A New Coherent Technique for Real-Time Shadow Generation with Respect to the Sun's Position

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Abstract: Soft shadow with respect to the sun's position in virtual environments is a fascinating topic in outdoor rendering. A coherent mathematic formula to create shadow with respect to the sun's position in specific location, date and time can make outdoor rendering as easy as indoor rendering. A target of this study is to propose a new coherent formula to do this. Outdoor rendering using a coherent formula will eliminate worrying about the sun's position and shadow status during the daytime. Low frames per second (FPS) in real-time rendering is a crucial problem in computer graphics, especially in soft shadow generation. A novel technique to create soft shadow in virtual environments is proposed. Geometric progression to select the color and a combination formula using sequence progression are proposed to determine the sample size. The new soft shadow generation, in addition to increasing FPS, enhances the quality of soft shadows. Finally, we strongly contend that the proposed technique can be used in commercial gaming and virtual reality systems.

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1. Introduction

Computer animation has become one of the most important components of online and off line games, advertisements and simulation in a virtual environment. Shadows are the main components of outdoor rendering used to make scenes realistic. After smooth motion, shadows are the second main effect used in computer animation to reveal information about the distance between objects and to show the complexity of objects in the scenes. Unfortunately, shadowing is still an expensive component of animation and games, especially in real-time rendering. In computer games, shadows give the gamers feelings that trigger the sense that they are playing in the real world, resulting in maximum enjoyment. Games which lack shadows are not seen as attractive, especially since gamers' have had a taste of virtual games and their imagination now requires more and more realistic situations when they are watching cartoons or playing games.

Soft shadow is another challenging factor in computer animation and computer games. Good quality and high frames per second are two components of soft shadow generation that require more improvement. Low rendering time required by projection shadowing leads us to extend this kind of shadow to create a high speed shadow generation method with respect to the sun's position during the daytime.

The sun's position and its effect on shadows during the daytime is another factor to consider when

attempting creating a more realistic scene. Calculating the shadow status during the daytime encouraged us to prepare this study.

2. Previous work

The first researcher who worked on shadow was Leonardo Da Vinci in 1460 (Rautenbach 2002). He focused on painting and static images. Hard shadows are types of shadows with a point light source, which have a sharp brim, and they include fully shadowed regions without any soft edges. Hard shadows will be generated by a point light source. Soft shadows are another kind of shadow which is caused by a wide light source. Soft shadows are more realistic for virtual environments. In the real world, most light sources are wide and wide light sources lead to the creation of soft shadow; as a result, the focus on soft shadow will be more appreciated. Soft shadows include two parts, umbra and penumbra. Umbra includes those parts of the shadow region which do not see any portion of the light source and are fully shadowed; it is like hard shadow. Penumbra is the other part of a shadow region which can see some portion of the light source.

The first researcher who seriously worked on realtime shadow generation was Crow (1977). He proposed shadow volume, which is a geometry based technique used to create hard shadow. Currently, shadow volume is still a famous algorithm used to create precise shadow, but the main drawback is that silhouette detection is expensive. Shadow mapping is a widely used image based technique proposed by Williams (1978). High speed rendering commonly uses this image based algorithm. Shadow maps suffer from aliasing and many improved algorithms have tried to remove aliasing but not completely been able to do so. (Scherzer, 2011)(Bittner, 2011)(Donnelly, 2006)(Lauritzen, 2008)(Liang, 2011) (Rehman et al., 2011) (Saba and Rehman, 2012).

Projection shadow proposed by Tessman et al. (1989) is the third type of shadow. Projection shadows are convenient for flat surfaces. High-speed rendering is the most important reason behind their use in recent games and animations. It is not so difficult to cast projection shadow on arbitrary objects.

Low speed rendering of soft shadow is a critical problem in computer graphics(Boulanger, 2008)(Wyman, 2004)(Zhang, 2007)(Liu, 2011)(Kolivand, 2013) Generating soft shadow using projection shadow with respect to the sun's position in a specific location, and specific date and time is the main purpose of this study.

