Study on Outdoor Soft Shadow Generation Method for Mobile Devices

Kozue Shoji* Noriaki Murayama** Kouichi Konno*
*Iwate University **Epson
E-mail: shoji@cis.iwate-u.ac.jp

Abstract

This paper proposes the method of soft shadow generation by extending the shadow volume to generate outdoor 3DCG images. In our method, two parameters, "*brightness of shadow*" and "*soft shadow range*", are introduced to enable various soft shadows in different time zones. This algorithm aims to mount our method onto portable devices, so that the shadow texture for a soft shadow is generated and a soft shadow can be generated with the processing that does not depend on hardware specifications.

Keywords: Soft shadow, Outdoor image, Mobile device

携帯端末のための屋外ソフトシャドウ生成法の検討

庄司こずえ* 村山紀章** 今野晃市*
*岩手大学 **(株)エプソン

概要

本論文では，屋外の 3DCG を生成するために，シャドウボリュームを利用してソフトシャドウを高速に生成する手法について提案する． 本手法では，「影の明度」と「ソフトシャドウの範囲」の二つのパラメータを持たせて，時間帯の違いによるいろいろなソフトシャドウの描画を可能にしている．また，本手法は携帯端末上への実装を目標としており，ソフトシャドウを表す影テクスチャを生成し，ハードウェアに依存しない処理でソフトシャドウを生成することができる．

キーワード：ソフトシャドウ，アウトドアイメージ，モバイルデバイス

1. Introduction

Shadow generation is one of the important representation methods for generating real images in computer graphics. Shadow increases not only the actual material feeling in 3DCG, but also effects for recognizing the position of an object in the virtual space [1]. For the shadow generation method, soft shadow generation is an indispensable technique to express the reality of an image.

For soft shadow generation, various researches have been done, while most of them use a field light source and a line light source in order to generate indoor soft shadows. For hard shadow generation, a lot of researches have also been done to simulate the parallel light source to express the outdoor sunlight. On the contrary, there have been only a few researches on the outdoor soft shadow generation. In the real world, however, soft shadows often appear on the surface of a building or on the ground because of diffuse reflection of light. In order to generate real outdoor images of 3DCG, soft shadow generation is indispensable.

When a shadow image is generated, both quality of shadows and generation speed are important factors. It is possible to achieve high-speed and high-resolution rendering by using high-end devices, which require dedicated graphics hardware. Compared to desktop computers, however, the display size of mobile devices is smaller and the resolution is lower. In addition, the hardware including the CPU, memories, and graphic devices are not so powerful enough in mobile devices. Because of those reasons, the software to realize high-speed rendering is expected [2,3].

If 3DCG is installed in mobile devices, we can get necessary information at any place, which greatly improves convenience of work, study and other various purposes. For example, it is useful for measurement confirmation and evaluation of buildings, presentation at the operation site, or the navigation system in a car. If mobile devices of not-so-high resolution are allowable, mobile devices are very useful. In addition, the quality of presented images is desirable to include soft shadows.

Currently 3DCG can be represented easily on mobile devises by using Open GL ES [4,5], which is one of the graphic libraries for mobile devises and a subset of Open GL.

This paper presents the method of soft shadow generation by extending the shadow volume to generate outdoor 3DCG images[6]. In our method, two parameters, "*brightness of shadow*" and "*soft shadow range*", are introduced to enable various soft shadows in different seasons and different time zones. This algorithm aims to mount our method onto portable devices. Our method does not depend on hardware specifications.

2. Previous Work

This section describes the existing methods of shadow generation. When a shadow image is generated, both quality of shadows and generation speed are the important elements. It is preferable that both the quality and the speed of the shadow generation are satisfied although they are in the trade-off relationship. At present, there are three popular methods for shadow generation: shadow volume method [7,8], forward shadow mapping method [1], and shadow mapping method [9,10]. The overview of each algorithm is described below.

2.1 Shadow Volume Method

The shadow volume method is proposed by Crow [8]. Shadow volume represents a part in a space that is not lit. Since an object locating in the shadow volume can be interpreted that the surface becomes shadow, the object must be shown darker, compared with the one outside the shadow volume. It is general to use the stencil buffer to select objects locating inside the shadow volume [9].

In the shadow volume method, an algorithm is presented to generate the shadow volume with using relation between the silhouette line of an object and the light source so as to generate soft shadows inside the shadow volume [7]. The shadow volume algorithm enables to generate highly accurate soft shadows, while the processing must depend on hardware specifications to realize fast shadow drawing, because the shadow volume must be generated from each polygon of the object's silhouette line.

2.2 Shadow Mapping Method

As the shadow mapping method, two algorithms have been presented: the conventional shadow mapping proposed by Williams [10] and the forward shadow mapping proposed by Zhang [1].

