Virtual Kawaradera: Fast Shadow Texture for Augmented Reality

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Abstract. The Kawaradera temple, formerly located in the village of Asuka, was one of the oldest temples in Japan; unfortunately, it was destroyed by fire in the latter part of the Muromachi Period. The Virtual Kawaradera Project is an outdoor on-site augmented reality application that uses a head mounted display, whose purpose is to reconstruct and represent Kawaradera virtually. We begin with a short introduction to the project. Then we suggest a method for fast shadowing of virtual objects using a set of *basis images* that has been rendered in advance. We first describe how, in the preparatory stages, we approximate the illumination of the scene with a number of directional lights and render the virtual objects with each light in order to obtain shadow images. We then describe how we synthesize these images with the linearity relationship between a luminance of light and a brightness of object surface, and set the synthesized shadow images onto *shadowing planes*, which cover objects roughly, as a texture. Finally we tell how we can compute shadings and shadows of virtual objects responding to the illumination of the real scene, and support a change of the user's viewpoint. The proposed method is especially appropriate for static models such as buildings. Hence, we chose to apply this method to the Virtual Kawaradera Project, with the goal of improving the quality of synthesized images in augmented reality systems.

1. Introduction

Augmented Reality (AR) systems allow us to see real scenes that contain computer-generated virtual objects [1][2]. As wearable computers are developed, outdoor applications, some of which are intended to represent lost cultural heritage objects with augmented reality systems, are rapidly become feasible [3][4]. Considering the problem of cost and archaeological concerns, it is difficult to rebuild these devastated buildings. Instead, rather than rebuilding the cultural heritage objects, it would be preferable to exhibit computer graphics models of them to visitors, hereby increasing the visitor's understanding of the significance of the historical sites. However, for the restriction of real-time synthesis of the virtual and real worlds, these applications had to simplify the rendering process and presented only subternatural images. Consequently, advancing the quality of synthesized images in the field of augmented reality would be a significant contribution to augmented reality systems.

For the seamless integration of virtual objects with an image of a real scene, it is important to achieve consistency of illumination. First of all, the shading of the virtual object needs to match that of other objects in the environment. Also, the virtual object must cast a correct shadow onto the real scene. But it is not easy to obtain correct illumination because real scenes usually include both direct and indirect illumination distributed in a complex way.

In the past, two typical methods were proposed. One technique measures the illumination of environment directly using a camera [5][6][7]. Another technique presumes the illumination environment from the shadow of the real object in an input image indirectly [8]. Even though many of these techniques enable us to obtain synthesized images with convincing shadings and shadowing, they are unsuitable for augmented reality because they take too much time for computation.

On the other hand, some methods for fast calculation of soft shadows have been proposed in the field of computer graphics [9][10][11]. These methods can generate a natural shadow efficiently, but it is rather difficult to correspond to the illumination of a real world that is changing every moment.

Recently, Sato et al. proposed a unique method for fast image synthesis with natural shading [12]. They use a set of images rendered in advance with multiple lights, which approximate the illumination of the real world, and synthesize these *basis images* (as they call them) to generate soft shadows using the linearity relationship between a luminance of light and a brightness of object surface. In this method, since generation of the shade of a virtual object is performed off-line, we have enough time for rendering so that we can get a high quality images with advanced rendering techniques such as the radiosity method. Moreover, in the synthetic stage of virtual objects and a real scene, the process of synthesizing virtual objects with an image of a real scene is fast because we compute only the linear sum of every *basis image* without re-rendering. However, this method is applicable only to still images and fixed viewpoints, and cannot handle scenes where the position and direction of a camera transform every second.

The purpose of this study is to present a new, efficient method for superimposing virtual objects onto real scenes with convincing shading and shadows cast onto the real scenes in the augmented reality application. In this paper, we extend Sato et al.'s work, and suggest a method, which can support arbitrary viewpoints with mapping shadows onto 3D models. We also use *basis images* for fast computation of natural shadows, but we finally set the generated shadows onto some planes (hereafter called *shadowing planes*), which cover objects roughly, so that we correspond to the movement of users' viewpoints and represent correct shadows.

