Real-time Soft Shadows in Mixed Reality using Shadowing Planes

Tetsuya Kakuta
Graduate School of Interdisciplinary Information Studies,
The University of Tokyo
kakuta@cvl.iis.u-tokyo.ac.jp

Takeshi Oishi
Institute of Industrial Science,
The University of Tokyo
oishi@cvl.iis.u-tokyo.ac.jp

Katsushi Ikeuchi
Interfaculty Initiative in Information Studies,
The University of Tokyo
ki@cvl.iis.u-tokyo.ac.jp

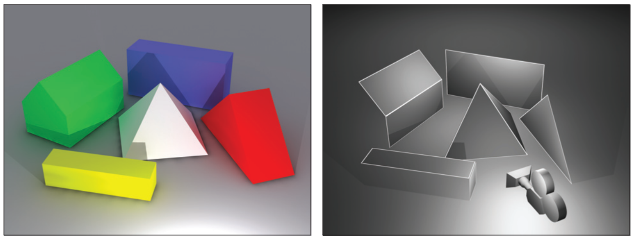
Abstract

This paper proposes a novel method to express soft shadows of virtual objects in Mixed Reality. We create shadows of virtual objects in a fast and efficient way using a set of pre-rendered basis images and shadowing planes generated from convex hulls of objects. In the preparatory stages, we approximate the illumination of the scene with a number of directional lights and render the scene with each light in order to obtain basis shadow images. We then synthesize basis images with luminance parameters and generate shadow images correspond to the real scene. Finally we map shadow images onto shadowing planes and express soft shadows of virtual objects in real-time. The proposed method can support both dynamic changes of illumination and movements of user's viewpoint, and is applicable only to the static scene. We successfully achieve the consistency of illumination and improve the quality of synthesized image in MR-systems.

1 Introduction

Mixed Reality (MR) systems allow us to see real scenes that contain computer-generated virtual objects [1][2]. For the seamless integration of virtual and real objects in MR, it is important to achieve the consistency of illumination. First of all, the shading of the virtual objects needs to match that of other objects in the environment. Also, the virtual objects must cast a correct shadow onto the real scene. However, it is not easy to obtain correct illumination because real scenes usually include both direct and indirect illumination distributed in a complex way.

There are some previous works related to the consistency of illumination. Jacobs and Loscos provide a detailed survey of illumination methods for MR[7]. They classify the various techniques based on their input requirements of geometry and radiance of real environment[10][6][5][4][3]. Most of these techniques are demonstrated on indoor scenes and few of them are carried out at interactive update rates. To simulate the naturally illuminated architectural environment, Nimeroff et al. presented an efficient re-rendering method using pre-rendered basis images[8]. Sato et al. applied this technique for MR and achieved a fast image synthesis with natural shading[9]. Nevertheless, their method is applicable only to still images and fixed viewpoints.



(a) Models (b) Shadowing planes

Figure 1: Generation of shadowing planes.

In this study, we propose a fast shadowing method for interactive MR application. We generate basis images only to express the shadows of virtual objects and set them onto other planate objects (hereafter called the shadowing planes) so that they correspond to both the arbitrary viewpoints and changing illumination of the real environment. The major contributions of this paper are as follows:

- Realistic soft shadows in real-time using pre-rendered basis images.
- Model-based shadowing that allows user to move the viewpoint.
- Hardware acceleration is available in the synthesis of basis images.

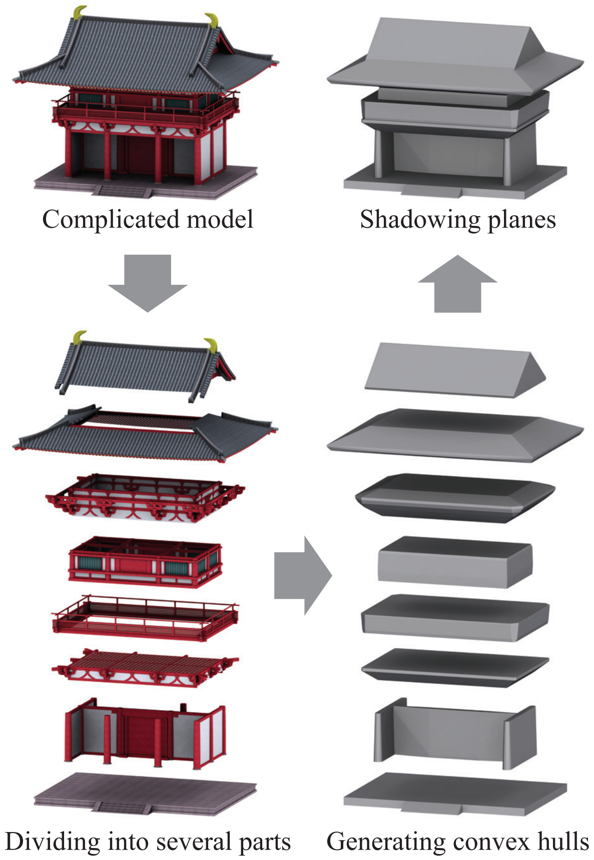


Figure 2: Generation of shadowing planes from a complicated model using convex hulls.