The shadow mapping algorithm generates a shadow from the depth information stored in a shadow map. To generate a shadow, two scenes are drawn first; one viewed from the viewpoint and the other from the light source. Then the depth information of the scenes is stored in each shadow map and the two shadow maps are compared to extract the shadow part.

The forward shadow mapping algorithm [1] can show illuminated pixels directly by transforming pixels in the light's depth buffer to the eye's view using 3-D image warping techniques. This algorithm is the reversal of the traditional shadow mapping algorithm, in which a view point is projected to the light source using the shadow map. This algorithm does not interfere with the normal texture mapping and supports anti-aliased shadow edges and projective textures. Access to shadow maps and projective textures is done in the sequence of pixels. This algorithm is advantageous when the speed of texture mapping becomes the performance bottleneck, which is often the case in visual simulations and game applications.

In the shadow mapping method, a soft shadow is easily generated by performing anti-aliasing to the edges of a shadow. Note, however, anti-aliasing may draw soft shadows outside a compared section of the shadow map. Since soft shadows may be generated on a section, which must not originally become a shadow, the consistency of the shadow may not be maintained. Besides, jaggy appears depending on the accuracy of the shadow map and the problem of the quality remains.

2.3 Problem of Soft Shadow Generation

Important factors in a soft shadow generation are the quality of soft shadow and the generation speed. On these two points of view, the shadow mapping method has a big problem of jaggy that debases the quality of shadow, and in addition, the soft shadow generated by performing anti-aliasing on the shadow edges does not satisfy the correspondence. The shadow volume method can generate and render high-quality soft shadows, while the calculation cost is high.

We propose the algorithm that reduces the calculation cost, while the advantages of the shadow volume method are maintained.

3. Soft Shadow Generation Algorithm

This section describes a low-cost soft shadow generation algorithm based on the shadow volume method. This algorithm constructs a computing model to represent a soft shadow similar to the actual outdoor shadow. We acquired some samples of actual outdoor shadow, and investigated the brightness of the actual shadow and the variation of the actual soft shadow according to the distance between the object and the shadow.

Based on the result of the investigation, we propose a new computing model, which has two parameters, *brightness of shadow* and *range of soft shadow*, to represent soft shadow. The details are described in the following sections.

3.1 Sample Acquisition and Investigation

This section describes the investigation of the sample of the actual shadow and its result. Figure 1 shows the image taken by a digital camera. To take the photo, a pillar-shaped object is placed in an outdoor location and a white paper is placed on the shadow. The size of soft shadow area depends on the distance between the object and the ground as shown in Figure 1. For our investigation, the shadows of the three sections were acquired: lower, middle, and upper parts of the pillar-shaped object. The distance between each section of object and the shadow have been 0.3m, 1.5m, and 3m, respectively.

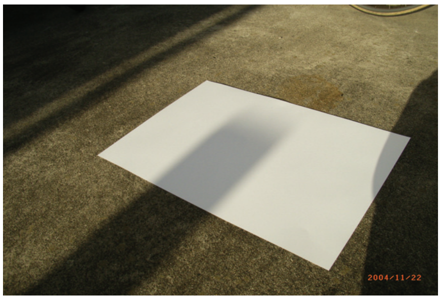


Figure 1. Actual shadow

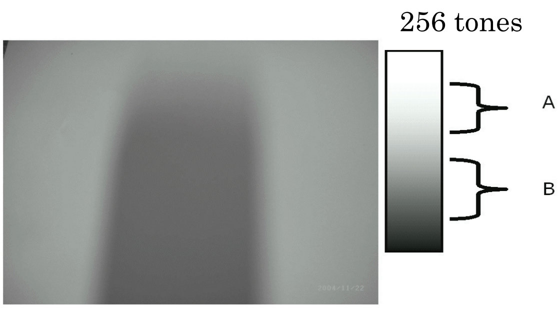


Figure 2. Result of analysis of a shadow

First, the brightness of the hard shadow section is investigated from the acquired sample to determine the pixel value of the shadow texture. Next, the range of the soft shadow section is surveyed and the result is reflected to the shadow texture.

As shown in Figure 2, the brightness of the shadow in the acquired sample is investigated in the following procedure.

(1) A sample image is converted to a 256-tone gray-scale image.

(2) Two brightness values are extracted: one from the outside of the shadow section and the other from the hard shadow section.

(3) Each of the brightness values is applied to contrast conversion with the 256-tone gray-scale, so that the brightness of the hard shadow section is determined.