The rest of the paper is organized as follows. In Section 2, we introduce the history of Kawaradera and its current state, and the details of creating a computer graphics model of this temple. In Section 3, we explain how to approximate the illumination of the real world, how to generate the *basis images* of every *shadowing plane*, and how to synthesize virtual objects and a real scene with convincing shadings and shadowing. Then, in Section 4, we describe the experimental results of our proposed method when applied to outdoor environments as in the site of Kawaradera. Finally, Section 5, we present concluding remarks.

2. The virtual reconstruction of Kawaradera

In this section, we describe the historical background of the Kawaradera temple and its current state. Then we explain how to construct the computer graphics model of Kawaradera.

2.1 Kawaradera temple

The Kawaradera Temple, located in the village of Asuka, about 25 kilometers south of Nara city, is, like the famous Horyuji Temple, one of the oldest temples in Japan. It is considered to have had its beginning during the reign of Emperor Tenji (662-671) and came to flourish as the national religion. In the 8th century, Kawaradera declined because of the capital relocation to Heijokyo in Nara, and eventually burned down in the late Muromachi period. Nowadays, the main buildings are lost and only the foundation and cornerstones are left just like many of the ruins of wooden temples of those days (see Fig.1 left). As a result of the latest excavation, it become clear that Kawaradera was absolutely magnificent; it had a tower, two main halls of a Buddha temple, a bell tower, a scripture house, three viharas, an inner gate, a south gate, and many corridors. Although Kawaradera receives much attention and many tourists visit it, they are disappointed to find that so little remains of the original structure.

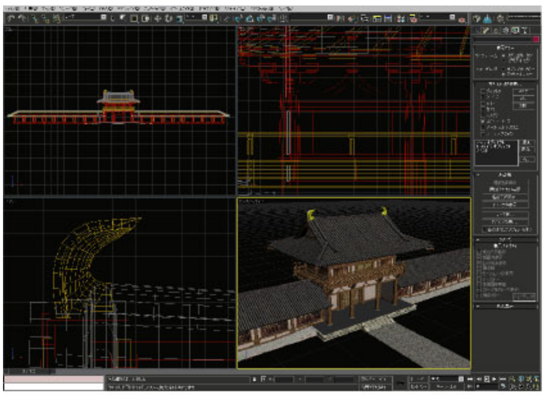
Therefore, we decided to begin the Virtual Kawaradera Project, by which we intend to virtually restore Kawaradera to its original state. The purpose of this research is not only to present a computer graphics model of those days, but also to exhibit the restoration model with augmented reality systems for tourists. Finally, we aim to develop effective presentation.

The current state of Kawaradera | CG model (Chumon and Kairo)

Fig.1 The site of Kawaradera and the computer graphics model of restration

2.2 Modelling and texture mapping

In the process of constructing the computer graphics model of Kawaradera, we referred to the detailed restoration proposal based on the result of the excavation in 1957. Most of the Japanese temples usually consist of many components; some of them, such as Hijiki and Kaerumata, have complicated curved surfaces. In order to improve the performance of real-time rendering, a very detailed model is undesirable because of the increase in computation cost. Therefore, we decided to make a simple geometric form, and use texture mapping to cover the expression of details. Since the target building had already been lost, we used a photograph of another temple, the Horyuji Temple, which is believed to have been built around the same time as the Kawaradera. At the present moment, we are in the process of building a 3D model of this temple, and have just completed the Chumon (inner gate) and the Kairo (corridor) (see Fig.1 right). Fig.2 shows the source materials for modelling and texture mapping.



Modelling with 3ds max by discreet

Fig.2 The source materials and the process of modelling

3. Synthesis of virtual object and real scene

In the following subsections, we explain how to synthesis virtual objects and a real scene with natural shading and shadowing. First, we describe the approximation process of the illumination of the real world. Then we show the details of *basis images* and *shadowing planes*, which are set to surfaces of virtual objects as a texture. Finally, we explain how to measure the illumination of the scene, and the process of computing natural shadows and superimposing virtual objects onto a real image.

3.1 Approximation of the illumination of the scene

Considering the illumination of the real world, we have to take into account both the direct light source, such as sun and electric lighting, and effect of inter-reflection from wall, floor, and any surface of the scene. For the purpose of regarding all these contributions of the illumination of the scene, we assume a hemispheric surface light source as illustrated in the left part of Fig.3.