2 Generation of Shadowing Planes and Basis Images

2.1 Setting up of shadowing planes

We generate a set of the basis images at the preprocessing stage using shadowing planes. In order to obtain the basis images, we set up the shadowing planes on the geometry of the scene (Figure 1).

Shadowing planes are generated from convex hulls of each virtual object. In case of complicated object, we need to divide the object into some clusters previously. Figure 2 shows the generating process of shadowing planes from complex architectural model. Each shadowing plane covers virtual objects roughly, and is offset a little in the direction of a user's viewpoint. Therefore, they are put between the objects and user's viewpoint.

We render the scene in advance and record the shadows of virtual objects projected onto shadowing planes as basis images. Then we map shadow images synthesized from basis images on shadowing planes as alpha transparency texture so that we can express pseudo shadows of virtual objects.

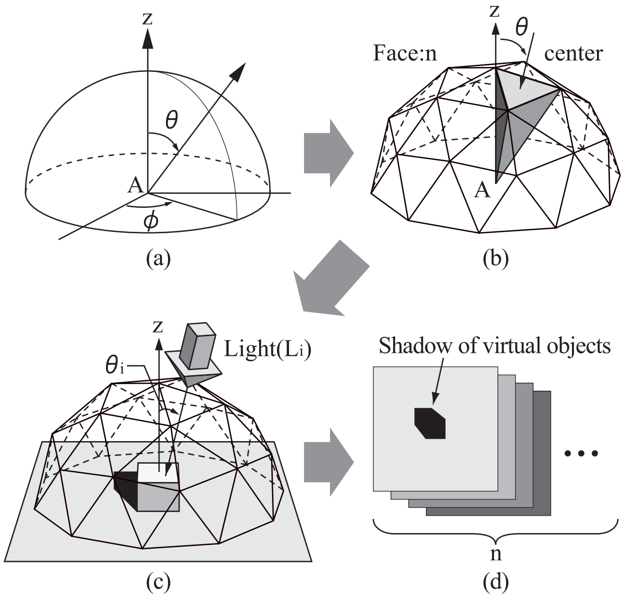


Figure 3: Approximation of the illumination; (a) hemispheric surface light source; (b) area lights on the face of a polyhedron; (c) rendering with directional lights; (d) generation of basis images.

2.2 Approximation of the illumination

We assume that the illumination in the scene is a hemispheric surface light source as illustrated in Figure 3(a). In this model, we can compute the illuminance E of the point A with whole surface light source as

$$E = \int_{-\pi}^{\pi} \int_{0}^{\frac{\pi}{2}} L_0(\theta_i, \phi_i) \cos\theta_i \sin\phi_i d\theta_i d\phi_i \qquad (1)$$

where $L_0(\theta_i, \phi_i)$ is the luminance per unit solid angle from the direction of (θ_i, ϕ_i), and $\cos\theta_i$ is the parameter which means the attenuation relating to the direction of incidence.

Then we apply a polyhedron to this hemisphere, and approximate the surface light source by the assembly of area lights located on the every face of this polyhedron (Figure 3(b)). Moreover, we approximate these area lights by the assembly of directional lights, which are located on the center of each face of the polyhedron looking toward point A (Figure 3(c)). The illuminance E of point A is represented simply as

$$E = \sum_{i=1}^{n} L_i \cos\theta_i \qquad (2)$$

where L_i is the intensity of every directional lights.

2.3 Generation of basis images

After setting up m shadowing planes $P_j(j = 1, 2, ..., m)$ and n directional lights $L_i(i = 1, 2, .., n)$,

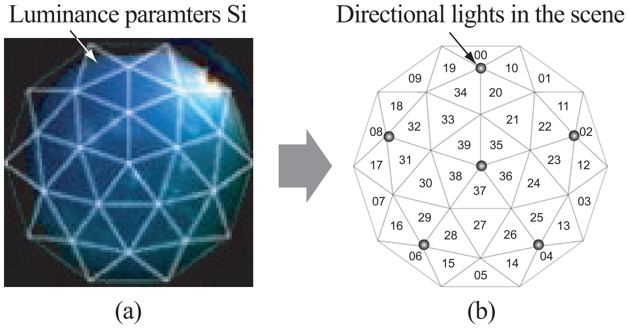


Figure 4: Acquisition of the luminance; (a) omni-direcitonal image of the real scene; (b) distribution of lights in the scene.

