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SIMULATING TILT-SHIFT LENS USING DISTRIBUTED RAY TRACING

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ABSTRACT

In recent years, photographs and videos of actual scenery look like the miniature diorama have been gaining attention. This method of photography is involves the use of cameras equipped with a tilt-shift lens. In this study, we have reproduced the effect created by such a lens by integrating the mechanism of a tilt-shift lens into a distributed ray-tracing program. We were able to manipulate which portions of the scene fall into the region of sharp focus by simulating tilted lens. By using our method, we demonstrated to generate pan-focused images in which the entire scene is in focus and miniature-model images featuring greater blur than normal blur.

1. INTRODUCTION

Among computer-graphics camera models, a pinhole camera model is the simplest one. This model captures images whereby all objects are in focus. However, this model can not produce focal blur effects represented in images shot by an ordinary camera. The technique of generation of computer graphics images that include blur has been intensively studied. Additionally, the technique for generation of lens glare and flare effects in real-time has been examined.

To approximate computer graphics images to real images, a camera model equipped with a real lens must be used. In this context, we have focused our attention on a tilt-shift lens. This lens can control a range in focus of an image by tilting the lens. If we want to change the size and range of blur using conventional computer-graphics camera models, it was necessary to change the depth of field by changing the aperture of the lens. By using a tilt-shift lens, it is possible to change the size and range of blur without changing the depth of field. This study aims to reproduce the depth of field effect observed in a tilt-shift lens by using computer graphics.

2. RELATED WORKS

Potmesil et al.[1] proposed a method to create a blurred image in order to simulate the depth of field effect of a real lens. In their method, at first an image was created using a pinhole camera, and the image was post-processed to add blur. With this approach, the image used as reference has a single view point. Therefore, it is not possible to take occlusion into account. Cook[2] proposed the distributed ray tracing method in which it was possible to generate images that contain lens blur by tracing multiple light rays for a single pixel. Haeberli and Akeley[3] proposed a method in which the depth of field effect was expressed by creating and adding multiple images after setting multiple positions on the lens plane as view points. In these previous works, tilt lenses were not used.

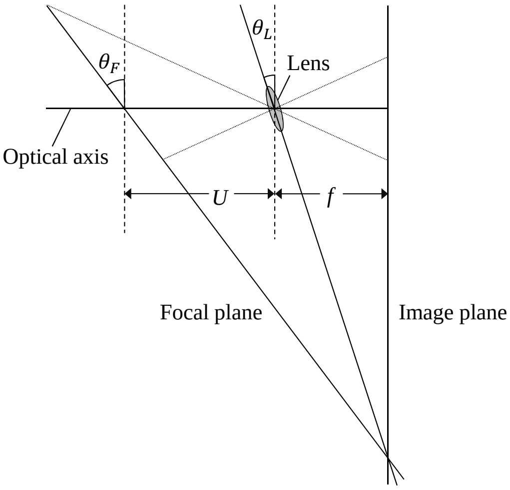


Figure 1: Camera model for tilt lens.

Held et al.[4] have studied the effect of images captured with a tilt-shift lens on the perception of size. In addition, Barsky and Pasztor[5] have proposed a method to create images containing a tilt-shift lens effect using OpenGL. However, a comparative evaluation of images taken with an actual tilt-shift lens and computer-graphics images has not been conducted. Furthermore the application of their works are limited because all pixels in the field of view must have finite focal distances.

3. SIMULATION OF THE DEPTH OF FIELD EFFECT IN TILT-SHIFT PHOTOGRAPHY

On a normal lens, the lens plane, the image plane, and the focal plane are all parallel to each other. On a tilt-shift lens, when the lens is tilted with respect to the image plane, the focal plane also tilts with respect to the image plane. The tilts of the lens and the focal plane are determined according to the Scheimpflug principle (Fig. 1). This principle states