In Figure 2, the brightness value of the soft shadow section (the section of A) is approximately 150 and the hard shadow section (the section of B) is approximately 80. Since a white paper was used for the background of the actual shadow when the sample was acquired, the ideal brightness value of the outside of the shadow maybe 255. Then, the contrast conversion is applied linearly so that the brightness value of the outside of the shadow is assumed to be the maximum of 255. As a result, the brightness value of the hard shadow section becomes 128. Since we generate the hard shadow part as a shadow texture, the pixel value of the shadow texture is set to 128. The algorithm of the shadow texture generation is described later.

Next, the range of the soft shadow that differs depending on the distance from an object to its actual shadow is investigated. Figure 4 shows the result of extracting soft shadows from each of the shadow sections shown in Figure 3. By using the same method as the algorithm that determined the brightness of the hard shadow section, a section between the outside of the shadow and the hard shadow was extracted. Then, the expansion ratio for the area of the hard shadow is determined to generate the shadow volume in which the area of soft shadow is involved. The calculation formula is as follows:

$$\text{Expansion ratio} = \frac{S}{H}$$

S: Diameter of shadow involving soft shadow
H: Diameter of hard shadow

Table 1 shows the expansion ratios. When the distance between an object and the shadow is 0.3m, soft shadow can be involved with the expansion ratio 101%. In the same manner, the soft shadow sections can be involved with the expansion ratios 110% and 120% respectively to the cases of 1.5m and 3.0m. In our algorithm, the area of the soft shadow is determined by using these expansion ratios shown in Table 1.

Table 1. Quantity of soft shadow distribution

Distance	0.3m (near)	1.5m (middle)	3m (far)
Expansion ratio	101%	110%	120%

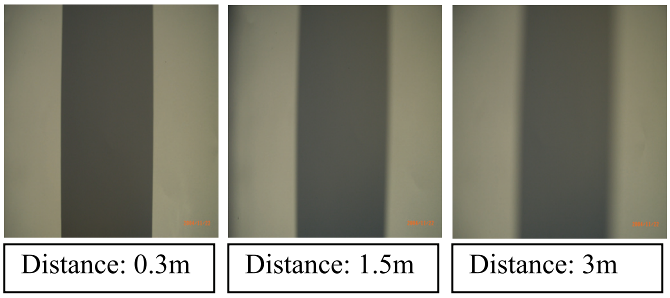


Figure 3. Sample of actual shadows

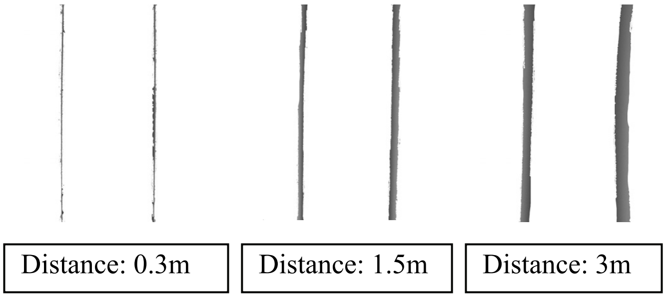


Figure 4. Extracting soft shadows

3.2 Soft Shadow Generation Algorithm

This section presents a soft shadow generation algorithm. The following describes the outline of the algorithm.

(1) Generate a shadow volume and expand it.

(2) Render the shadow volume in a stencil buffer and extract the pixels representing the shadow to the shadow texture.

(3) Generate a soft shadow by processing image data processing to the shadow texture.

(4) Perform alpha blending for the shadow texture and the image rendered on an object.

3.2.1 Generation of Shadow Volume

The method of generating the shadow volume in order to generate hard shadow from parallel light source is enhanced, and the shadow volume in which soft shadow is included is generated. It is difficult to keep geometrical consistency when soft shadow is generated inside the shadow volume since the hard shadow becomes thin. To avoid the above problem, the shadow volume is expanded in this algorithm. The silhouette line of the shadow volume corresponds to the silhouette line of the actual soft shadow investigated in section 3.1. Therefore, the consistency can be maintained and the generated shadow remains to be thin, even if the shadow volume is expanded.

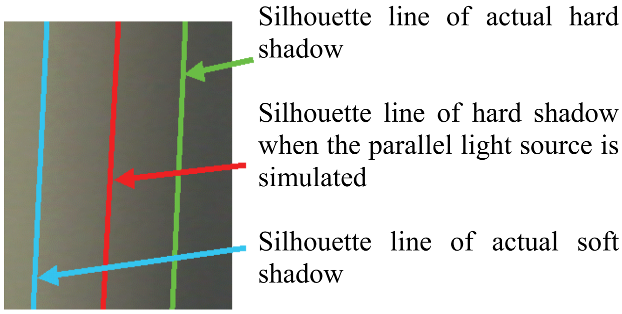


Figure 5. Relation of hard shadow and soft shadow

Figure 5 shows the enlarged image of an actual soft shadow when the distance from an object to the shadow is 3m. In this figure, three silhouette lines are overlapping: the silhouette line of the actual hard shadow (green line), the silhouette line of the hard shadow when the parallel light source is simulated (red line), and the silhouette line of the actual soft shadow (blue line). The silhouette line of the actual soft shadow is obtained by expanding the silhouette line of the actual hard shadow by 120%. Based on the silhouette line of the hard shadow under the parallel light source, the silhouette line of the actual soft shadow is generated 10% outside and the silhouette line of the actual hard shadow is generated 10% inside. Then, the shadow volume will be expanded by the outline of the hard shadow under the parallel light source, where the expansion ratio is 10% when the distance from an object to the shadow is 3m. When the distance between the object and the shadow becomes long, the soft shadow part increases and the expansion ratio increases.