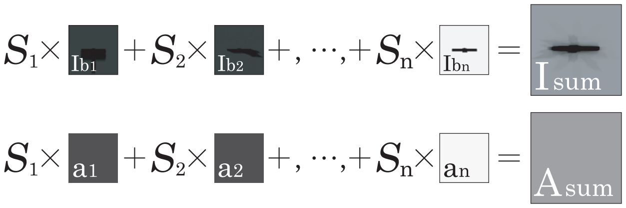


Figure 5: The linear combination of luminance parameters and basis images

the virtual objects are rendered with each light. Virtual cameras, which look towards each shadowing plane perpendicularly, capture the shadows of virtual objects cast on the shadowing planes. Finally, we obtain basis images $Ib_{j,i}(j = 1, 2, ..., m, i = 1, 2, ..., n)$ with every shadowing planes and lights (Figure 3(d)).

3 Real-time shadowing process

3.1 Acquiring the luminance of the scene

We obtain the information in the luminance of the scene with an omni-directional image taken by a video camera with a fisheye lens. Then we project the polyhedron noted above onto the omni-directional image, and compute the sum total value of internal pixels per each triangular region (Figure 4(a)). At this point, we bring in the luminance parameter $S_i(i = 1, 2, .., n)$ to represent the luminance of each light source.

For the shading of virtual objects, we set six virtual directional lights in the scene. The intensity of every light is determined by the parameter Si (Figure.4(b)). With that we can express correct shadings of virtual objects responding to the real scene.

3.2 Synthesis of basis images

Meanwhile, we compute the linear combination of basis images $Ib_{j,i}$ with S_i as shown in Figure 5.

$$Isum_j = \sum_{i=1}^{n} S_i \times Ib_{j,i} \tag{3}$$

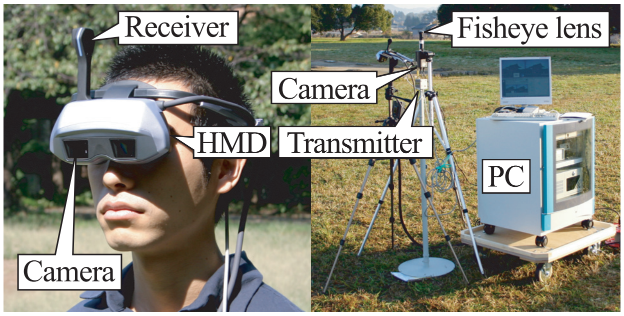


Figure 6: Apparance of our MR-system

$$Asum_j = \sum_{i=1}^{n} S_i \times a_{j,i} \tag{4}$$

where $Isum_j$ is the synthesized soft shadow image, $a_{j,i}$ make up the area of remaining unaffected by any shadow of virtual objects in basis images, and $Asum_j$ shows the sum total of no shadowing area so that the ratio of $Isum_j$ and $Asum_j$ represent the effect of shadows of virtual objects.

3.3 Mapping shadow images onto shadowing planes

Finally, we superimpose virtual objects onto a real image. We set soft shadow images synthesized from basis images onto shadowing planes as an alpha texture. Then we render the virtual scene and synthesize it with the real scene. Virtual objects are properly shaded with light sources responding to the illumination of the real scene.

The shadowing plaenes can represent simulated shadows of virtual objects over both the real image and objects themselves. And also, they can express the shadows on virtual objects casted by real objects using basis images which store shadows generated from objects corresponding to the real scene.

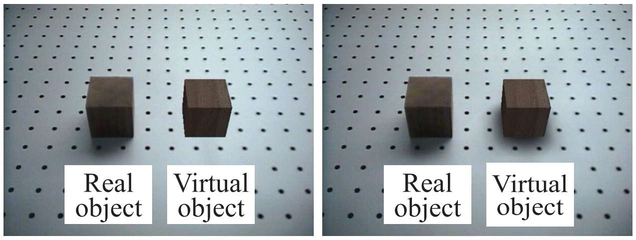
4 Experimental Result

We tested our proposed method in both an indoor scene and an outdoor scene.