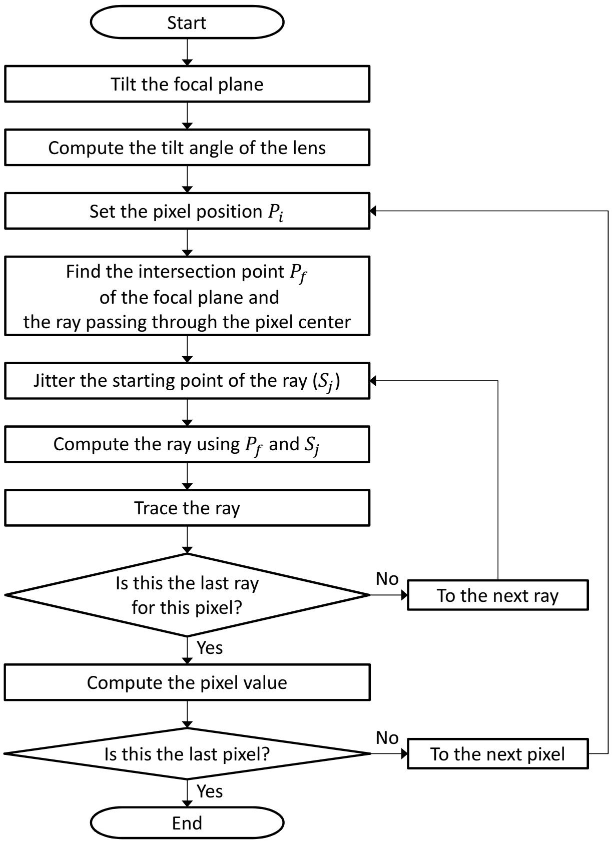


Figure 2: How to achieve the effect of tilting the lens using distributed ray tracing.

that the lens plane, the image plane, and the focal plane all intersect on the same line. As shown in Fig. 1, the angle formed between the focal plane and the vertical plane to the optical axis is denoted as θ_F. The distance from the center of the lens to the focal plane on the optical axis is denoted as U, and the distance from the center of the lens to the image plane on the optical axis, also known as the lens focal length, is denoted as f. According to the Scheimpflug principle, the tilt angle of the lens θ_L can be found using the following equation.

$$\theta_L = \tan^{-1}\left\{\frac{f \tan\theta_F}{U + f}\right\} \tag{1}$$

The tilt-shift lens effect can be reproduced by extending the source code of an existing open-source 3D renderer, namely the Persistence of Vision Raytracer (POV-Ray). It is possible to create the blur with the distributed ray tracing method. Fig 2. is the flowchart of the distributed ray tracing program integrated the function of tilting the lens and the focal plane. In our method, first, we find the intersection of the focal plane and the initial ray passing through the lens center. After that, rays are computed so as to pass through the intersection while jittering the starting point (Fig 3). In this way, the program produces the depth of field effect when the focal plane is tilted. We can compute rays even though the intersection point of the focal plane and the initial ray is behind the lens.

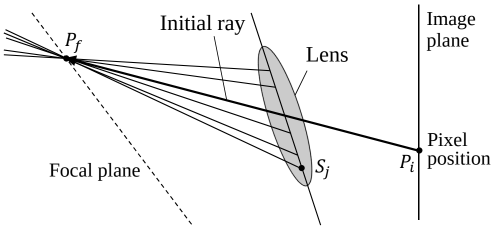
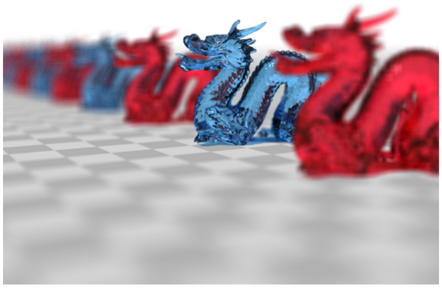
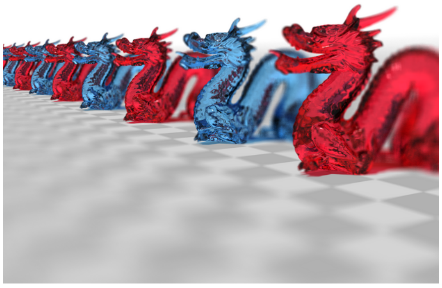


Figure 3: Determination of rays.



(a) Normal lens.