First, the silhouette line of a shape is extracted by using the direction of the light source vector. As the silhouette line is swept along in the direction of the light source, the shadow volume representing the hard shadow is generated (volume A shown by blue lines in Figure 6). Next, the mean normal vector of the vertices on the silhouette line is calculated. In

Figure 6, for example, face F1 is composed of vertices b, e, f, and c, and face F2 is composed of vertices a, d, f, and c. F1 and F2 adjoin each other about vertex c. The unit normal vector of F1 is N1 and that of F2 is N2. When the normal vector of the vertex c on the silhouette line is supposed to be N, the normal vector of the vertex c is calculated as following equation.

$$N = \frac{N1 + N2}{2}$$

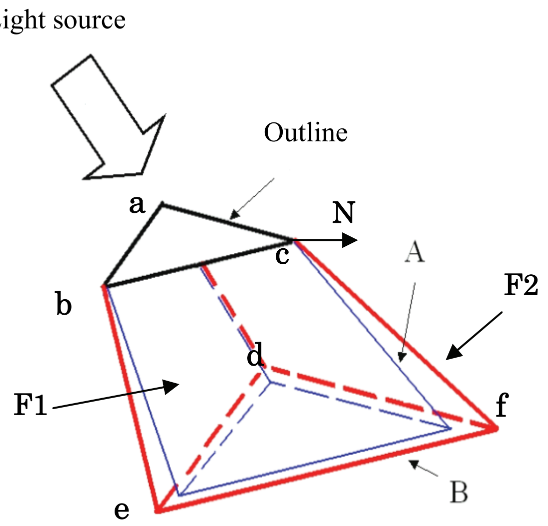


Figure 6. Shadow volume

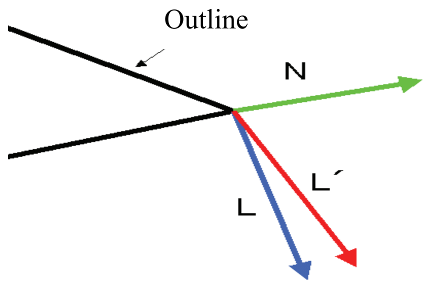


Figure 7. Expansion direction of shadow volume

In Figure 7, **N** is the unit normal vector of a vertex, *L* is the direction of the parallel light source, and *L'* is the direction obtained by moving *L* to the direction of the normal vector in order to expand the shadow volume.

When *L'* is moved to the direction of the normal vector according to the result of section 3.1 and Figure 5, the calculating formula is approximated as follows.

$$L' = \frac{L + (\mathrm{N} \times 0.1)}{|L + (\mathrm{N} \times 0.1)|}$$

In Figure 6, *A* shows a shadow volume generated at parallel light source, and *B* shows an expanded shadow volume.

3.2.2 Generation of shadow texture

First, the shadow volume is rendered in stencil buffer. Then, the pixel information on the hard shadow is extracted from the stencil buffer, and the shadow texture is generated. Afterward, the soft shadow is generated by image data processing onto the shadow texture. The algorithm to generate the shadow texture is presented specifically below.

(1) The shadow texture whose size is the same as the stencil buffer is prepared. Since the shadow texture is a basic information that is used for making soft shadow with alpha blending, the shadow texture is supposed to have pixel value, α value, intensity value of soft shadow, and shadow determination value. When shadow is generated closely to an object, the hard shadow appears strongly, and on the contrary, if shadow is distant from an object, the soft shadow appears strongly. This is called “soft shadow intensity” in our research. A pixel with low intensity of soft shadow tends to be the hard shadow and with high intensity of soft shadow tends to be the soft shadow. Shadow determination value is used to determine three states of shadow: outside of shadow, soft shadow and hard shadow. The shadow determination value of a pixel which is not related to shadow is set to -1, hard shadow part is set to 1, soft shadow part is set to 2. To each of pixel value, α value, intensity value of soft shadow, and shadow determination value in a pixel, the initial value 0 is set.