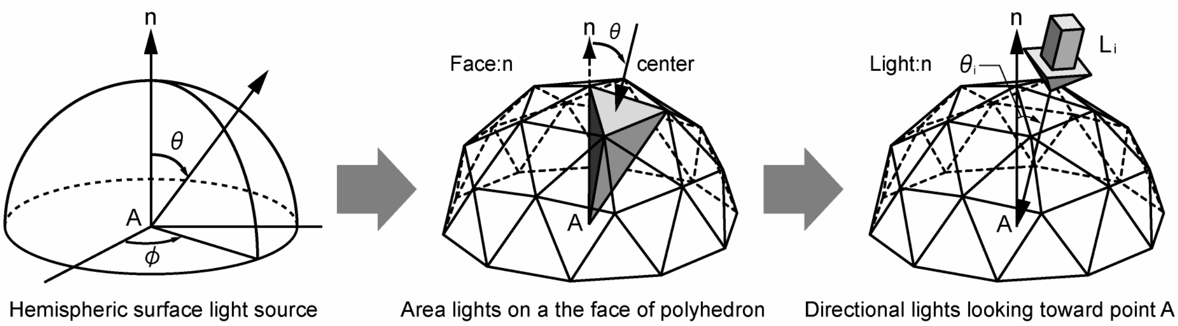


Fig.3 The approximation of illumination of the real world

In this model, we can compute the illuminance of the point A with whole surface light source as

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

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 (see Fig.3 center). In this paper, we adopted the geodesic dome Class 1 D-2 as a polyhedron model. It consists of 40 triangular faces, which have about the same area.

At this stage of approximation, Sato et al. took samples only from the direction of vertices, but we decided to take samples from whole points in every polyhedron face, so that we can correspond to various conditions of outdoor scenes. However, the computation of area lights takes a lot of time, so we approximate the attenuation parameter $\cos\theta_i$ of every pixel within the triangular faces by that of the center of the face. Then the illuminance of the point A is represented as

$$E = \sum_{i=1}^{n}\cos\theta_i \sum_{j=1}^{p} L_j \tag{2}$$

where L_j is the luminance per unit area, $\cos\theta_i$ is the attenuation parameter of the central pixel, p is the number of pixels in each face, and n is the number of faces in applied polyhedron, e.g., 40 in this paper. At this stage, we can approximate the double integral of the above equation (1) by the discrete integral with every face of the polyhedron.

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 (see Fig.3 right). We compute the value of whole pixels in each face, of course, but let these directional lights represent the effect of whole illumination of the scene. The illuminance of point A is represented as

$$E = \sum_{i=1}^{n} L_i \cos\theta_i \tag{3}$$

where L_i is the intensity of every directional lights.

As shown in Fig.4, we generate *basis images* with each directional light later. However, for the restriction of a valid number of light sources in OpenGL, we have to reduce the number of light sources in the virtual scene by six. So we selected six light sources out of 40 directional lights, and set each light source to respond to neighbourhood triangular areas.