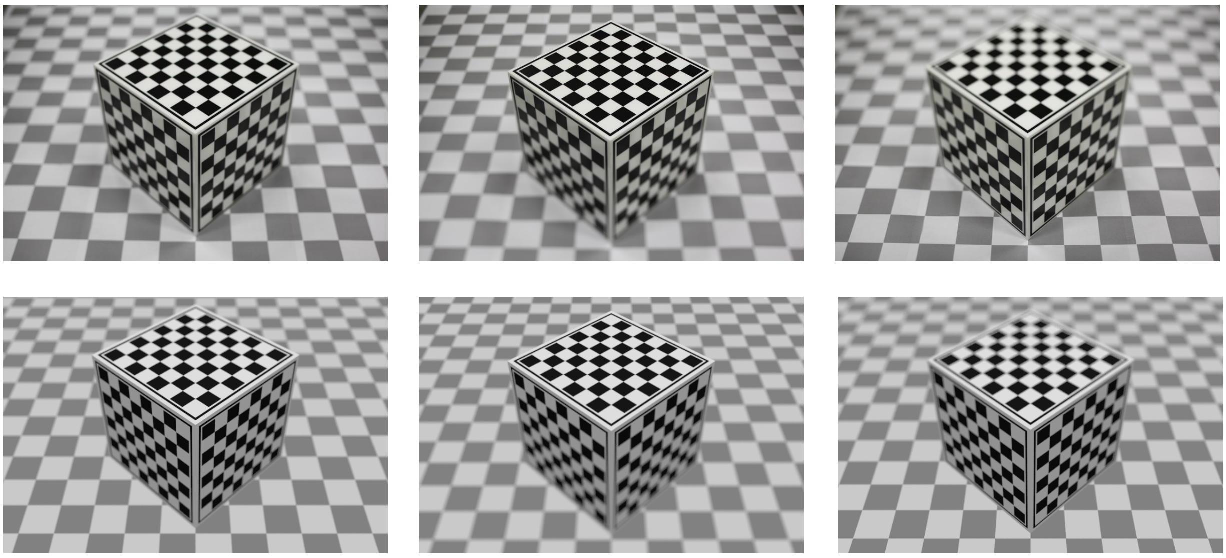
(b) Tilted lens.

Figure 4: Results of the tilt-shift lens effect.

4. SIMULATION RESULTS AND ANALYSIS

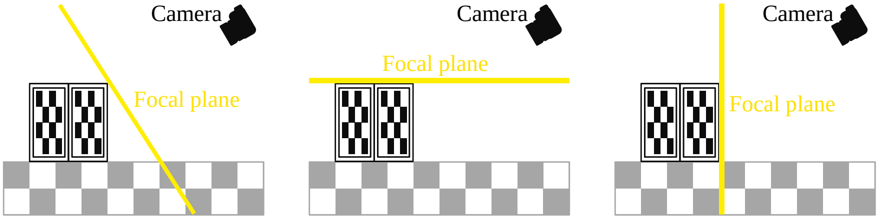
4.1. REPRODUCTION RESULTS OF A TILT-SHIFT LENS EFFECT

An image generated using a normal thin lens model is shown in Fig. 4 (a). As we can see, only one dragon is in focus. On the other hand, the image in Fig. 4 (b) was generated using our method. In contrast, all dragons are in focus in this image. We mention that it is possible to set the focal plane on any plane in our approach.



(a) Normal lens. (b) Tilted lens. (c) Reverse-tilted lens.

Figure 5: Photographed images and CG images.



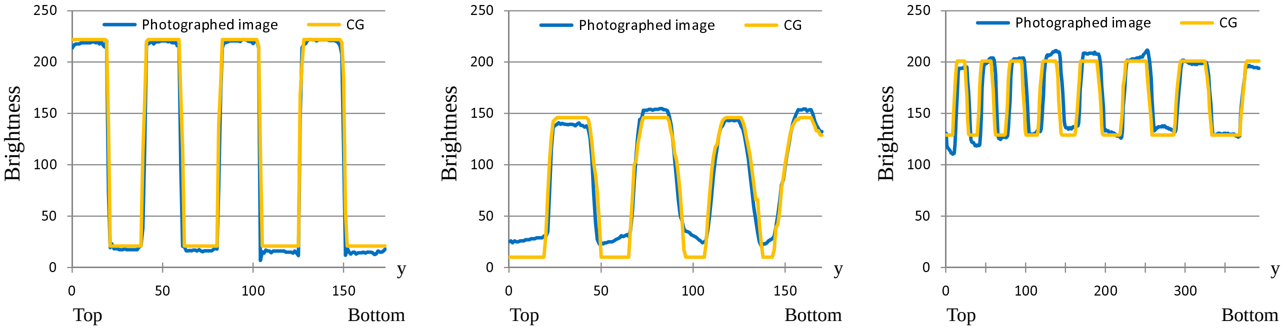
(a) Normal lens. (b) Tilted lens. (c) Reverse-tilted lens.

Figure 6: State of the focal planes.