The principle calculations of the sun's position have been very well known for a long time. The sun's position and the amount of sunshine has historically been a very attractive subject for most of researchers. For example Nawar et al. (1958) worked on the principle amount of sunshine in a day. Kambezidis et al. (1990) provided several functions to calculate the sun's position by focusing on factors such as light refraction.

A coherent formula for shadow and the sun's position in specific longitude, latitude, date and time can be used in virtual environments such as games and 3D animations.

This paper presents a coherence formula to create exact shadow with respect to the real sun's position in specific location, date and time that can be used in augmented reality to keep the virtual shadows without worrying about confusing between real shadow and virtual ones.

3. Material and Methods

3.1. The Sun's Position

Suppose that the earth is a sphere. Julian dating is a precise technique to calculate the sun's position. The sun's position relative to earth can be calculated for a specific longitude, latitude, date and time using Julian dating.

Assume that f is a function sphere: $f(\theta, \varphi) = \cos^2 \theta \cos^2 \varphi + \sin^2 \theta + \sin^2 \theta \cos^2 \varphi - r^2$ $0 \le \theta \le \frac{\pi}{2}$ $0 \le \varphi \le 2\pi$ (1)

where θ and ϕ are zenith and azimuth respectively.

$$t = t_s + 0.17\sin(\frac{4\pi(J-80)}{373}) + 0.129\sin(\frac{2\pi(J-8)}{355}) + 12\frac{SM-L}{\pi}$$
(2)

where

t: Solar time t_s: Standard time J: Julian date SM: Standard meridian LO: Longitude The solar declination is calculated as follows:

$$\delta = 0.4093 \sin(\frac{2\pi (J-81)}{368}) \tag{3}$$

The time is calculated in decimal hours and degrees in radians (Kolivand et al. 2011) (Zafar 2012). Finally, zenith and azimuth can be calculated as follows:

$$\theta_s = \frac{\pi}{2} - \sin^{-1}(\sin l \sin \delta - \cos l \cos \delta \cos \frac{\pi l}{12}) \tag{4}$$

$$\varphi_s = \tan^{-1}\left(\frac{-\cos\delta\sin\frac{\pi}{12}}{\cos l\sin\delta - \sin l\cos\delta\cos\frac{\pi}{12}}\right)$$
(5)

 θ_{s} : Solar zenith

 φ_{s} : Solar azimuth

l : Latitude

3.2. Shadow Calculation

To calculate the shadow on a plan f, very simple calculations are needed. L is light source, P is a point of occluder and S is the projection of P in the plan f. Figure 1 illustrates the generation of projection shadow.



Figure 1. Shadow generation theory

where

 $L = (l_x, l_y, l_z)$: light source point

$$P = (p_x, p_y, p_z)$$
: point of occlude

$$S = (s_x, s_y, s_z)$$
: projection of p

 $N = (n_x, n_y, n_z)$: normal vector of f

$$E = (e_x, e_y, e_z)$$
: a point of f
 $L, P, S, E \in \mathbb{R}^3$

The equation of a straight line from *L* to *S* is:

$$x = L + \alpha(P - L) \tag{6}$$

The formula off will be:

$$(x-E).N=0\tag{7}$$

By combining (6) and (7):

$$(L - E + \alpha(P - L)).N = 0 \tag{8}$$

Then

$$\alpha = \frac{E.N - L.N}{N.(P - L)} \tag{9}$$

Finally, for S we can have:

$$S = L + \frac{E.N - L.N}{N(P - L)} (P - L)$$
(10)

