ICIC Express Letters
Volume **18**, Number **3**, March **2024**
ICIC International ©2024 ISSN 1881-803X
pp. **235–239**

HIGH QUALITY METHOD FOR STRIPE-PATCHWORK IMAGES GENERATED USING SMOOTHING AND INVERSE FILTERS

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Received May 2023; accepted July 2023

Abstract. *A non-photorealistic rendering method has been proposed for automatically generating stripe-patchwork images from photographic images using smoothing and inverse filters. However, the conventional method cannot generate stripe-patchwork patterns in white areas of photographic images. Therefore, we extend the conventional method to generate stripe-patchwork patterns in white areas of photographic images. This improvement improves the quality of stripe-patchwork images. Our method generates stripe-patchwork patterns by expanding the range of the pixel value in the process of the conventional method. To verify the effectiveness of our method, we conducted experiments using several photographic images with the white areas. As a result of the experiments, it was found that our method can generate stripe-patchwork patterns in the white areas of photographic images.*
Keywords: Non-photorealistic rendering, Stripe-patchwork image, High quality, Smoothing filter, Inverse filter, Automatic generation

1. **Introduction.** Non-photorealistic rendering (NPR) [1, 2, 3, 4, 5, 6, 7, 8] is a general term for computer graphics technology [9, 10] that generates non-realistic images. NPR is used to emphasize a part of the scene or change the expression of the scene through the intervention of the user, instead of communicating the scene as it is like a photograph. NPR has the advantage of being able to execute process semi-automatically or automatically.

We focus on stripe-patchwork images [11, 12, 13, 14], which are automatically generated using NPR. Stripe-patchwork images are non-realistic images that imitate stripe patchwork and locally cause changes that resemble stripe-patchwork patterns in accordance with the shading and edges in photographic images. Previous NPR researches have proposed methods for generating stripe-patchwork images from photographic images. The conventional methods [11, 12, 13] are executed by the following processes: [11] uses k-means clustering and inverse filter [15], [12] uses entropy and inverse filter, and [13] uses smoothing and inverse filters. The conventional methods [11, 12] have the disadvantage of long processing time, but the conventional method [13] has significantly reduced the processing time. The conventional method [14] extends the conventional method [13] to improve the preservation of the brightness of photographic images in stripe-patchwork images. However, the conventional methods [11, 12, 13, 14] cannot generate stripe-patchwork patterns in white areas of photographic images as shown in the yellow ellipses in Figure 1. Since the overall visual uniformity is important in NPR, adding non-realistic patterns to areas where non-realistic patterns cannot be generated can enhance the uniformity of

DOI: 10.24507/icicel.18.03.235

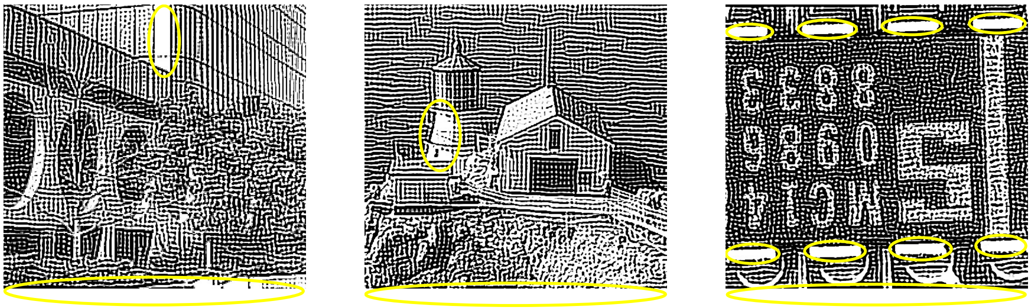


FIGURE 1. Stripe-patchwork images generated by the conventional method [13]

the entire non-photorealistic image. Therefore, a method is needed to generate stripe-patchwork patterns even in the white areas to improve the quality of stripe-patchwork images.

We focus on the conventional method [13] that can process at high speed, and improve it so that stripe-patchwork patterns can be generated even in the white areas of photographic images. Our method generates stripe-patchwork patterns by expanding the range of the pixel value in the process of the conventional method. To verify the effectiveness of our method, we conducted an experiment using several photographic images with the white areas. Additionally, we also conducted an experiment to visually confirm stripe-patchwork patterns generated by changing the value of the newly added parameter in our method.

