DEVELOPMENT AND EVALUATION OF ASUKA-KYO MR CONTENTS WITH FAST SHADING AND SHADOWING

Tetsuya Kakuta [a], Takeshi Oishi [a], Katsushi Ikeuchi [a]

[a] The University of Tokyo, Interfaculty Initiative in Information Studies, 7-3-1 Hongo Bunkyo-ku Tokyo, Japan - (kakuta, oishi, ki)@cvl.iis.u-tokyo.ac.jp

ABSTRACT:

We developed Mixed Reality (MR) contents that reconstructed the ancient capital of Asuka-Kyo and applied a fast shading and shadowing method that used shadowing planes. We conducted a subjective evaluation experiment with Head Mounted Display, which showed that displaying these contents increased the audience's knowledge of both Asuka-Kyo and MR technologies. We also conducted impression evaluation tests with and without shading and shadowing. These tests confirmed that shading and shadowing increased the audience's favorable responses to the evaluating factors of "Realistic," "Spectacular," and "Entertaining."

1. INTRODUCTION

Virtual Reality (VR) technologies enable us to digitalize cultural heritage objects as 3D reconstructed models (Utsugi et al., 2001; Tanikawa et al., 2004; Callieri et al., 2006). Using internet and VR systems, we can release to the public the digital contents of these objects that are normally confined to a museum or located in their original sites. These digital contents can then be utilized by educational, entertainment, and tourism industries.

Superimposing reconstructed 3D models of cultural heritage objects on their original sites using Mixed Reality (MR) has been widely carried out in recent years (Azuma, 2001). There are some restrictions on conventional VR contents. One limit is that we cannot appreciate them outside PC monitors and VR theaters. Another is that they lack a sense of reality compared with the original structures in their natural environments. On the other hand, MR allows us to make use of the landscape and atmosphere of the real environment and provide better experience for the users. Discovered ruins should be kept as close to the originals as possible for purposes of archaeological studies. MR can achieve effective representation of a reconstructed 3D model without having much effect on the original site and can thus strike a balance between preservation and presentation.

Many MR systems have been developed to virtually reconstruct 3D models of lost cultural heritage objects. Remains of ancient Greece have been reconstructed by the ARCHEOGUIDE project (Vlahakis et al., 2002). The LIFEPLUS project proposes 3D reconstruction of ancient frescos and paintings of Pompeii (Papagiannakis et al., 2002). Some old wooden Japanese buildings, the Nara palace site (Tenmoku et al., 2004), and the Kawaradera temple (Kakuta et al., 2004), are also represented by using MR technologies.

For the MR systems that aim to restore archaeological sites outside, it is important to achieve consistency of illumination. The shading of the virtual objects needs to match that of other objects in real environments. The virtual objects should also cast a correct shadow onto the real scene. Several methods have been proposed to solve this photometric problem in MR. Jacobs et al. provided a detailed survey of illumination techniques for MR (Jacobs et al., 2004). However, most methods are demonstrated on indoor scenes, and few of them are carried out at interactive update rates. Kakuta et al. suggested a novel method to express soft shadows of virtual objects in real time (Kakuta et al., 2007). This method is considered appropriate for static models in outdoor scenes, but it does not include actual applications for cultural heritage objects or subjective evaluation.

The evaluation of subjective psychological factors related to the illuminant consistency in MR is not emphasized in present research projects. Sato et al. reported an evaluation of shadow error between real and virtual occlusion objects (Sato et al., 2003). Sugano el al. also pointed out the importance of shadow representation for increasing object presence (Sugano et al. 2003). Photometric inconsistency on human faces was evaluated by Takemura et al. (Takemura et al., 2006). Though they performed a quantitative evaluation test for illuminant consistency, there was no discussion on what subjective psychological factors contributed to the sense of reality and presence, or how we could increase the overall satisfaction level of users with the contents. Furthermore, these cases were executed in an indoor environment, and subjective evaluation for actual MR contents in outdoor scenes was not carried out.

In this paper, we report an advanced evaluation test for illuminant consistency in MR. The motivation of this research is to identify psychological factors that influence evaluation of the contents and evaluate the subjective effectiveness of shadow representation using actual MR contents in an outdoor scene. We developed the MR contents of Japan's oldest capital, Asuka-Kyo, and applied the real-time illumination method (Kakuta et al., 2007) to this content.