Assume that:

$$d = L.N \tag{11}$$

$$c = E.N - d \tag{12}$$

Then

$$S = L + \frac{c}{N.(P-L)}(P-L) \tag{13}$$

$$s_{i} = l_{i} + \frac{c(p_{i} - l_{i})}{NP - d}$$

$$\forall i = x, y \text{ and } z$$
(14)

$$s_{x} = \frac{l_{x}n_{x}p_{x} + l_{x}n_{y}p_{y} + l_{x}n_{z}p_{z} - dl_{x} + c(p_{x} - l_{x})}{n_{x}p_{x} + n_{y}p_{y} + n_{z}p_{z} - d}$$
$$s_{y} = \frac{l_{y}n_{x}p_{x} + l_{y}n_{y}p_{y} + lyn_{z}p_{z} - dl_{y} + c(p_{y} - l_{y})}{n_{x}p_{x} + n_{y}p_{y} + n_{z}p_{z} - d}$$

$$s_{z} = \frac{l_{z}n_{x}p_{x} + l_{z}n_{y}p_{y} + l_{z}n_{z}p_{z} - dl_{z} + c(p_{z} - l_{z})}{n_{x}p_{x} + n_{y}p_{y} + n_{z}p_{z} - d}$$



Figure 2. Projection shadow

3.3. Shadow Formula with Respect of the Sun's Position

To use the zenith and azimuth in specific location with radiance ρ of the sky dome the statements of (16) are used (Kolivand and Sunar, 2012).

$$x_{s} = \rho \sin \varphi_{s} \cos \theta_{s}$$

$$y_{s} = \rho \sin \varphi_{s} \sin \theta_{s}$$

$$z_{s} = \rho \cos \varphi_{s}$$
(16)

In this case x_s , y_s , z_s are the sun's position in specific location, date and time. Therefore, to calculate the projection of each pixel of occluder on the *f* the triple of (17) are obtained. In the other word, the projection of pixel $P = (p_x, p_y, p_z)$ With respect to specific longitude, latitude, date and time is pixel *S*.

$$S = \left(\frac{\rho \sin \varphi_{s} \cos \theta_{s} (n_{x} p_{x} + n_{y} p_{y} + n_{z} p_{z} - d - c) + c p_{x}}{n_{x} p_{x} + n_{y} p_{y} + n_{z} p_{z} - d}\right)$$

$$\frac{\rho \sin \varphi_{s} \cos \theta_{s} (n_{x} p_{x} + n_{y} p_{y} + n_{z} p_{z} - d - c) + c p_{y}}{n_{x} p_{x} + n_{y} p_{y} + n_{z} p_{z} - d},$$

$$\rho \sin \varphi_{s} \cos \theta_{s} (n_{x} p_{x} + n_{y} p_{y} + n_{z} p_{z} - d - c) + c p_{z}$$

 $n_x p_x + n_y p_y + n_z p_z - d$

where

p: radiance of sky dome

 θ_{s} : Solar zenith

 φ_{s} : Solar azimuth

 $n_i \forall i = x, y \text{ and } z \text{ is } i^{th} \text{ component of the normal}$

vector of the plan

d and c are defined in (12).

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Figure 3. Projection shadow using new formula at 8:12 am of the day on 6th November in Universiti Teknologi Malaysia (latitude: 1.26 and longitude: 103.45)

4. Soft Shadow

Soft shadow will be produced if the light source is wide or there is more than one light source in the scene. Since most light sources in the real world are wide focus on soft shadow, using projection shadow due to low rendering time can be more beneficial (Bavoil, 2011).

4.1 Soft Shadow Sampling

Although soft shadow generation using hard shadow sampling is an old technique, improvements in projection shadow can produce a faster method to create soft shadow. This technique can be used for complex scenes and improves the quality of the results(Liu, 2011).

To create some hard shadow samples of different color, the smallest sample is created with less diffuse illumination (Forest, 2006). The largest sample is created with high diffuse illumination. In our method, to have different colors of different samples, a geometric progression is used.

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Figure 4. Projection shadow using new formula at 11: 25 am of the day on 6th November in Universiti Teknologi Malaysia

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Figure 5. Projection shadow using new formula at 4:55 pm of the day on 6th November in Universiti Teknologi Malaysia

In projection shadow, the amount of color and samplesize are calculated using the (18) and (19) formulas.

$$S_n = S_0 + \sqrt{d} \left(\frac{\Omega}{\omega}\right)(n-1) \tag{18}$$

$$C_n = C_0 q^{n-1} \tag{19}$$

where

 $S_0 = 0.2$ (can be changeable)

 S_n is size of nth sample.