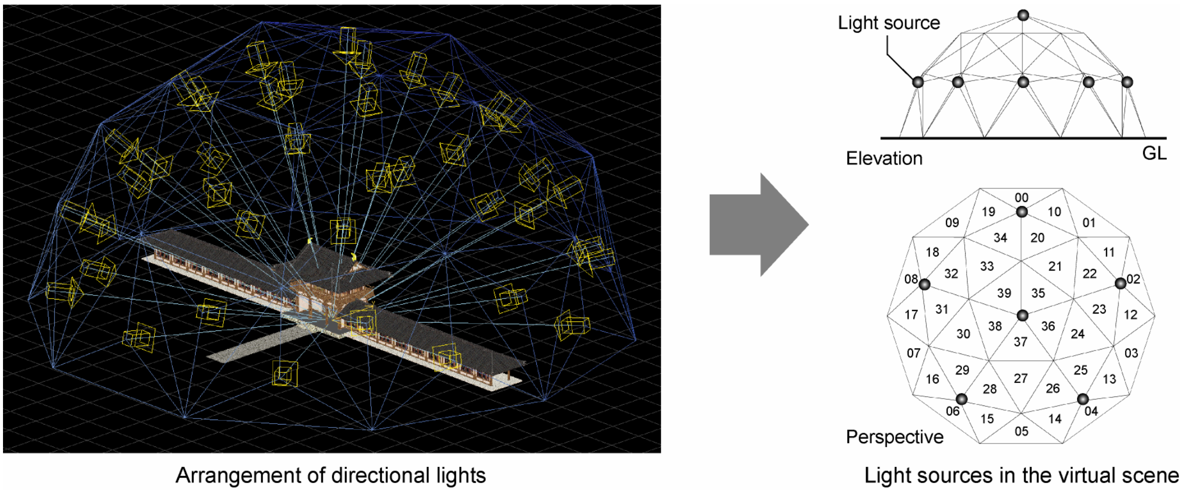


Fig.4 The arrangement of directional lights and light sources in the virtual scene

3.2 Generation of the *basis images*

As described in the previous section, we approximate the luminance of the real scene by a number of directional lights. Secondly, we render virtual objects with each directional light in order to obtain *basis images*, which show shadows of virtual objects and are intended for use in generating soft shadows later. Fig.5 shows the part of the *basis images*, which expresses the shadow of the virtual object cast onto the ground.

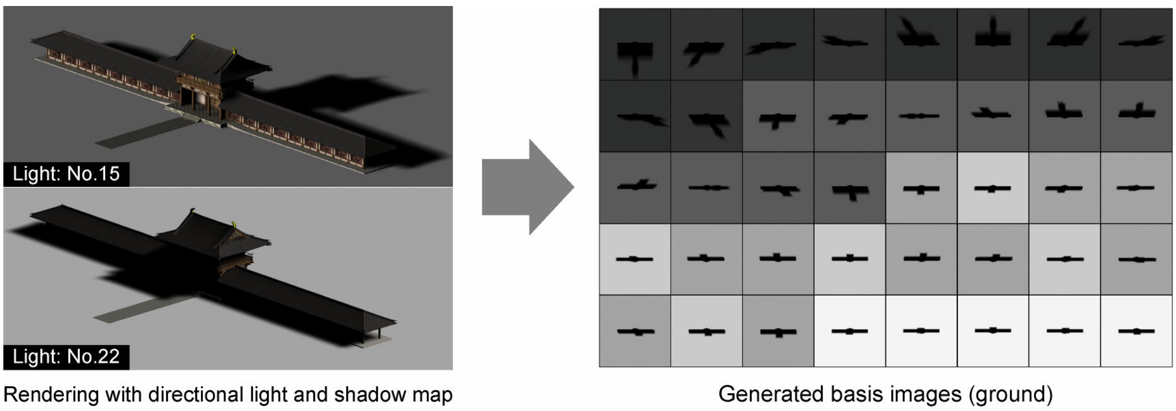


Fig.5 The Generation of *basis images*

Our target, the old Japanese architecture, consists of many complicated parts; therefore, it is not efficient to calculate shadows of all components. So we decided to express the shadow with rough areas, which include many detailed components. Actually, we set some *shadowing planes* in front of virtual objects, and onto which map shadow images, that are synthesized with *basis images*, as mask texture so that these shadowing planes only display as shadows. Each *shadowing plane* covers virtual objects roughly, and is offset a little in the direction of a user's viewpoint (see Fig.7 right). In off-line rendering, we take into account all parts of virtual objects in the scene for generating *basis images*, but in on-line rendering, we cut the cost of computation by using only *shadowing planes* to show shadows of virtual objects.

We explain the process of generating *basis images* as follows. First, we set parallel projected cameras along the normal direction of every *shadowing plane*. Then we perform rendering with each directional light $(L_j; i = 1,2,\cdots,n)$ and get *basis images* $(Ib_{j,i}; j = 1,2,\cdots,m, i = 1,2,\cdots,n)$ per each *shadwing planes* (m). We use 3ds max 6 TM by discreet as a rendering software, and use shadow map algorithm for shadowing.

On the other hand, if we set n lights and m planes on the scene, $m \times n$ *basis images* will be generated. However, some planes, which cover the walls of virtual buildings and stand vertically, might completely be included with shadows in the case of being illuminated from behind. So we do not need to use these entire black images as texture that was generated by this specific situation. Instead of them, we just count zero luminance.