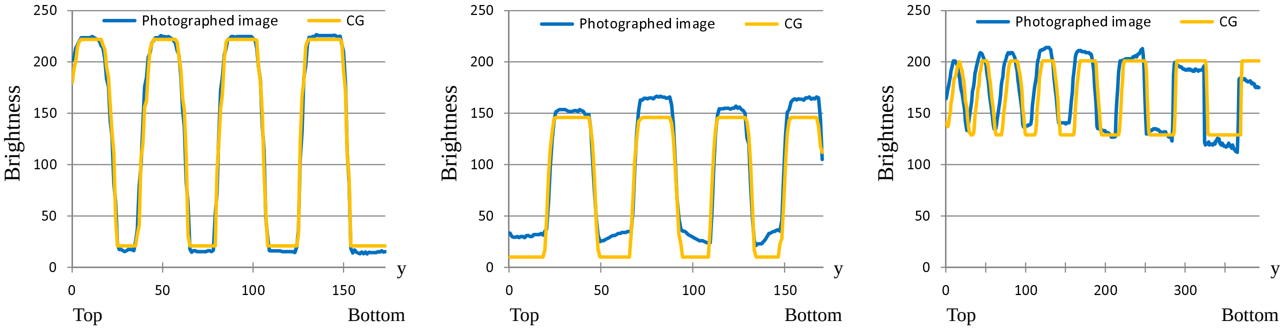
4.2. COMPARISON OF REAL PHOTOGRAPHS WITH COMPUTER-GRAPHICS IMAGES

We compared the images taken by a camera with a tilt-shift lens (the upper images in Fig. 5) and the images created by computer graphics (the lower images in Fig. 5). The scene setting including the camera, the checker board, the box, and the focal plane is shown in Fig. 6. The pictures in Fig. 5 (a) were taken or created by the lens in the normal state, as shown in Fig. 6 (a). In these images, the focal plane is parallel to the lens and image plane. The pictures in Fig. 5 (b) were taken or created by the tilted lens. In these images, the focal planes were set parallel to the floor, as shown Fig. 6 (b). The entire surface of the top of the box is in focus. The pictures in Fig. 5 (c) were taken or created by the tilted lens, but tilt directions of the lens are opposite to Fig. 5 (b). The focal planes were set so as to pass through the perpendicular edge of th box closest to the camera, as shown Fig. 6 (c).

For the comparison of photographed images and computer graphics images generated by our method, we graphed brightness profiles on some lines. As shown Fig. 7, lines were set on the upper and side plane of the box, and the floor plane. The first line is indicated by the red line, the second is green, the third is pink. The brightness profile of Fig. 5 (b) on the red line is shown in Fig. 8 (a), and same one on the green line is shown in Fig. 8 (b), and same one on the pink line is shown into Fig. 8 (c). Similarly, The brightness profile of Fig. 5 (c) on the red line is shown into Fig. 8 (d), and same one on the green line is shown into Fig. 8 (e), and same one on the pink line is shown into Fig. 8 (f). The average errors of brightness in each combination results are shown in Table 1. We consider that these errors were caused by the position error in the incomplete scene reproduction and inaccurate estimation of the lens aperture which determines the degree of blur.



(a) Fig.5 (b) on the red line. (b) Fig.5 (b) on the green line. (c) Fig.5 (b) on the pink line.



(d) Fig.5 (c) on the red line. (e) Fig.5 (c) on the green line. (f) Fig.5 (c) on the pink line.

Figure 8: Brightness profiles on each line.

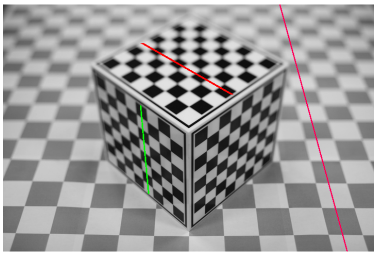


Figure 7: Lines used for brightness profiles.

