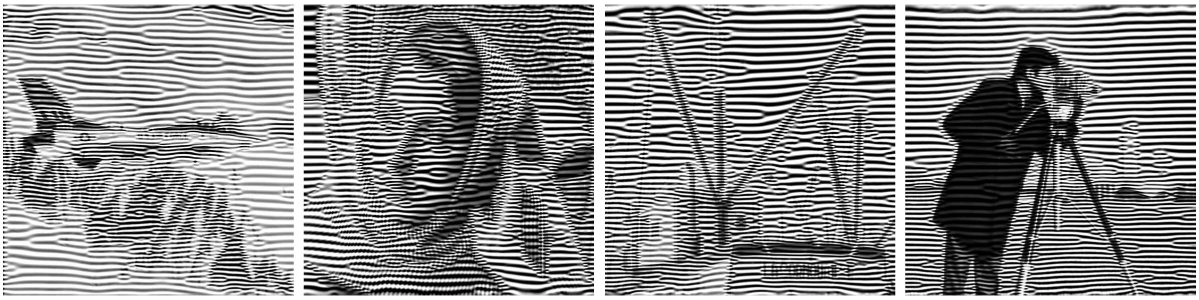


Figure 9. Various width-changing ripple images

smaller the average difference is, the better the preservation of the photographic image is evaluated in the ripple image. The average differences of four width-changing ripple images in Figure 9 generated by our method were 64.813, 79.058, 87.387, and 73.778 from the left. On the other hand, the average differences of four ripple images generated by the conventional method [7] from photographic images in Figure 4 were 71.981, 88.258, 94.131, and 78.358 from left to right. At this time, the window size of the conventional method [7] was set to 7, which is an intermediate value between the window sizes W_1 and W_2 of our method used to generate ripple images in Figure 9. Since our method has these smaller average differences than the conventional method [7], it is a good possibility that our method can generate ripple images with higher photographic image preservation than the conventional method [7].

Width-changing ripple images can be used on SNS (Social Networking Service) and web pages. More specifically, width-changing ripple images can be used as profile icons on SNS or as backgrounds on web pages. Furthermore, it is also possible to use width-changing ripple images as print designs on T-shirts.

4. Conclusions.

We proposed a non-photorealistic rendering method for generating width-changing ripple images from photographic images. Our method was executed by an iterative process with region-divided smoothing filter with changing the window size according to the pixel values of photographic images. To verify the effectiveness of our method, experiments were conducted using Woman image and other photographic images. As a result of the experiments, it was clarified that our method can change the width of ripple patterns according to the pixel values.

A subject for future study is to expand our method for application to color photographic images and videos.

Acknowledgment. This work was supported by JSPS KAKENHI Grant Number JP23K 11727 and The Telecommunications Advancement Foundation Grant.

REFERENCES

[1] H. Jeong, Y. Yi and D. Kim, An innovative e-commerce platform incorporating metaverse to live commerce, *International Journal of Innovative Computing, Information and Control*, vol.18, no.1, pp.221-229, 2022.

[2] P. Haeberli, Paint by numbers: Abstract image representations, *ACM SIGGRAPH Computer Graphics*, vol.24, no.4, pp.207-214, 1990.

[3] J. Lansdown and S. Schofield, Expressive rendering: A review of nonphotorealistic techniques, *IEEE Computer Graphics and Applications*, vol.15, no.3, pp.29-37, 1995.

[4] T. Hiraoka and K. Urahama, Generation of moire-picture-like color images by bilateral filter, *IEICE Transactions on Information and Systems*, vol.E96-D, no.8, pp.1862-1866, 2013.

[5] A. Werth, Turing patterns in Photoshop, *Proceedings of Bridges 2015: Mathematics, Music, Art, Architecture, Culture*, pp.459-462, 2015.

[6] T. Hiraoka, Generation of ripple images using intensity gradient, *ICIC Express Letters*, vol.13, no.2, pp.1097-1101, 2019.

[7] T. Hiraoka, Generation of ripple images by smoothing filters using different regions, *Transactions of the Institute of Systems, Control and Information Engineers*, vol.33, no.4, pp.105-109, 2019.

[8] T. Hiraoka, Generation of arbitrarily-oriented ripple images using circular-sector-type smoothing filter and inverse filter, *Journal of Robotics, Networking and Artificial Life*, vol.6, no.4, pp.213-216, 2020.

[9] Z. Yu and K. Urahama, Iterative method for inverse nonlinear image processing, *IEICE Transactions on Fundamentals*, vol.E97-A, no.2, pp.719-721, 2014.

[10] T. Hiraoka, Generation of two-oriented ripple images by two smoothing filters using different regions in window, *ICIC Express Letters*, vol.15, no.2, pp.149-155, 2021.