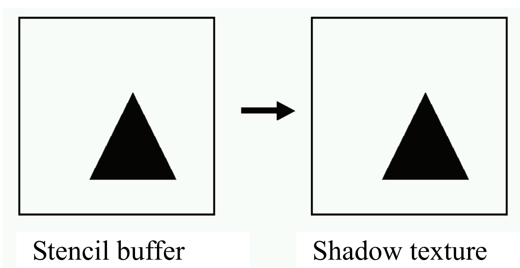


Figure 8. Generation of shadow texture

(2) The value of the stencil buffer is extracted as the result of shadow volume drawing. Since a pixel whose stencil value is 1 or greater represents shadow, the shadow determination value of the corresponding shadow texture is initially set to 1 (Figure 8), which is defined as a shadow section.

3.2.3 Soft Shadow Generation

Soft shadow is generated by performing image processing to the shadow section stored in the shadow texture. In this method, comfortable soft shadow is generated without physical calculation in order to reduce the calculation cost. The following describes the soft shadow generation algorithm.

(1) A rough direction in which a shadow can be generated is obtained from the positional relationship between a light source and an object. For example, as shown in Figure 9, a shadow is generated rightward when the light source lies at the upper left of a pillar-shaped object. Soft shadow appears strongly in this direction. It is called the “intensity direction of soft shadow.”

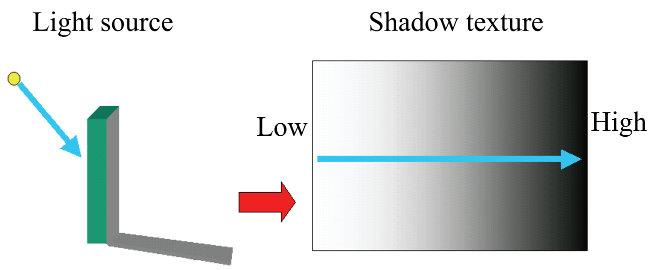


Figure9. Intensity of soft shadow

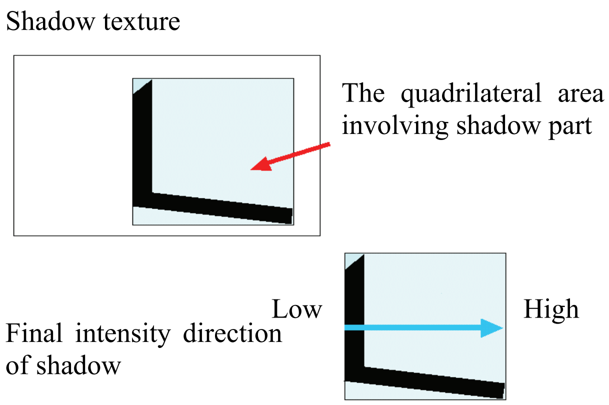


Figure 10. Correction of soft shadow intensity

(2) The quadrilateral area in which the pixels to become a shadow are involved is obtained. The black part in Figure 10 is the pixels each of whose shadow determination value is equal to 1. A quadrilateral area is obtained from the maximum and minimum values of x and y coordinate values of the shadow determination value stored in the shadow texture, as shown in Figure 10. From the direction obtained at (1) and the quadrilateral area, the start and end points in the intensity direction of the detailed soft shadow are obtained.

(3) The intensity value of a soft shadow is stored in each pixel. Intensity value is the intensity of gradation on the soft shadow, which lies from the outline of the hard shadow to that of the soft shadow. The shadow volume method extracts the shadow section of the projected object itself. Soft shadow does not appear easily in the shadow section of the object itself because the distance from the object is very short. Therefore, in Figure 10, the intensity value of the soft shadow of the leftmost pixel in the quadrilateral is assumed to be 0 and the intensity is stored in each pixel. Since the pixels lying outside the quadrilateral do not represent shadow, -1 is stored to those pixels as the intensity value of the soft shadow. The increasing amount of the strength is set to 10 as the result of section 3.1 is considered.

(4) From the intensity value of the soft shadow of pixels on the silhouette line, a pixel on the silhouette line and its neighborhood pixels are judged whether they can be shadow. The number of the pixels to be soft shadow is increased according to the intensity value of the soft shadow. When the pixel on the silhouette line is P_{ij} and the intensity value of the soft shadow is I, the pixels whether they can be soft shadow are expressed as $P_{i\pm I,j\pm I}$. For example, when the intensity value of the soft shadow of a pixel on silhouette line is 1, the pixel on silhouette line and 8 neighborhoods are judged. And when the intensity value is 2, the pixel on silhouette line and 24 neighborhoods are judged. When a pixel is included in the shadow section, the pixel represents the soft shadow and the shadow determination value is set to 2. When a pixel is not included in the shadow section, the shadow determination value is set to -1. In this way, as shown in Figure 11, the shadow texture is classified into three states: the white section that is not a shadow, the black section that is hard shadow, and the gray section that is soft shadow. Figure 12 shows the result of soft shadow judgment.