3.3 Synthesis of virtual object and real scene

This section explains how to calculate shadows rapidly using *basis images* generated in the preparatory stage. First, we get the information of the luminance of the scene with an omni-directional image taken by a CCD camera with a fisheye lens. Then we project the polyhedron noted above onto the omni-directional image, and calculate the sum total value of internal pixels per each triangular region. With that, we bring in the luminance parameter $S_i (i = 1,2,\cdots,n)$ to represent the luminance of each light source, which approximates the illuminance of the scene as we mentioned above. The sum value of each triangular region which correspond to faces of the polyhedron, are assigned to S_i.

Next, we decide the intensity of light sources in the virtual scene. Since the number of light sources in OpenGL is limited and smaller than that of S_i, we determin the intensity of light sources with the sum of S_i taken from neighborhood regions.

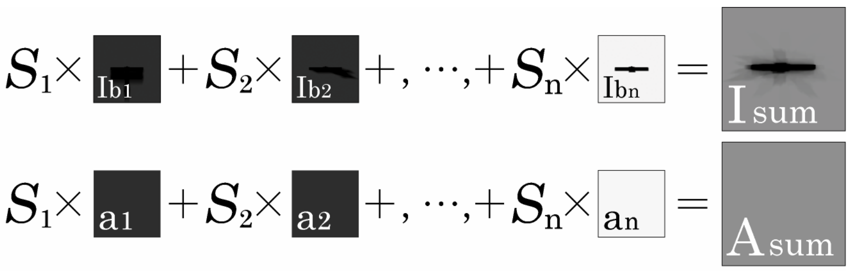


Fig.6 The linear sum of luminance parameter and *basis images*

Meanwhile, as shown in Fig.6, we calculate the linear sum of *basis images* $Ib_{j,i}$ with S_i as

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

where $Isum_j$ is the synthesized soft shadow image. In the same way, we calculate the sum of the brightness of pixels $a_{j,i}$, which make up the area of remaining unaffected by any shadow of virtual objects in *basis images*. The value of $a_{j,i}$ shows only the attenuation relating to the direction of incidence of light.

$$Asum_j = \sum_{i=1}^{n} S_i \times a_{j,i} \tag{5}$$

where $Asum_j$ is the sum total of the value of no shadowing area in each *basis image*. At this point, the ratio of $Isum_j$ and $Asum_j$ represent the effect of shadows of virtual objects. So we divide $Isum_j$ by $Asum_j$ and set it onto each *shadowing plane* as an alpha texture and express the rough shadows of virtual objects (see Fig.7).

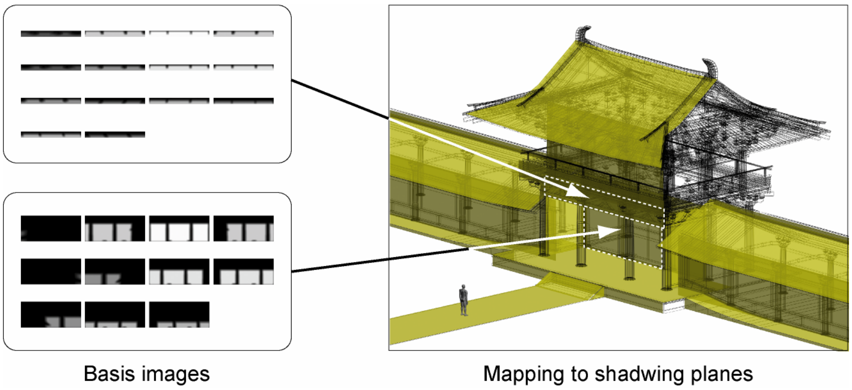


Fig.7 Mapping *basis images* onto *shadowing planes*

Finally, we superimpose virtual objects onto a real image. In the beginning, we divide the input image taken from a camera attached to a head mounted display into three areas. One is the pixels which show virtual objects. We superimpose this area directly onto a real image. Another is the pixels which show a real scene and we let it lie. The other is the pixels which show a real scene coming under the influence of shadows of virtual objects (e.g., a part of the ground near virtual buildings). We already set up the effect of shadows with the ratio of $Isum_j$ and $Asum_j$, so that we multiply the input image by this ratio as below.

$$P' = P\frac{Isum}{Asum} \tag{6}$$

where P is the input image of real scene. P' represented the shadowing area of synthesized image. Finally, we superimpose virtual objects onto a real image with convincing shadings and shadows onto the real scene. We are not concerned with the occluding of virtual and real objects in this work.