Our reconstruction target, as stated, was the ancient capital of Asuka-Kyo, which is said to have existed in the Asuka district around the sixth and seventh centuries. The evaluation test was carried out as part of an open demonstration for the public on site, and the evaluators were selected from general tourists. Then we compared the learning effect before and after experiencing the MR contents and evaluated the improvement of their knowledge and interest in Asuka-Kyo and MR

(a) Current state of Asuka-Kiyomiharanomiya
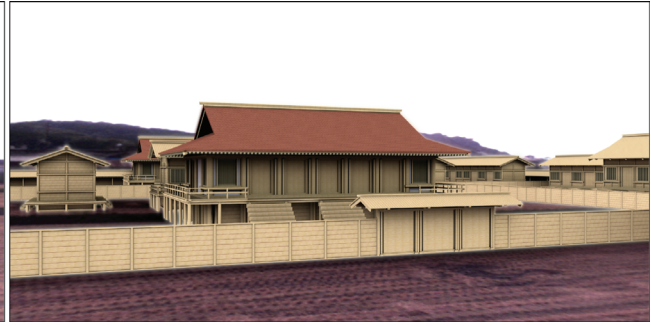
(b) Reconstruction image

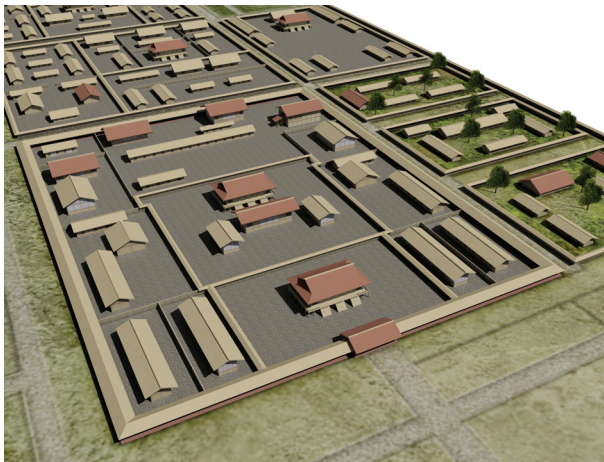Figure 1: Current photo of Asuka-Kiyomiharanomiya and its reconstruction image

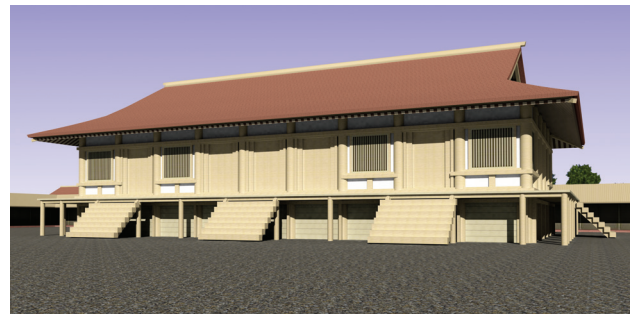Figure 2: CG model of Asuka-Kiyomiharanomiya palace

Figure 3: CG model of Ebinoko great hall

technologies. The effectiveness of shadow was evaluated by the semantic differential method and factor analysis using synthesized images with and without shade and shadow on the MR system.

The rest of the paper is organized as follows, In Section 2, we introduce the outline of Asuka-Kyo and the process of constructing its MR contents. Then we describe the fast shading and shadowing method that we apply to the contents. In Section 3, the educational effect of the proposed contents is evaluated. The effectiveness of shading and shadowing for MR is discussed in Section 4. Finally, in Section 5, we present concluding remarks.

2. ASUKA-KYO MR CONTENTS

In this section, we present a brief overview of Asuka-Kyo and the process of creating MR contents. The fast shading and shadowing method that we apply to the contents is explained in the next section.

