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GENERATION OF STARDUST-LIKE IMAGES USING CIRCULAR SLOPE FILTER

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Abstract. *The purpose of this paper is to develop a novel non-photorealistic rendering (NPR) that generates non-realistic images using computer graphics technology. We propose an NPR method for automatically generating stardust-like (SL) images from photographic images. SL images express patterns that stars are scattered in the night sky on photographic images, and are easy to recall photographic images by densely condensing SL patterns near the edges of photographic images. Our method is executed by iterative calculation using a new filter called circular slope filter. To verify the effectiveness of our method, we conducted an experiment to visually confirm SL images generated from several photographic images. In addition, we also conducted an experiment to visually examine how SL patterns generated by changing the values of the parameters in our method change. As a result of the experiments, it was found that our method can generate SL patterns that the stars were scattered in the night sky on photographic images, and can generate SL patterns near the edges of photographic images. In addition, it was found that the size of the dots in SL patterns and the brightness of the area other than SL patterns can be changed by changing the values of the parameters.*
Keywords: Non-photorealistic rendering, Stardust, Circular slope filter, Automatic generation

1. **Introduction.** The rendering method of computer graphics (CG) [1, 2] is mainly aimed at generating realistic CG images, and is called photorealistic rendering. Photorealistic rendering physically simulates the light that reaches the viewpoint. On the other hand, a rendering method that generates non-realistic CG images is called non-photorealistic rendering (NPR). NPR emphasizes important information, omits extra information, or adds other information. NPR includes simulations of existing drawing techniques such as oil paintings, pencil drawings and stippling [3, 4, 5] and expressions that incorporate patterns from the natural and human worlds such as leopard prints, mazes and oil films [6, 7, 8]. The quality of non-realistic CG images is not absolute and depends on the user's purpose and taste. Non-realistic CG images are often used as special effects on television, magazines and websites in recent years.

In this paper, we focus on NPR using the patterns in the natural world and propose a method for automatically generating stardust-like (SL) images from photographic images. SL images express patterns that stars are scattered in the night sky on photographic images, and are easy to recall photographic images by densely condensing SL patterns near the edges of photographic images. To generate SL images, we develop an unprecedented

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filter called circular slope filter. Circular slope filter calculates the averages of the pixel values included at regular intervals centering on the target pixel and call it the circular averages, and then calculates the average of the absolute values of the slopes between the circular averages. By executing circular slope filter multiple times, SL patterns are gradually generated. Filters close to circular slope filter, circular-sector-type smoothing filter [9] and cosine-wave-weight smoothing filter [10] have been proposed. Circular-sector-type smoothing filter calculates an average of pixels in circular sector, and ripple images are generated by using circular-sector-type smoothing filter and inverse filter [11]. Cosine-wave-weight smoothing filter converts the pixel value by weighing the cosine wave according to the distance from the target pixel, and fingerprint-pattern images are generated. An experiment with various photographic images has visually confirmed that SL images can be generated. In addition, through an experiment that changing the values of the parameters in our method was changed, the changes in the generated SL patterns were visually confirmed.

The rest of this paper is organized as follows. Section 2 describes our method for generating SL 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 largely executed in two steps. In the first step, SL patterns are generated from a photographic image by the iterative calculation using circular slope filter. In the second step, an SL image is created by converting the shade of the image after processing in the first step. A flow chart of our method is shown in Figure 1.

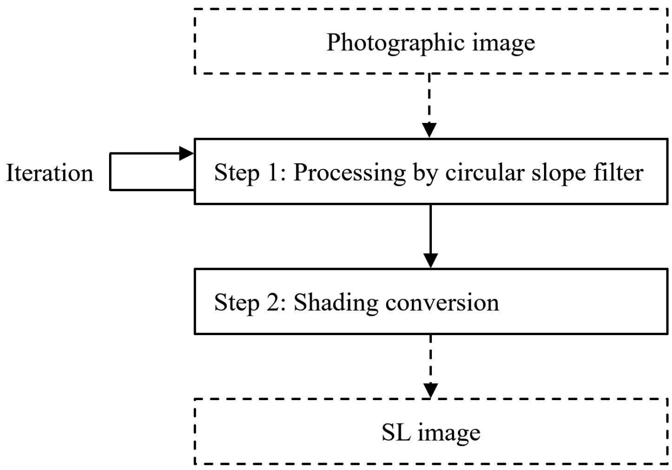

FIGURE 1. Flow chart of our method

Details of the steps in Figure 1 are explained below.

Step 0: Let $f_{i,j}$ be the input pixel values on coordinates (i, j) of a gray-scale photographic image. The pixel values $f_{i,j}$ have value of U gradation from 0 to $U - 1$.

Step 1: Let $f_{i,j}^{(t)}$ be the pixel values obtained at the t-th time by the iterative calculation using circular slope filter, where $f_{i,j}^{(0)} = f_{i,j}$. Let $a_{i,j,k}^{(t-1)}$ be the averages of the pixel values included in the range where distance from the target pixel (i, j) is greater than k and less than or equal to $k + 1$, where k is a natural number greater than or equal to 1 and less than or equal to K, and $a_{i,j,0}^{(t-1)} = f_{i,j}^{(t-1)}$. Let $s_{i,j}^{(t-1)}$ be the averages of the absolute values of the slopes between adjacent k. That is, $s_{i,j}^{(t-1)}$ are calculated as follows.

$$s_{i,j}^{(t-1)} = \frac{\sum_{k=1}^{K} \left| a_{i,j,k}^{(t-1)} - a_{i,j,k-1}^{(t-1)} \right|}{K} \tag{1}$$

The pixel values $f_{i,j}^{(t)}$ are calculated using $s_{i,j}^{(t-1)}$ as follows.