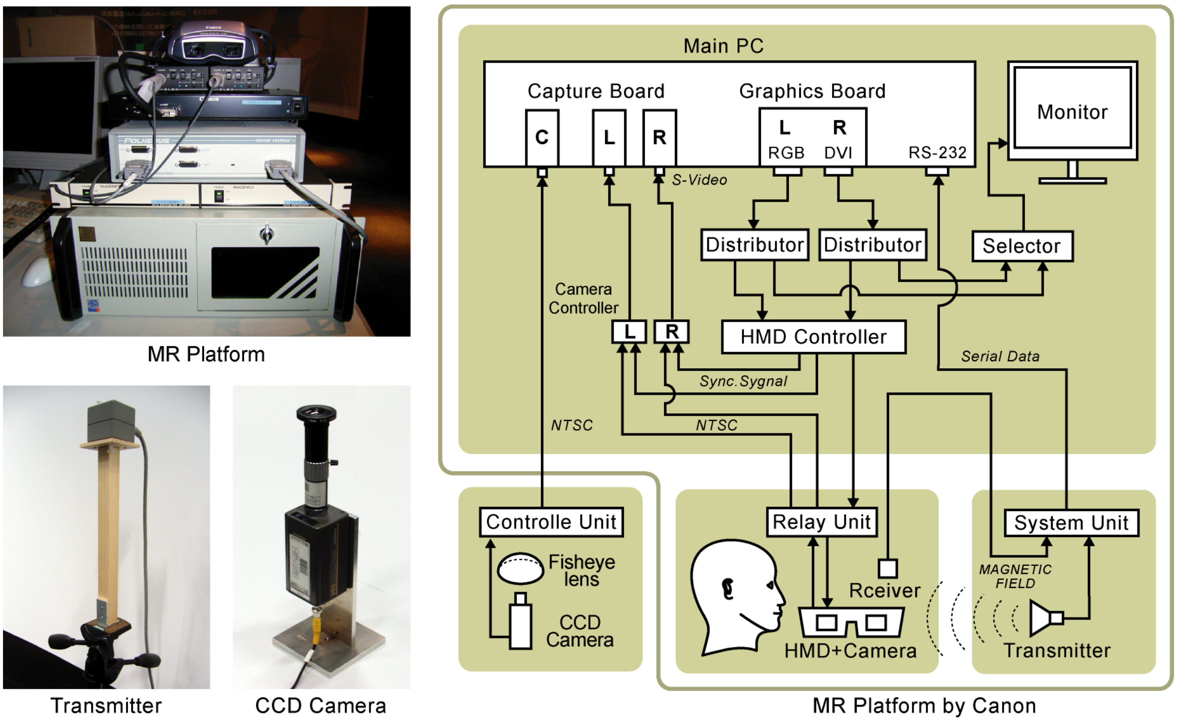


Fig.8 MR Platform, Transmitter and CCD camera with a fisheye lens

4 Experimental Results

We have tested our proposed method in outdoor environments as in the site of Kawaradera. Our system is mainly based on Canon's MR Platform system[14], which includes a video see-through head mounted display. We also used the Polhemus's Fastrak, six degree-of-freedom (DOF) electromagnetic tracking sensor, and Linux PC (2.80GHz Pentium4 CPU, 1024MB RAM, nVIDIA GeForce FX5950 Ultra GPU). The detail of the MR Platform system is shown in Fig.8, and the appearance of our equipment is shown in Fig.9.