This paper is organized as follows: the second section describes our method for generating stripe-patchwork patterns in the white areas of photographic images, the third section shows experimental results and reveals the effectiveness of our method, and the conclusion of this paper is given in the fourth section.

2. **Our Method.** Our method is implemented in three steps: Step 1 is the process using smoothing filter, which blurs the images, Step 2 is the process using inverse filter that expands the pixel value range, which attempts to restore the blurred images to the images before blurring, and Step 3 is the process using inverse filter within the pixel value range of photographic images. The difference between Step 2 and Step 3 is the range of the pixel values that the processed image can take, and Step 2 has a wider range of the pixel values than Step 3. Here, Step 1 and Step 2 are repeatedly processed. In the iterative calculation, the restoration errors are accumulated to generate stripe-patchwork patterns. The difference between our method and the conventional method is that the pixel value range in Step 2 is expanded. A flow chart of our method is shown in Figure 2.

Details of the steps in Figure 2 are explained below.

Step 0: The pixel values on coordinates (i, j) of a gray-scale photographic image are defined as $f_{i,j}$ $(i = 1, 2, \ldots, I;\ j = 1, 2, \ldots, J)$. The pixel values $f_{i,j}$ have value of U gradation from 0 to $U - 1$. The pixel values of the image at the t-th iteration number are defined as $f_{i,j}^{(t)}$, where $f_{i,j}^{(0)} = f_{i,j}$.

Step 1: The pixel values $f_{i,j}^{(t-1)}$ are smoothed to the pixel values $SM\left(f_{i,j}^{(t-1)}\right)$ as

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

where W is the window size, and k and l are the positions in the window.

Step 2: The pixel values $f_{i,j}^{(t)}$ using inverse filtering are computed as

$$f_{i,j}^{(t)} = f_{i,j}^{(t-1)} - SM\left(f_{i,j}^{(t-1)}\right) + f_{i,j} \tag{2}$$

The pixel values $f_{i,j}^{(t)}$ must be set to $-D$ if the pixel values $f_{i,j}^{(t)}$ are less than $-D$, and the pixel values $f_{i,j}^{(t)}$ must be set to $U+D-1$ if the pixel values $f_{i,j}^{(t)}$ are greater than $U+D-1$, where D is a positive constant.

Step 3: The pixel values after repeating Steps 1 and 2 T times are $g_{i,j}$. The pixel values $g_{i,j}$ must be set to 0 if the pixel values $g_{i,j}$ are less than 0, and the pixel values $g_{i,j}$ must be set to $U-1$ if the pixel values $g_{i,j}$ are greater than $U-1$. An image composed of pixel values $g_{i,j}$ is a stripe-patchwork image.