2.1 Reconstruction of CG model of Asuka-Kyo

Asuka-Kyo indicates the generic name of the capital where the palaces of various emperors were assumed to be in the Asuka area from the late sixth to the late seventh centuries. Though many tourists visit the historic sites of Asuka village, most of them cannot visualize the original sites and there is no way other than to rely on imagination to visualize the spectacle of Asuka at that time. Since Asuka village is a part of the application region of the "Law Concerning Special Measures for Preservation of Historic Natural Features in Ancient Cities" and there is strict development control, it is difficult to build a new museum or replica for tourist. Moreover, excavation still

continues and there is a possibility that the restoration plan will change with a newly-discovered archaeological fact. Against such a background, MR technology is very effective in reconstructing the ruins because it can overlay virtual buildings on the real site without harmful effect.

The restoration area in this project extends about 1350 meters in the north-south direction and about 600 meters in the east- west direction. Our MR contents contain the Asuka-Kiyomiharanomiya palace, the Kawaradera temple, the Asukadera temple, the Ishigami site, and the Asuka Enchi site.

It is known that there are multilayered remains in the palace area. We also decided to restore the Den-Asuka-Itabukinomiya III-B term (672-694) because it is in the upper layer and the position of the buildings is already known. The III-B term called Asuka-Kiyomiharanomiya differs from the III-A term called Nochino-Asuka-Okamotonomiya in the existence of the additional Ebinoko great hall in the southeast region. The Asuka-Kiyomiharanomiya palace expands 720 meters in the north-south direction and 100-450 meters in the east-west direction. It is said that there were government offices and gardens around the palace.

To create the CG model of Asuka-Kyo, we referred to the reconstruction drawings provided from the Nara National Research Institute for Cultural Properties and the Archaeological Institute of Kashihara. We modelled CG buildings of Asuka-Kyo with 3dsmax by Autodesk Inc. manually. The painted surface, tiled roofs of temples and the plain wood material of palace buildings are expressed by texture images. Figure 2 shows the reconstruction model of the Asuka-Kiyomiharanomiya palace, and Figure 3 shows that of the Ebinoko great hall. Figure 1 shows the synthesized image of the Asuka-Kiyomiharanomiya palace and the current landscape of the Asuka village. The total number of polygons in these models is about 686,000.
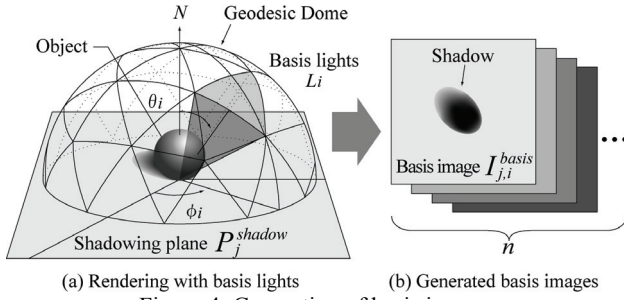
(a) Rendering with basis lights   (b) Generated basis images

Figure 4: Generation of basis images

(a) Generation of shadow image

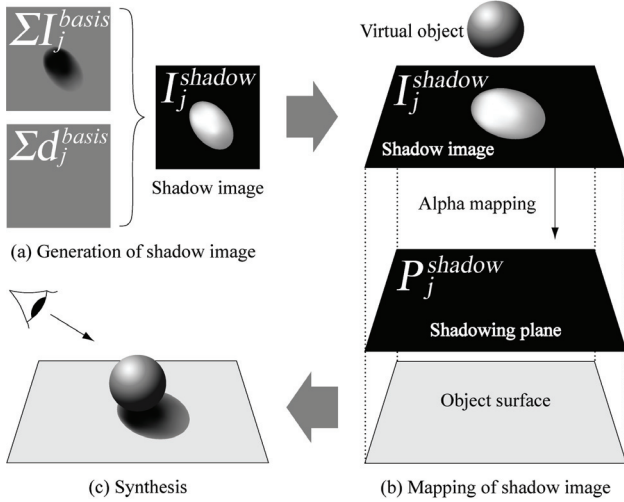(c) Synthesis   (b) Mapping of shadow image

Figure 5: Generation of shadow images and mapping onto shadowing planes

The requirements for the Asuka-Kyo MR content are:
1. Rendering large-scale complex models in real time.
2. Realistic rendering for a close look by users.
3. Realistic illumination corresponding to the change of illumination outside.