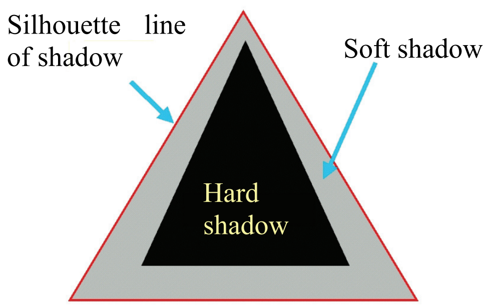


Figure 11. Shadow texture

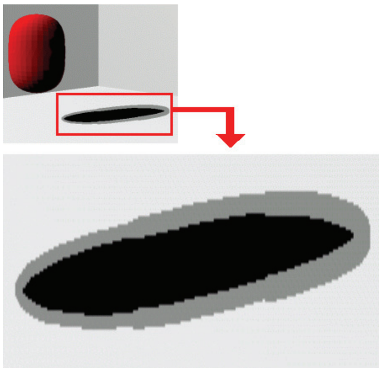


Figure 12. Result of judgment

(5) Soft shadow is linearly interpolated as the α value of the shadow silhouette line is assumed to be 0% and the α value of the hard shadow silhouette line is assumed to be 100%, so that the shadow texture is generated. Soft shadow can be generated with the above processing and by performing alpha blending on the shadow texture and an object.

4. Results

This section presents the results of applying our algorithm. We had experiment in soft shadow generation and comparison with the actual soft shadow.

4.1 Rendering of Soft Shadows in Different Time Zones

Figures 13, 14, and 15 show the photographs taken in the morning, daytime, and evening of a day in spring, and the images of soft shadow generated with using our algorithm. Two parameters, "*brightness of the shadow*" and "*range of the soft shadow*", are used when soft shadow is generated. Table 2 shows each value of these parameters. Since the shadow lengthens in the evening and the distance between the object and the projection ground becomes longer, the parameter about the range of the soft shadow increases. By changing the range of the soft shadow in this way, the variation of shadow in a day can be expressed. On the contrary, the difference of shadow between seasons was not able to be compared although we took photos of shadow in different seasons, because the brightness of shadow changed even at the same hour. By changing the parameter value about the brightness, however, the difference of weather, clear or cloudy, can be expressed.

Table 2. Comparison of parameter values

Time	9:20	13:21	16:21
Range of the soft shadow	6	5	8
Brightness of the shadow	110	120	180

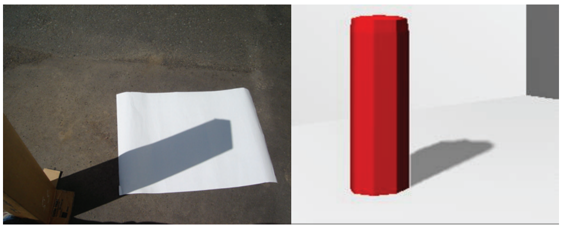


Figure 13. Picture at 9:20 on April 27

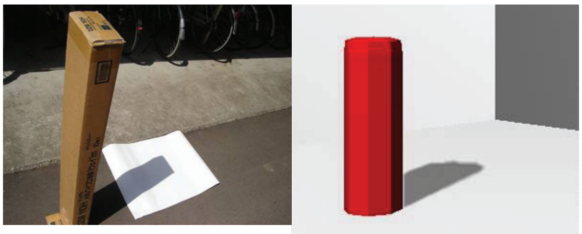


Figure 14. Picture at 13:21 on April 20

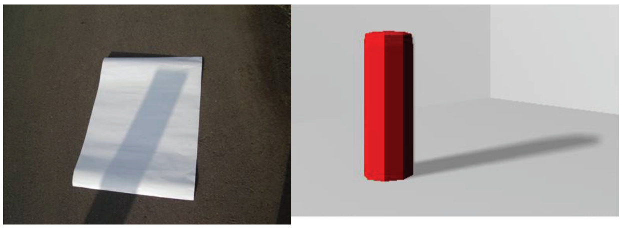


Figure 15. Picture at 16:21 on April 20

4.2 Evaluation of Our Algorithm

Figure 16 shows the outdoor soft shadow generated by applying our algorithm. In the experiment, we used Windows2000 OS of Intel Pentium4 on 2.8GHz CPU with 512Mbyte RAM.

The soft shadow appears more remarkably as the distance from the object lengthens, which expresses the soft shadow more realistically. Figure 17 shows an enlarged section of the shadow of Figure 16. The soft shadow can be expressed as nicely as the actual soft shadow shown in Figure 2. Figure 18 shows the result of application of our technique to another shape, in which the soft shadow is also expressed satisfactorily. In this figure, the soft shadow can be expressed on a complex shape, which has a rough surface or holes.