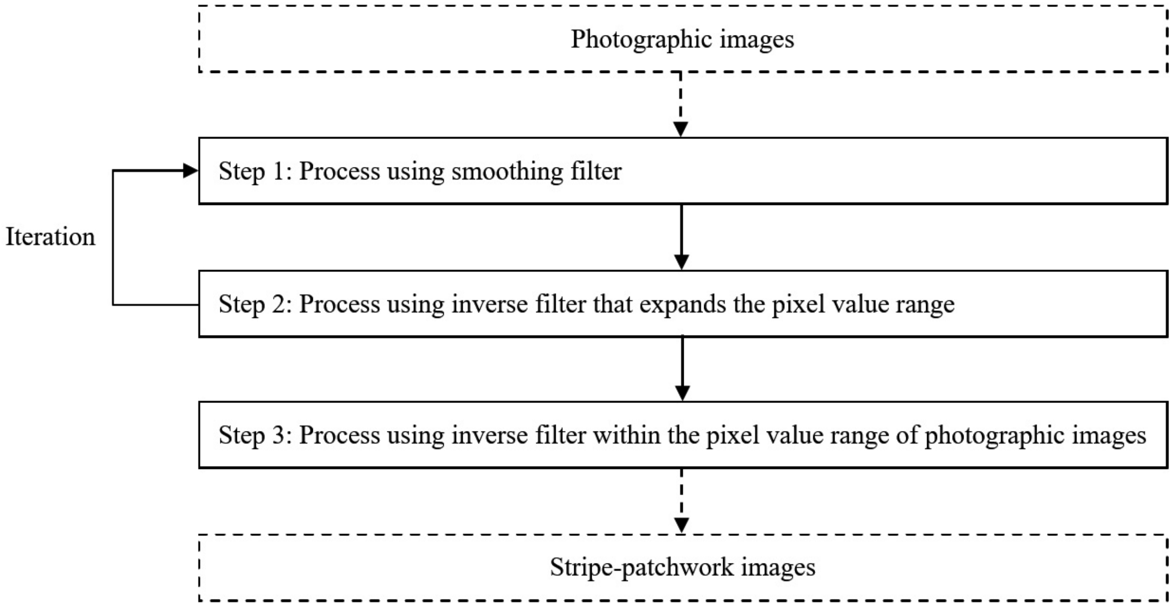


Figure 2. Flow chart of our method

3. **Experiments.** We conducted two experiments: the first experiment applied our method to three photographic images with white areas shown in Figure 3, and the second experiment was conducted to visually confirm stripe-patchwork patterns generated by changing the value of the newly added parameter D in our method. All photographic images used in the experiments were $512*512$ pixels and 256 gradations. With reference to [13], the values of the parameters W and T were set to 5 and 40, respectively. In the experiments in [13], as the value of the window size W was larger, the interval of stripe-patchwork patterns increased. In our experiments, the value of W was set to 5 to facilitate the visual recognition of stripe-patchwork patterns and to better recall photographic images. And, as the value of the iterative number T was larger, stripe-patchwork patterns became clearer and converged at about 40 times.

Our method was applied to three photographic images with the white areas shown in Figure 3. The value of the parameter D was set to 100. The results of the experiment

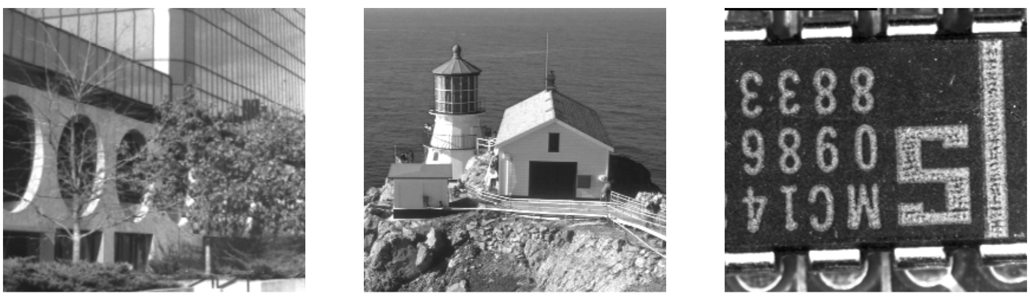


Figure 3. Photographic images

are shown in Figure 4. Comparing stripe-patchwork images generated by our method (see Figure 4) with stripe-patchwork images generated by the conventional method (see Figure 1), it was found that our method can generate stripe-patchwork patterns even in the white areas that could not be generated by the conventional method. Additionally, it was found that our method can generate clearer stripe-patchwork patterns even in areas with fine textures than the conventional method (see the trees in the leftmost photographic images of Figure 1 and Figure 4). Furthermore, it was found that stripe-patchwork patterns of our method and the conventional method did not differ significantly except for the white areas and the areas with fine textures.

