ICIC Express Letters
Volume **15**, Number **7**, July **2021**

pp. **719–724**

GENERATION OF EDGE-PRESERVING THERMOGRAPHIC IMAGES USING INVERSE FILTER AND SMOOTHING FILTER WITH SWAPPING BETWEEN RGB

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Received November 2020; accepted February 2021

Abstract. *We propose a non-photorealistic rendering method for generating edge-preserving thermographic (EPT) images from photographic images. EPT images are images that express the temperature difference obtained by thermography in color, and are images that the color changes along the edges of photographic images. The proposed method is implemented by an iterative calculation using inverse filter and smoothing filter with swapping between RGB, and can generate different EPT images according to the iteration number. In order to verify the effectiveness of the proposed method, we perform experiments using various photographic images and visually confirm EPT images generated according to the iteration number. We also experiment with changing the window size in the proposed method, and visually confirm the change in the generated EPT patterns.*
Keywords: Non-photorealistic rendering, Thermography, Edge preservation, Swapping between RGB, Inverse filter, Smoothing filter

1. **Introduction.** In resent years, mobile terminals equipped with cameras, such as smartphones and tablets, have become widespread, making it easy to take pictures. In addition, photographic images can be easily uploaded to social networking service (SNS) and websites, and be viewed and downloaded by unspecified number of people. However, from the viewpoints of personal information protection, copyright protection, and information security, there are cases that it is not desirable to specify a person, a product, a signboard, and a place from photographic images on SNS and websites. Then, photographic images are blurred or mosaiced. If photographic images can be converted in an artistic expression, it is thought that the value of use in SNS and websites will be improved.

The technique of converting photographic images into non-realistic images using image processing [1, 2] and computer graphics [3] are called non-photorealistic rendering (NPR), and NPR methods for generating a variety of non-realistic images have been proposed [4, 5, 6, 7]. In recent years, researches of NPR incorporating textures of the natural world and the human society have been performed [8, 9, 10, 11]. Reaction-diffusion patterns [8], which are used to depict the skin patterns of diverse animals, are generated using the mathematical model used in biology. Cell-like images [9] are generated using inverse iris filter, labyrinth images [10] are generated using inverse Laplacian filter, and moire-like images [11] are generated using bilateral filter and unsharp mask.

In this paper, focusing on the NPRs of the human society, we propose a method for generating thermographic images from photographic images. Thermographic images are images that express the temperature difference obtained by thermography in color. Furthermore, the proposed method can generate thermographic patterns along the edges

DOI: 10.24507/icicel.15.07.719

of photographic images. Therefore, thermographic images generated by the proposed method will be referred to as edge-preserving thermographic (EPT) images. The proposed method is implemented by an iterative calculation using inverse filter [12, 13] and smoothing filter with swapping between RGB. Since the proposed method can generate different EPT images according to the iteration number, the user can select from multiple EPT images according to his/her preference and intended use. In order to verify the effectiveness of the proposed method, we performed experiments using various photographic images and visually confirmed EPT images generated according to the iteration number. We also experimented with changing the window size in the proposed method, and visually confirmed the change in the generated EPT patterns. As a result of the experiment, it was found that as the iteration number increases, the number of EPT patterns increases along the edges. It was also found that the larger the window size, the larger the interval between EPT patterns.

This paper is organized as follows: the second section describes the proposed method for generating EPT images from photographic images, the third section shows experimental results and reveals the effectiveness of the proposed method, and the conclusion of this paper is given in the fourth section.

2. **Proposed Method.** The proposed method is executed in two processes. In the first process, the values between RGB are swapped, and then images are generated by smoothing filer. In the second process, the images smoothed after swapping between RGB are restored using inverse filter. By repeating the two processes, EPT images are generated. Inverse filter is a filter that restores an image converted by a certain process, but the restored image includes an error in some cases. The proposed method generates EPT images by emphasizing the restoration error. A flow chart of the proposed method is shown in Figure 1.