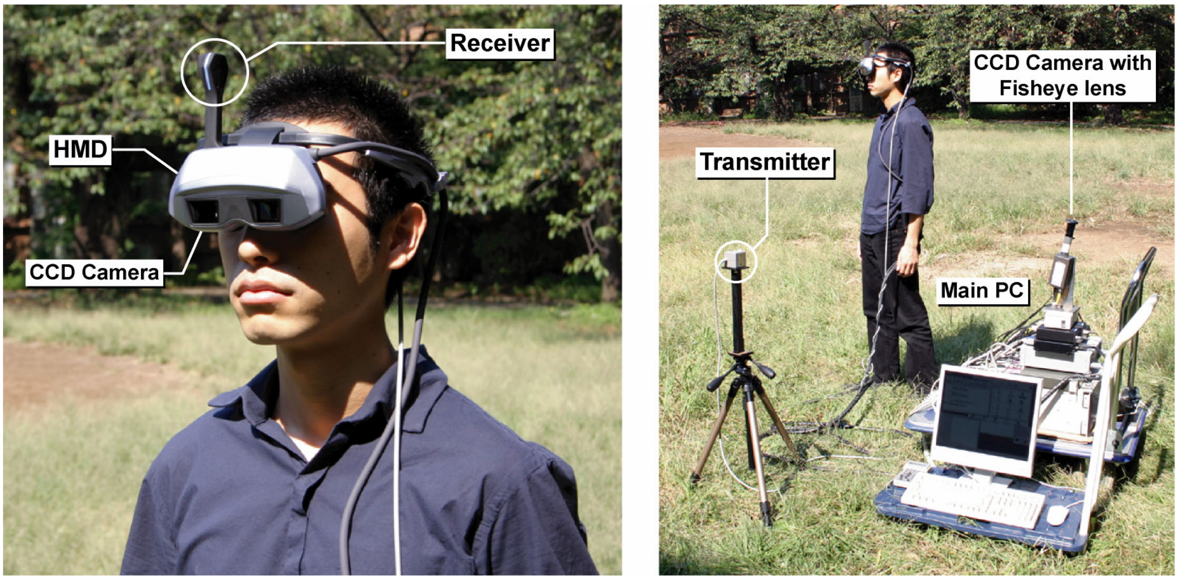


Fig.9 HMD and other equipments

For the geometric alignment, we adopted the hybrid method which combines a 6-DOF tracking sensor and computer vision technique using marker, offered by MR Platform system. The virtual model we use is the Chumon (inner gate) and a part of Kairo (corridor) of Kawaradera, and we cut off objects that are hidden from the user's eye, in order to improve the rendering performance.

Fig.10 and Fig.11 show the result of the experiment. We can see that both the shading and the shadow of virtual building are reasonably well matched to the real scene and that the shadow of virtual objects is convincingly cast onto the real ground according to changing illumination conditions.

In the experiment, it became clear that the number of *basis images* has a significant effect on the processing speed. We used 40 directional lights and 8 *shadowing planes* to generate *basis images*, and removed meaningless images, which are completely black with shadows. Finally, we were able to reduce the number of *basis images* from 320 to 170. Besides this work saving, we also cut out the effect of comparatively low Si because a much weaker light source has almost no discernible affect on the calculation of linear sum of Si and $Ib_{j,i}$. We set a threshold for the and skip computation and have successfully improved the frame rate.

Furthermore, we noticed that the illumination of the outdoor environment changes little or nothing all in every frame. Thus, we computed the difference of luminance parameter S_i, and recompute the shadings and shadowing of virrual objecs only if it exceeded the threshold. In the experiment, almost every frame did not need the recomputation in fact, and finally we could improve the frame rate about 6.3FPS. Currently, the model of the virtual temple is relativery complicated and heavy to display. Even where we do not excute processing of shadowing (only display models), we could get only 6.8FPS. For the purpose of real-time rendering, it is also nesessary to improve the efficiency of rendering process of virtual models.