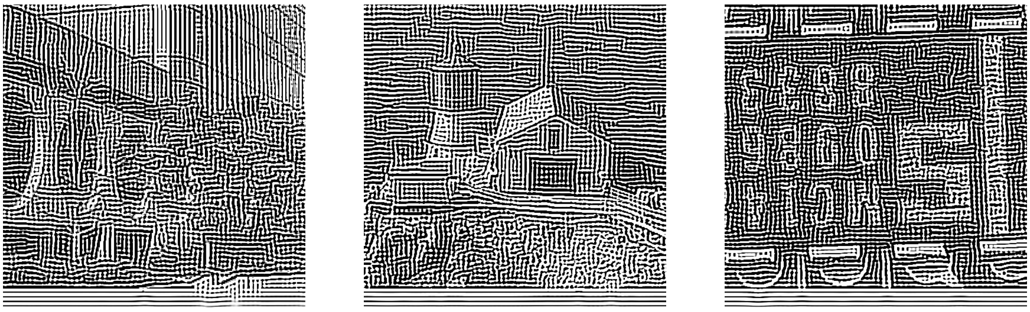
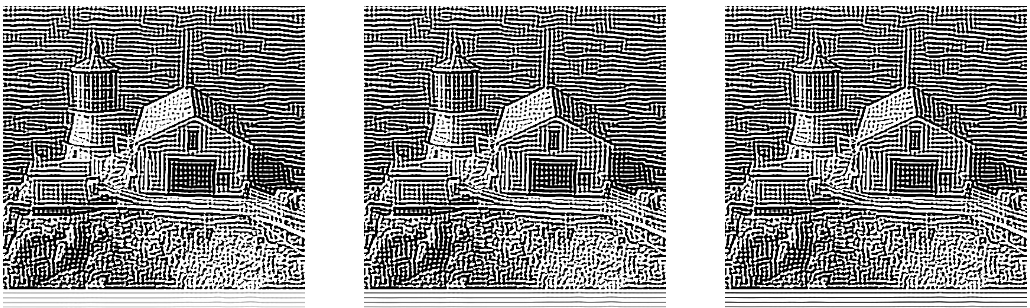
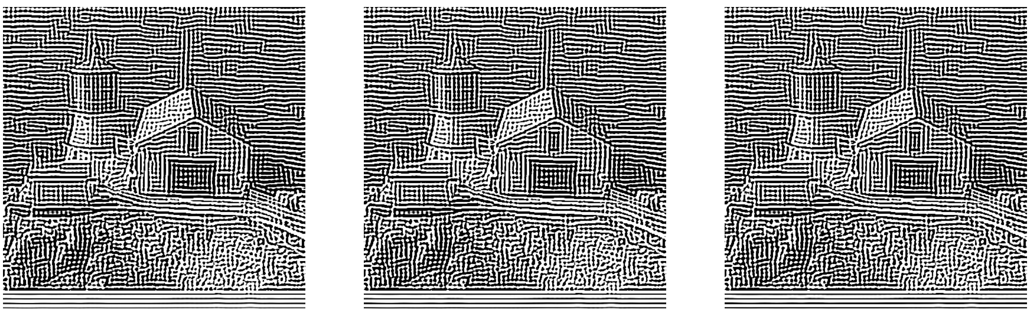


Figure 4. Stripe-patchwork images generated by our method

Stripe-patchwork images generated by changing the value of the newly added parameter D were confirmed visually using the photographic image in the middle of Figure 3. The value of D was set to 20, 40, 60, 80, 100, and 120. The results of the experiment are shown in Figure 5. Focusing on the white areas of stripe-patchwork images in Figure 5, it was found that as the value of D increased, stripe-patchwork patterns were expressed darker and more linearly in the white areas. Additionally, it was found that when the value of D was around 100, the darkness of stripe-patchwork patterns converged.



(a) $D = 20$ (b) $D = 40$ (c) $D = 60$



(d) $D = 80$ (e) $D = 100$ (f) $D = 120$

Figure 5. Stripe-patchwork images generated by our method

4. **Conclusions.** We extended the conventional method to automatically generate stripe-patchwork patterns in white areas of photographic images. Our method generated stripe-patchwork patterns by expanding the range of the pixel value in the process of the conventional method. To verify the effectiveness of our method, we conducted an experiment using three photographic images with the white areas. Additionally, we also conducted an experiment to visually confirm stripe-patchwork patterns generated by changing the value of the newly added parameter in our method. As a result of the experiments, it was found that our method can generate stripe-patchwork patterns even in the white areas of photographic images. Additionally, it was found that stripe-patchwork patterns were expressed darker as the value of the newly added parameter increased.

A subject for future study is to expand our method for application to color photographic images, videos, and three-dimensional data.

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

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