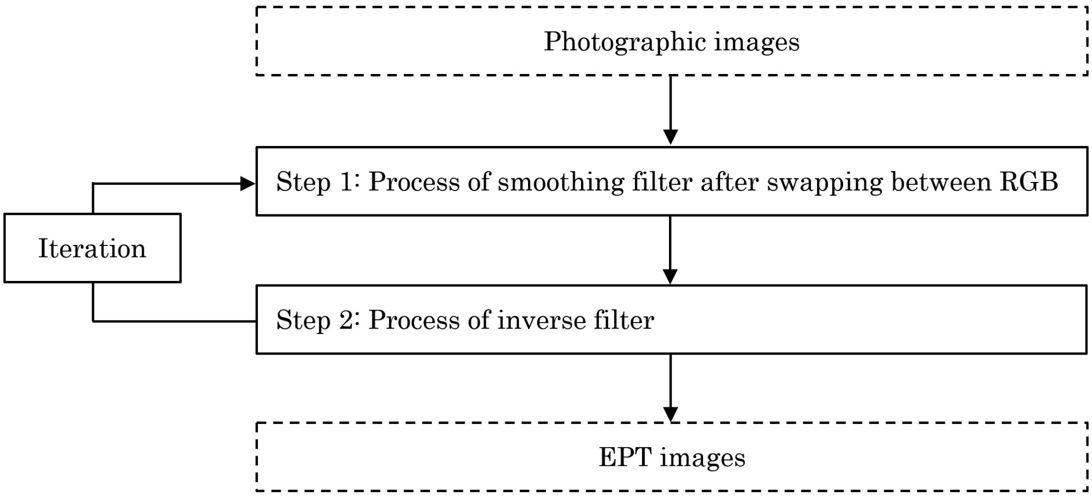


FIGURE 1. Flow chart of the proposed method

Details of the procedure in Figure 1 are explained below.

Step 0: The input pixel values (R, G, B) for spatial coordinates (i, j) of a photographic image are defined as $f_{R,i,j}$, $f_{G,i,j}$, and $f_{B,i,j}$, respectively. The pixel values $f_{R,i,j}$, $f_{G,i,j}$, and $f_{B,i,j}$ have value of U gradation from 0 to $U-1$. Then, the pixel values of the image at the t-th iteration number are defined as $f^{(t)}_{R,i,j}$, $f^{(t)}_{G,i,j}$, and $f^{(t)}_{B,i,j}$, where $f^{(0)}_{R,i,j} = f_{R,i,j}$, $f^{(0)}_{G,i,j} = f_{G,i,j}$, and $f^{(0)}_{B,i,j} = f_{B,i,j}$.

Step 1: The output pixel values $g^{(t)}_{R,i,j}$, $g^{(t)}_{G,i,j}$, and $g^{(t)}_{B,i,j}$ are calculated by smoothing filter with swapping between RGB as follows:

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

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

$$g_{B,i,j}^{(t)} = \frac{\sum_{k=i-W}^{i+W} \sum_{l=j-W}^{j+W} f_{R,k,l}^{(t-1)}}{(2W+1)^2} \quad (3)$$

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

Step 2: The pixel values $f_{R,i,j}^{(t)}$, $f_{G,i,j}^{(t)}$, and $f_{B,i,j}^{(t)}$ using inverse filtering are calculated as follows:

$$f_{R,i,j}^{(t)} = f_{R,i,j}^{(t-1)} - g_{R,i,j}^{(t)} + g_{R,i,j}^{(t)} \quad (4)$$

$$f_{G,i,j}^{(t)} = f_{G,i,j}^{(t-1)} - g_{G,i,j}^{(t)} + g_{G,i,j}^{(t)} \quad (5)$$

$$f_{B,i,j}^{(t)} = f_{B,i,j}^{(t-1)} - g_{B,i,j}^{(t)} + g_{B,i,j}^{(t)} \quad (6)$$

In case $f_{R,i,j}^{(t)}$, $f_{G,i,j}^{(t)}$, and $f_{B,i,j}^{(t)}$ are less than 0, then $f_{R,i,j}^{(t)}$, $f_{G,i,j}^{(t)}$, and $f_{B,i,j}^{(t)}$ must be set to 0, respectively. In case $f_{R,i,j}^{(t)}$, $f_{G,i,j}^{(t)}$, and $f_{B,i,j}^{(t)}$ are greater than $U-1$, then $f_{R,i,j}^{(t)}$, $f_{G,i,j}^{(t)}$, and $f_{B,i,j}^{(t)}$ must be set to $U-1$, respectively.

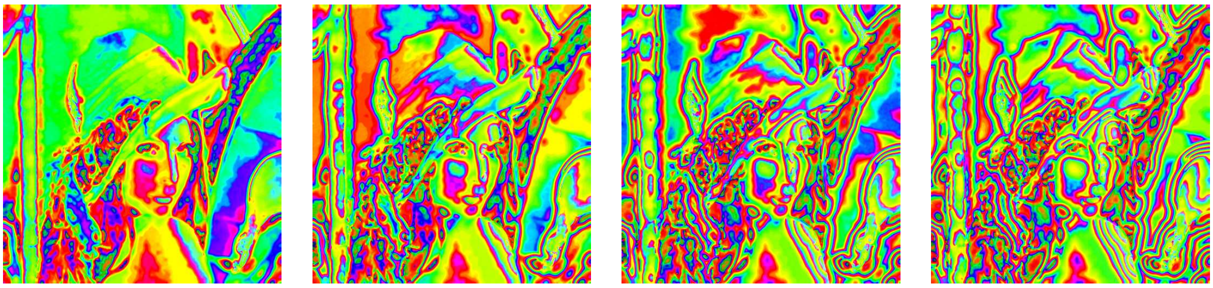
The processes of Steps 1 and 2 are repeated T times, and then an image composed of the pixel values $g_{R,i,j}^{(T)}$, $g_{G,i,j}^{(T)}$, and $g_{B,i,j}^{(T)}$ is the EPT image.