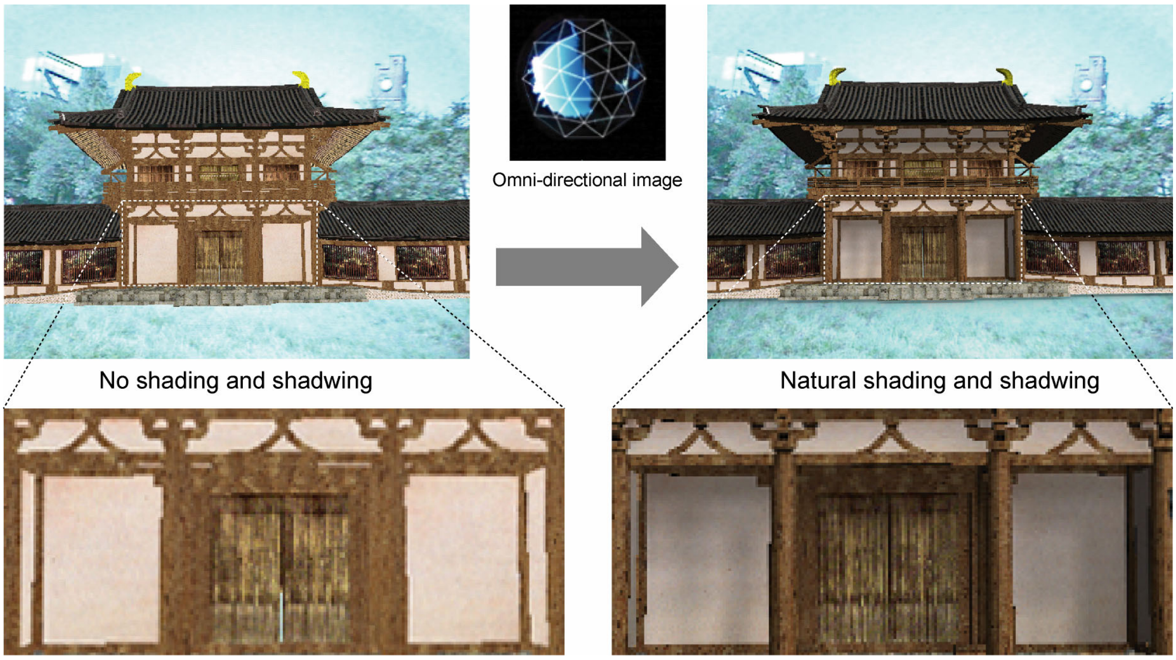


Fig.10 The effect of natural shading and shadowing

Fig.11 Synthesized images under changing illumination condition

4. Conclusion

In this paper, we introduce the Virtual Kawaradera Project, which is intended to not only reconstruct the lost cultural heritage virtually, but also to represent on site with an augmented reality system. Furthermore, we propose the method of fast shadowing, which is especially appropriate for a static scene like buildings. In the presented method, a set of *basis images* rendered in advance is used to generate a soft shadow in real-time and the synthesized shadow is set to a *shadowing plane* as a texture. Therefore, our method can support the movement of the user's viewpoint in the augmented reality system.

In the experiment, we approximated the illumination of the scene by 40 directional lights. The sampling rate of lights is essential to improve the photographic reality of synthesized images. However, considering the cost of computing, we need to contrive a strategy for managing many *basis images*. With regard to this matter, one method we are trying is to compute the difference of illumination of the scene and add it to the previous frame. Also the parallel processing with GPU will have the effect of speeding up computation.

As the future work, we will continue to create the entire model of Kawaradera, and try to improve the efficiency of rendering process of virtual models. In addition, we will also attempt to solve a more challenging problem such as matching the radiance of the virtual scene with that of the real scene automatically for the further advancement of synthesized images in augmented reality systems.

Acknowledgments

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The texture of the CG model in Fig.1, Fig.2, Fig.4, Fig.5, Fig.10, and Fig.11 is synthesized from the pictures of "Nara Rokudaiji Taikan vol.1 Horyuji vol.1"[14], "Horyuji Gojyunoto Fumetsu no konchiku 1"[15], and "Toshodaiji Kondo Fumetsu no kenchiku 2" [16]. The line drawings in Fig.2 are sited from National Research Institute for Cultural Properties, Nara's "Drawings of Kawaradera restoration model"[17]. Fig.2 upper center images of Onigawara and Kegyo are cited from "Nara Rokudaiji Taikan vol.1 Horyuji vol.1"[18]. Fig.2 bottom center image of ceiling is cited from "Toshodaiji Kondo Fumetsu no kenchiku 2"[19]. Fig.2 bottom center image of door is cited from "Horyuji Gojyunoto Fumetsu no konchiku 1"[20].

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