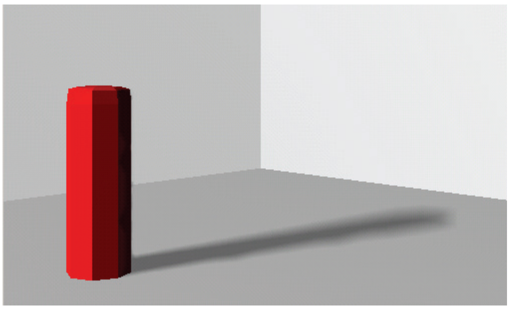
Table 3 shows the processing time to render the hard shadow only and that to render soft shadow in addition. The calculation time necessary for the hard shadow rendering increases in proportion to the number of the polygons, while the calculation time of the soft shadow rendering adds about 70ms to 100ms, which is approximately 20% of the entire processing time. The increase of the processing time is gradual, compared to that of the number of polygons. It is thought that soft shadow generation does not constrain the processing cost. Our algorithm can realize fast processing and applicability to portable devices.

Our method presents a general algorithm, which does not depend on hardware, to solve the calculation cost of the previous shadow volume method, which solves the calculation cost by using graphics hardware. Therefore our method is easily applicable to mobile devices. At present, however, the mobile system environment is assumed to be iPAQ rx1950, Windows mobile 5.0, SC32442-300MHz processor, and 30MHz memory. Since CPU clock of PocketPC is 10 times slower than that of a desktop computer, drawing speed is assumed to be 10 times later in mobile devices. In practical use, the number of polygons is suitable for drawing less than about 1,000.

Table 3. Processing time of hard shadow and soft shadow

Number of polygons	176 (pillar)	1472 (ball)	26584 (dragon)
Hard shadow	121[ms]	267[ms]	516[ms]
Soft shadow	196[ms]	349[ms]	622[ms]

Windows 2000, Intel Pentium4, 2.8GHz CPU, 512Mbyte RAM.



Range of the soft shadow:10
Brightness of the shadow :128

Figure 16. Result of experiment using our algorithm

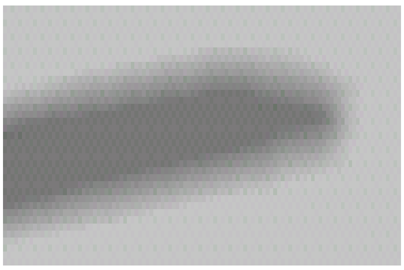


Figure 17. Expansion of the shadow part

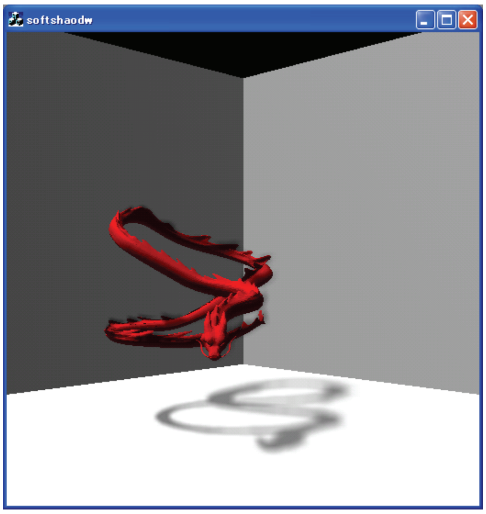


Figure 18. Result of application of our algorithm

Figure19 shows the result of soft shadow generated on a complex background image. The range sensor [11] was used to generate the background image, where each pixel has RGB color data and a depth value. By adjusting the two kinds of information to the background and by setting the depth value to the initial value of the z buffer, the background image is generated and soft shadow is calculated. Figure 20 shows the result of representing only a soft shadow without applying RGB colors to the background image. In the same way, Figure 21 and Figure 23 show the soft shadow generation to another complex background image, Figure 22 and Figure 24 show only soft shadow without applying RGB colors to the background image. In these figures, the soft shadow can be expressed satisfactorily on the complex background.

5. Conclusions and Future Work

In this paper, we have described the algorithm to generate a soft shadow with shadow volume with 2D image processing. Various shadows in different seasons and time zones can be generated as the input parameters “brightness of shadow” and “range of soft shadow” are used. In our algorithm, the shadow texture that shows a soft shadow is generated and a soft shadow can be generated with the processing that does not depend of hardware specifications. In addition, this algorithm does not depend on background images and realizes low-cost processing when a shadow is generated with shadow volume with 2D image processing. Our future problem is to mount this algorithm on mobile devices.

Acknowledgement

The dragon data was offered from Lattice technology, Inc. Our research was partly supported by the Science and Technology Research Program of Iwate Prefecture Government.