3. **Experiments.** We mainly conducted two experiments. First, the experiment with changing the values of the parameters in the proposed method was conducted using Lenna image shown in Figure 2. Second, the experiment to apply the proposed method to various photographic images shown in Figure 3 was conducted. All photographic images used in the experiments were $512 * 512$ pixels and 256 gradation. The computing environment for all experiments was a Windows 10 Enterprise 2016 LTSB operating system on a computer with a 3.20 GHz CPU and a 8.00 GB of memory. The programming language used in all experiments was VC++.

FIGURE 2. Lenna image

FIGURE 3. Various photographic images

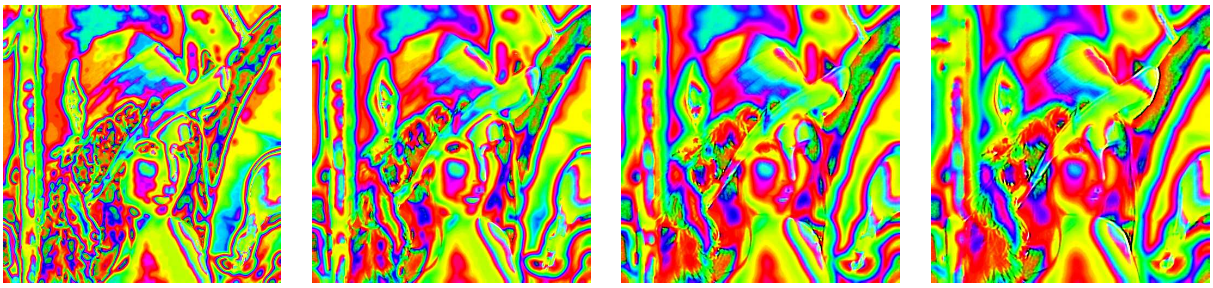
3.1. **Experiment with changing parameters.** EPT images by changing the iteration number T were visually confirmed using Lenna image. The iteration number T was set to 50, 100, 150, and 200. The window size W was set to 1. The EPT images generated under the above conditions are shown in Figure 4. As the iteration number T increased, the number of EPT patterns increased along the edges. On the other hand, as the iteration number T increased, it became difficult to recognize Lenna image. In actual use, the user may select a favorite EPT image from a plurality of EPT images according to the intended use.



(a) $T = 50$ (b) $T = 100$ (c) $T = 150$ (d) $T = 200$

FIGURE 4. EPT images in the case of the iteration number $T = 50$, 100, 150, and 200

EPT images by changing the window size W were visually confirmed using Lenna image. The window size W was set to 1, 2, 3, and 4. The iteration number T was set to 100. The EPT images generated under the above conditions are shown in Figure 5. The larger the window size, the larger the interval between EPT patterns and the smoother the shape of EPT patterns. The user may select a desired EPT image according to the intended use.