 Ω is distance between occluder and shadow receiver. ω is distance between light source and shadow receiver.

d is ratio between two consequent samples.

q is a decimal number to control the amount of penumbra.

 C_0 is darkness of umbra.

 C_n is color of nth sample.

In this case, the proposed technique is called hard shadow sampling using geometric progression.

Figure 6 illustrates that to control the size of umbra and penumbra, the ratio of Ω and ω is important. To contribute these main parameters Ω/ω in equation (18) is a convenient ratio. The sample size is related to the Ω . When Ω increases, sample sizes will be increased. On the other hand, when ω increases the region of umbra will be decreased. This converse relationship improves the main problem of soft shadow algorithms when the distance between occluder and light source is small.



Figure 6. Soft shadow parameters.

4.2 Blending of Hard Shadow Samples

To create soft shadow, sample blending of hard shadow is common. The other contribution of this paper is to combine hard shadow samples using geometric progression to select the color and size of different samples in projection shadow.

In traditional sample blending, when the number of light or number of samples increases, the FPS decreases slightly.

The relationship between the number of hard samples and FPS is illustrates in Figure 7. The initial impression of Figure 7 is that almost half of the samples of traditional sample blending are required

for geometric progression blending. This means that with each quality, the FPS of using geometric progression is higher than simple blending. FPS decreases slightly when the number of samples increases. A comparison between FPS without progression and using geometric geometric progression is shown in Figure 7. GP samples are the number of samples using geometric progression. Simple samples are the number of samples without the use of geometric progression. For example, to have good quality soft projection shadows like Figure 8, sample blending using geometric progression requires 130 samples, compared to 255 for soft projection shadow without using geometric progression.

The relation between the required number of samples with the same FPS in simple sample blending and sample blending using geometric progression is shown in Figure 7.

Figure 8 illustrates the relation between sample size and Ω where Ω is the distance between occluder and shadow receiver. It shows that when occluder is near the light source, the sample size enlarges faster but when occluder is near the shadow receiver, the sample size enlarges slowly.



Figure 7. Compare FPS for simple sampling and sampling using proposed algorithm.

Using the proposed technique for samples size not only can improve the FPS but also affects the quality of shadow. As revealed in Figure 7, to create the same result as Figure 11 (Right) using traditional sampling, 780 samples are needed.

A big drawback of projection shadow is the inability to have shadow on other objects. Stencil buffer can solve this problem as well as shadow volume. Figure 9 is the result of soft projection shadow using stencil buffer with 360 samples. Figure 10 is the result of projection shadow using geometric progression and stencil buffer with 255 samples. The difference in quality can be seen in the comparison of 9 and 10.



Figure 8. Relation between size of samples and Ω .

5. Conclusion and Future Work

Projection shadows are one of the wellknown algorithms used to create shadow. Although it is convenient only for flat surfaces, rendering time is low enough. Projection shadows are not only suitable for flat surfaces but also, with some calculations and using stencil buffer, can be used for casting shadow on arbitrary surfaces. High rendering speed is the main reason we have tried to improve it for generating soft shadow.





The sun's position is one of main factors in outdoor games. Outdoor rendering is widely used situation for game programmers. Combination of accurate position of the sun and shadows is necessary for mixed reality to cast shadows in precise position.

Soft shadows are the most important shadows and this paper has accordingly focused on them. Soft shadows need big improvements, which can be implemented in a real-time environment. Although sample blending of hard shadow is a common way to create soft shadow, the stability of FPS is very important. FPS is compared using zero to 256 samples without geometric progression and using geometric progression.



Figure 10. Result of soft projection shadow with 256 samples using geometric progression for choosing color samples and proposed formula to choose size sampling and stencil buffer.

To choose color for different samples, to control the sample size in projection shadow and to create soft shadow, geometric progression is used with acceptable results.

The new technique can be implemented in shadow volume to have shadow on arbitrary objects without using double blending.



Figure 11. Left, simple sampling using 360 samples; Right, GP Sampling using 360 samples

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