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

If $f_{i,j}^{(t)}$ is greater than $U-1$, then $f_{i,j}^{(t)}$ must be set to $U-1$. Step 1 is repeated T times.

Step 2: Since the image becomes brighter by process of Step 1, now darken the image. The pixel values $o_{i,j}$ after converting the shade of the image after processing in Step 1 are calculated as follows.

$$o_{i,j} = (U-1)\left(\frac{f_{i,j}^{(t)}}{U-1}\right)^{\alpha} \tag{3}$$

where α is a positive constant. The larger the value of α, the darker the image. An image composed of pixel values $o_{i,j}$ is an SL image.

3. **Experiments.** We conducted two experiments. In the first experiment, we visually confirmed SL patterns by changing the values of the parameters in our method using Woman image shown in Figure 2. In the second experiment, we applied our method to five photographic images shown in Figure 3. All photographic images used in the experiments were $512 * 512$ pixels and 256 gradation.

FIGURE 2. Woman image

FIGURE 3. Photographic images

3.1. **Experiment with changing parameters.** SL images generated by changing the values of the parameters T and K were confirmed visually using Woman image. The value of T was set to 5, 10, 15, 20 and 25, and the value of K was set to 1, 2, 3, 4 and 5. The value of α was set to 2.0. The results of the experiment are shown in Figure 4. As the value of T increased, SL patterns became clearer. If the value of T was too small, the number of points was small and it is difficult to visually recognize SL patterns, and if the value of T was too large, the number of points was large and it is difficult to recognize points individually. The larger the value of K, the larger the value of T was required to express SL patterns clearly. In addition, as the value of K increased, the size of the dots in SL patterns was expressed larger.

FIGURE 4. SL images when changing the values of T and K

The averages of the absolute values of the pixel value differences between 25 SL images in Figure 4 and Woman image (hereafter referred to as average error 1) were obtained. A smaller average error 1 means that SL image is closer to Woman image. The average error 1 is shown in Table 1. When the values of K are 1, 2, 3, 4 and 5, the minimum values of the average error 1 were 10, 15, 15, 15 and 15, respectively. Also, the averages of the values obtained by subtracting the pixel values of 25 SL images from 255 (hereafter referred to as average error 2) were obtained. The smaller the average error 2, the more SL patterns are expressed. The average error 2 is shown in Table 2. The larger the values of T and K, The larger the average error 2. From Figure 4, Table 1 and Table 2, we think that when the values of K are 1, 2, 3, 4 and 5, the values of T should be around 10, 15, 15, 15 and 15, respectively.

Table 1. Average error 1

	$T = 5$	$T = 10$	$T = 15$	$T = 20$	$T = 25$
$K = 1$	48.248	35.191	42.489	63.750	80.773
$K = 2$	50.100	39.489	34.157	59.211	91.154
$K = 3$	49.765	40.698	35.960	46.655	79.153
$K = 4$	49.453	40.748	36.448	39.759	54.832
$K = 5$	49.098	40.395	35.961	37.901	47.360

Table 2. Average error 2

	$T = 5$	$T = 10$	$T = 15$	$T = 20$	$T = 25$
$K = 1$	168.234	123.115	83.383	57.628	40.167
$K = 2$	169.845	148.261	108.759	63.077	29.771
$K = 3$	169.461	152.507	123.786	83.142	42.183
$K = 4$	169.276	154.599	133.073	104.755	71.867
$K = 5$	169.082	155.528	137.286	114.602	88.536

$\alpha = 1.0$ $\alpha = 1.5$ $\alpha = 2.0$ $\alpha = 2.5$ $\alpha = 3.0$

Figure 5. SL images when changing the value of α

SL images generated by changing the value of the parameter α were confirmed visually using Woman image. The value of α was set to 1.0, 1.5, 2.0, 2.5 and 3.0. The values of T and K were set to 20 and 4, respectively. The results of the experiment are shown in Figure 5. The larger the value of α, the darker the area other than SL patterns became and the more it became like a night sky.

3.2. **Experiment using various photographic images.** Our method was applied to five photographic images shown in Figure 3. Refer to the results in the previous section, the values of the parameters T, K and α were set to 20, 4 and 2.0, respectively. The results of the experiment are shown in Figure 6. Our method could express SL patterns that stars were scattered in the night sky on photographic images, could generate SL patterns near the edges of photographic images, and could express the dots of SL patterns in several sizes. If we dare to give non-realistic CG images that are close to SL images, there are sand-style images [12] that are studded with sand. However, SL images and sand-style images had distinctly different textures.

Figure 6. SL images

4. **Conclusions.** We proposed a new NPR method for automatically generating SL images from photographic images using circular slope filter. Through an experiment using various photographic images, it was found that our method can generate SL patterns that stars were scattered in the night sky on photographic images, and can generate SL patterns near the edges of photographic images. In addition, through an experiment that the values of the parameters in our method were changed, it was found that the number and size of the dots on SL patterns can be adjusted, and the darkness of the area other than SL patterns can be adjusted.

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

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