(a) $W = 1$ (b) $W = 2$ (c) $W = 3$ (d) $W = 4$

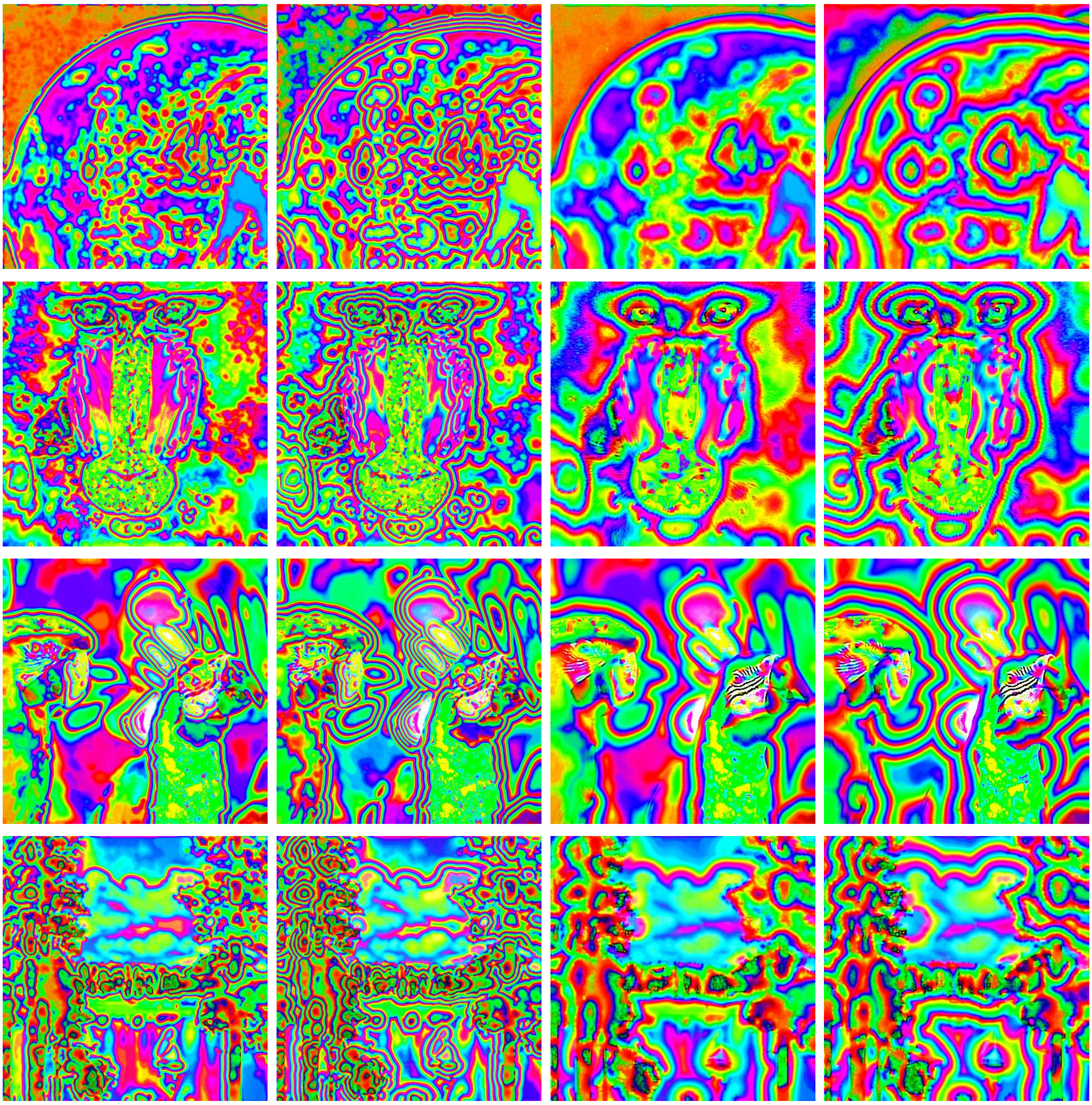
FIGURE 5. EPT images in the case of the window size $W = 1$, 2, 3, and 4

For reference, the calculation time of the proposed method was measured using Lenna image. The iteration number T was set to 50, 100, 150, or 200, and the window size W was set to 1, 2, 3, or 4. The results of the experiment are shown in Table 1. Real-time processing is difficult, but it is a calculation time that can be used in actual use.

TABLE 1. Calculation time of the proposed method [second]

	$W = 1$	$W = 2$	$W = 3$	$W = 4$
$T = 50$	1.768	3.595	6.313	10.502
$T = 100$	3.547	7.080	12.626	21.004
$T = 150$	5.360	10.596	18.987	31.146
$T = 200$	7.173	14.112	25.488	41.272

3.2. **Experiment using various photographic images.** The proposed method was applied to four photographic images shown in Figure 3. The iteration number T was set to 100 or 200, and the window size W was set to 1 or 3. The EPT images generated under the above conditions are shown in Figure 6. All EPT images were represented in color, similar to thermographic temperature images, and could change color along the edges of photographic images.



(a) $T = 100$, $W = 1$ (b) $T = 200$, $W = 1$ (c) $T = 100$, $W = 3$ (d) $T = 200$, $W = 3$

FIGURE 6. Various EPT images

4. **Conclusions.** We proposed an NPR method for generating EPT images from photographic images. The proposed method was implemented by an iterative calculation using inverse filter and smoothing filter with swapping between RGB. Through experiments using Lenna image and other photographic images, it was confirmed that EPT images can be represented in color, similar to thermographic temperature images. It was also confirmed that the number of EPT patterns along the edges and the interval between EPT patterns can be adjusted by changing the iteration number and the window size, respectively.

A subject for future study is to expand the proposed method for application to videos and three dimensional data.

Acknowledgment. This work was supported by JSPS KAKENHI Grant Number JP19K 12664.

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