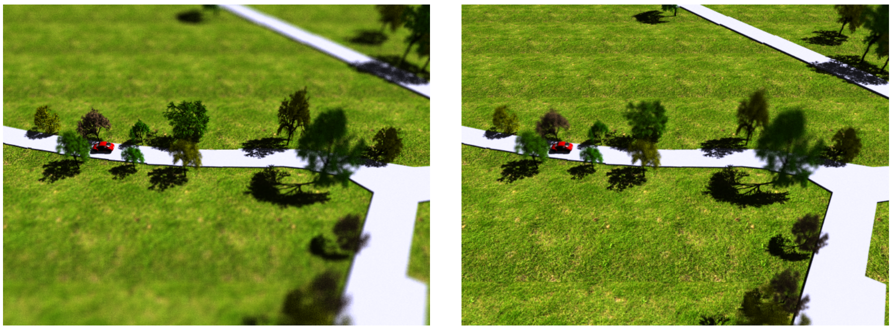
Table 1: Average errors.

	Red line	Green line	Pink line
Fig.5 (b)	6.45	10.5	11.3
Fig.5 (c)	5.67	13.7	16.1

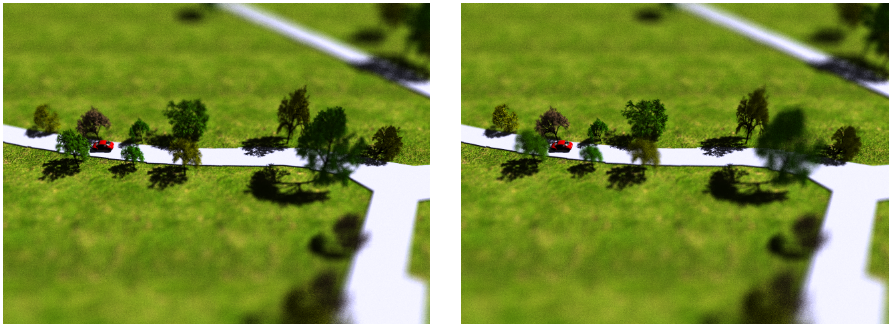
4.3. LANDSCAPE-STYLE SCENES

We have created a scene of landscape on computer graphics. In contrast to the previous subsection, we examine only the results obtained from the graphical simulation, because the scenes are too complex to set up the same situation in real world. Fig. 9 (a) was rendered with the lens in the normal state. Fig. 9 (b) was rendered with the tilted lens. In this image, the focal plane was set parallel to the ground. The entire ground is in focus, and some parts of trees that are away from the ground are blurred. Compared with Fig. 9 (a), the blur is small. Fig. 9 (c) was rendered with the tilted lens, but tilt directions of the lens are opposite to Fig. 9 (b). In this image, the focal plane was set perpendicular to the ground. Compared with Fig. 9 (a), the blur amount is large. Fig. 9 (d) was rendered with the lens that have twice as large aperture as Fig. 9 (a).

In both real and generated images, the depth of field is shallow when the lens aperture is large. When the image of the landscape have the bigger blur, we confuse the subjects with the miniature diorama. The reason is that when the blur in images is large, we think that subjects are small and the distance from the camera to subjects is short. However, there is a limit to change the aperture of the lens in the actual lens. Adjustment by changing the aperture of the lens freely (in other words, changing the depth of field) is a method suitable for computer graphics. In Fig. 9 (b) and (c), the size of blur was changed without changing the lens aperture. Instead of changing the depth of field, the range in the depth of field was changed in these cases. This adjustment method of blur can be achieved for the actual tilt-shift lens.



(a) Normal lens. (b) Tilted lens.



(c) Reverse-tilted lens. (d) Large aperture lens.

Figure 9: Landscape-style scenes.

5. CONCLUSION

In this study, we extended ray tracing software to reproduce the depth of field effect in a tilt-shift lens. First, we implemented the function of the tilt-shift lens to set arbitrary the focal plane. Next, we compared photographs taken using a actual tilt-shift lens with images generated by computer graphics. The photographs and computer graphics images were prepared under the following three conditions: (1) the lens was in the normal state (the lens and focal plane were not tilted), (2) the lens was tilted (the focal plane was set to focus on the upper surface of the box), and (3) the lens was reverse-tilted (the tilt direction of the lens was opposite to (2)). For the comparison, we graphed brightness profiles on some lines. Then, we reproduced a tilt-shift lens effect in a landscape-style scene and generated images having the smaller or larger blur. To adjust the size of blur in images, two methods were adopted. One method involved changing the lens aperture to change the depth of field, and the other method used tilt-shift lens effects. We confirmed that it was possible to change the size of blur without changing the lens aperture using tilt-shift lens effects.

Future issues include reproducing the shift effect by tilt-shift lens, reproducing a combination of the tilt and shift effects, and equalizing the degree of blur for a real photography and a computer graphics image.

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