References

[1] H.Zhang, "Forward Shadow Mapping", In Proceedings of the 9th Eurographics Workshop on Rendering 1998, pp.131-138, June 1998.

[2] Kari Pulli, Tomi Aarnio,Kimmo Roimela, and Jani Vaarala, "Designing Graphics Programming Interfaces for Mobile Devices", IEEE Computer Graphics and Aplications, pp.66-74, November 2005.

[3] Luca Chittaro, "Visualizing Information on Mobile Devices", IEEE Computer Society, pp.40-45, March 2006.

[4] Khronos Group "OpenGL ES Overview" http://www.khronos.org/opengles/

[5] Zeus CMD "OpenGL ES Programming Tutorials http://www.zeuscmd.com/tutorials/opengles/index.php

[6] K.Shoji, N.Murayama, K.Konno, "Study on Outdoor Soft Shadow Generation Method for Mobile Devices", NICOGRAPH International 2006 ,Session Ⅶ Animation, 3rd June 2006.

[7] Ulf Assarsson and Tomas Akenine-Moller, "A Geometry-Based Soft Shadow Volume Algorithm using Graphics Hardware", Proc.SIGGRAPH2003, vol.22, No.3, PP.511-520, 2003.

[8] F.Crow, "Shadow algorithms for computer graphics", SIGGRAPH '77, Vol.11, No.2, pp.242-248, July 1977.

[9] David Blythe, "Lighting and Shading Techniques for Interactive Applications", SIGGRAPH '99 Course12, 1999.

[10] L.Williams, "Casting Curved Shadows on Curved Surfaces", SIGGRAPH '78, Vol.12, No.3, pp.270-274, August 1978.

[11] RIEGL Japan, http://www.riegl-japan.

Figure 19. Shadow generation to the complex background image

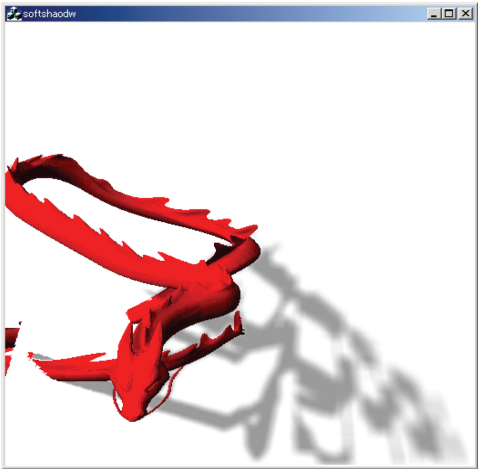


Figure 20. Shadow generation to the complex background image

Figure 21. Shadow generation to the complex background image

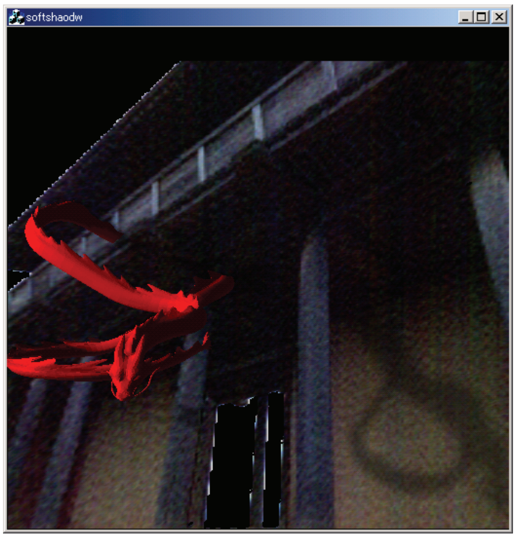


Figure 23. Shadow generation to the complex background image

Figure 22. Shadow generation to the complex background image

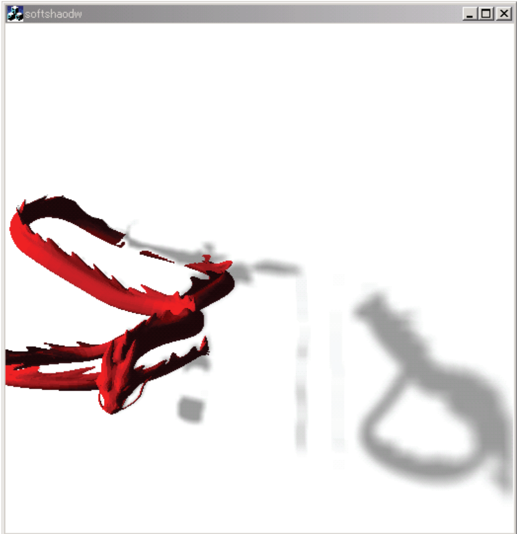


Figure 24. Shadow generation to the complex background image