Our system is mainly based on Canon's MR Platform system [11], which includes a video see-through head mounted display and the Polhemus's Fastrak, six degree-of-freedom (DOF) electromagnetic tracking sensor. We also used a Windows PC (2.40GHz Core 2 Duo E6600 CPU, 1024MB RAM, nVIDIA GeForce7950GT GPU). The appearance of our equipment is shown in Figure 6.

Figure 7 and 8 show the comparison of synthesized images. We can see that both the shading and shadows of virtual objects are reasonably matched to the illumination in the real scene.

In the experiment of an outdoor scene (Figure 8), we used 1520 basis images generated from 40 directional lights and 38 shadowing planes. The size of



(a) (b)

Figure 7: Results for an indoor scene;
(a) before shadowing; (b) after shadowing.

(a) (b)

Figure 8: Results for an outdoor scene;
(a) before shadowing; (b) after shadowing.

each basis image is 128 × 128 pixels and the resolution of the synthesized image is 640 × 480 pixels. We implemented the computation of the linear combination of basis images on the fragment shader to making use of GPU acceleration. The virtual objects consist of 58500 polygons and we successfully achieved about 18fps frame rate.

5 Conclusion

This paper proposed a fast shading and shadowing method for MR. We approximate the illumination in the scene and generate the basis images using the shadowing planes. Soft shadow images, correspond to the illumination of the real scene, are synthesized from basis images. Then we map these shadow images onto shadowing planes as alpha texture and express soft shadows of virtual objects in real-time. However the proposed method is applicable only to static scene, it is effective for a specific application (e.g. MR-based restoration of cultural herigates in outdoor scene). Our method can achieve the consistency of illumination and improve the quality of synthesized image in MR-systems.

Acknowledgement

This research was, in part, supported by the Ministry of Education, Culture, Sports, Science and Technology, under the program, "Development of High Fidelity Digitization Software for Large-Scale and Intangible Cultural Assets." The experiment in Asuka Village was supported by the Ministry of Land, Infrastructure and Transport. We are also grateful to the village office of Asuka, the Archaeological Institute of Kashihara and the National Research Institute for Cultural Properties.

References

[1] R. Azuma, “A survey of augmented reality,” *Presence: Teleoperators and Virtual Environments*, vol. 6, no. 4, pp. 355–385, August 1997.

[2] R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre, “Recent advances in augmented reality,” *IEEE Computer Graphics and Applications*, vol. 21, no. 6, pp. 34–47, November 2001.

[3] O. Bimber, A. Grundhofer, G. Wetzstein, and S. Knodel, “Consistent illumination within optical see-through augmented environments,” in *Proc. IEEE and ACM Int. Symp. on Mixed and Augmented Reality (ISMAR03)*, October 2003, pp. 198–207.

[4] P. Debevec, “Rendering synthetic objects into real scenes: bridging traditional and image-based graphics with global llumination and high dynamic range photography,” in *Proc. SIGGRAPH ’98*, July 1998.

[5] S. Gibson, J. Cook, T. Howard, and R. Hubbold, “Rapid shadow generation in real-world lighting environments,” in *Proc. Eurographics Symp. on Rendering (EGSR03)*, June 2003, pp. 219–229.

[6] M. Haller, S. Drab, and W. Hartmann, “A real-time shadow approach for an augmented reality application using shadow volumes,” in *Proc. Symp. on ACM Virtual Reality Software and Technology(VRST’03)*, October 2003, pp. 56–65.

[7] K. Jacobs and C. Loscos, “Classification of illumination methods for mixed reality,” in *Proc. Eurographics State of the Art Report(STAR)*, September 2004, pp. 95–118.

[8] J. S. Nimeroff, E. Simoncelli, and J. Dorsey, “Efficient re-rendering of naturally illuminated environments,” in *Proc. Eurographics Workshop on Rendering (EGWR94)*, June 1994, pp. 359–373.

[9] I. Sato, M. Hayashida, F. Kai, Y. Sato, and K. Ikeuchi, “Fast image synthesis of virtual objects in a real scene with natural shading,” *The Institute of Electronics, Information and Communication Engineers, D-II (in Japanese)*, vol. J84-D-II, no. 8, pp. 1234–1242, August 2001.

[10] I. Sato, Y. Sato, and K. Ikeuchi, “Acquiring a radiance distribution to superimpose virtual objects onto a real scene,” *IEEE Trans. on Visualization and Computer Graphics*, 1999.

[11] S. Uchiyama, K. Takemoto, K. Satoh, H. Yamamoto, and H. Tamura, “Mr platform: A basic body on which mixed reality applications are built,” in *Proc. Int. Symp. on Mixed and Augmented Reality (ISMAR02)*, September 2002, pp. 246–253.