However, there is a general trade-off between quality and efficiency in the rendering process. Conventional methods (Haller et al., 2003; Jacobs et al., 2005) can express only hard shadows in fixed illumination. We applied the fast shadowing method to the proposed contents in order to fulfil these three requirements. We found it is easy to apply the shadowing plane method proposed in (Kakuta et al., 2007) to the models of Asuka-Kyo because they are basically static and have a simple form without complex wooden parts. Also they consist of only diffuse materials without specular components, so it is possible to generate correct shadows from basis images.

2.2 Shading and Shadowing

The shadowing method that we applied to the proposed MR contents can express soft shadows of virtual objects efficiently. The method renders basis images offline and synthesizes them to create soft shadow images corresponding to the illumination of the real environment. We describe this shadowing process briefly.

2.2.1 Generation of Basis Images: In order to obtain the basis images, we set up the shadowing planes $P_j^{shadow}\{j=1,2,\ldots,m\}$ on the geometry of the scene. Shadowing planes are generated from convex hulls of each virtual object. Each shadowing plane covers virtual objects roughly, and is offset a little in the direction of a user's viewpoint to avoid
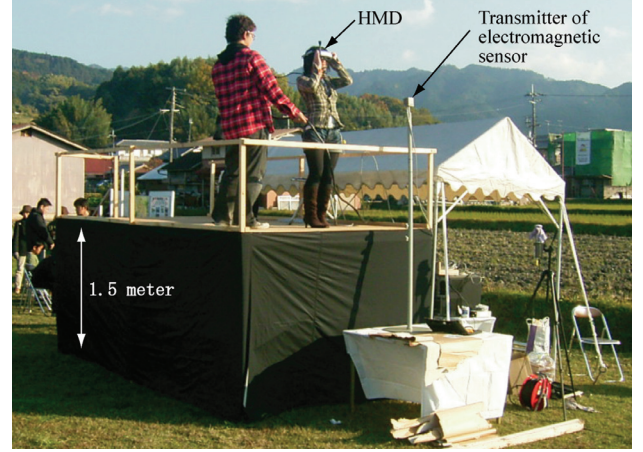

Figure 6: Appearance of evaluation experiment

z-fighting error. Then we assume the illumination of the scene is a hemispheric surface light source. We divide this surface light source by the geodesic dome model and generate basis lights $L_i\{i=1,2,\ldots,n\}$ as shown in Figure 4. Using each basis light, we render the scene and obtain basis images $I_{j,i}^{basis}$ and diffuse components $d_{j,i}^{basis}$ on the surface. The basis images show the shadow of objects in the scene.

2.2.2 Mapping to Shadowing Planes: We obtain the illumination of the real environment from a video camera with a fisheye lens. The radiance parameters that indicate the distribution of scene radiance are computed from an omnidirectional image taken by the camera. Using this radiance parameter, we control the intensity of scene light and are able to express correct shading of virtual objects. Next we compute the linear combination of the basis images and radiance parameters and generate a soft shadow image that corresponds to the scene illumination. Finally, generated soft shadow images are mapped onto previously-installed shadowing planes as an alpha texture. Rendering the scene with these shadowing planes, we can express soft shadow images of virtual objects (Figure 5). Note that we can compute the linear combination of basis images on a standard Graphical Processing Unit (GPU). As a result, the soft shadow images are generated very fast, and this method can be implemented for a real-time interactive MR application.

2.3 Experimental Setup

2.3.1 MR system: Our MR system is mainly based on Canon's MR Platform system (Uchiyama et al., 2002), which includes a video see-through head mounted display (HMD) and the Polhemus's Fastrak, six degree-of-freedom (DOF) electromagnetic tracking sensor. This MR system enables us to acquire the image of the real site, align virtual objects to the image, and synthesize them. The size of the image displayed on HMD is 640x480 pixels. The evaluation tests to be described are performed on a standard computer system with an Intel Core 2 Duo E6850 CPU, NVIDIA GeForce 8800GTS GPU and 4GB RAM. For obtaining the illumination, we use Victor's CCD video camera KY-57 equipped with a fisheye lens (Fit Corporation's FI-19).

2.3.2 Displaying Procedure: We carried out subjective evaluation tests on the historical site of Asuka village. Since the reconstructed CG model of Asuka-Kiyomiharanomiya contains wooden fences 2 meters high in the inner bailey, we put up a scaffolding 1.5 meters high so the user could overlook the
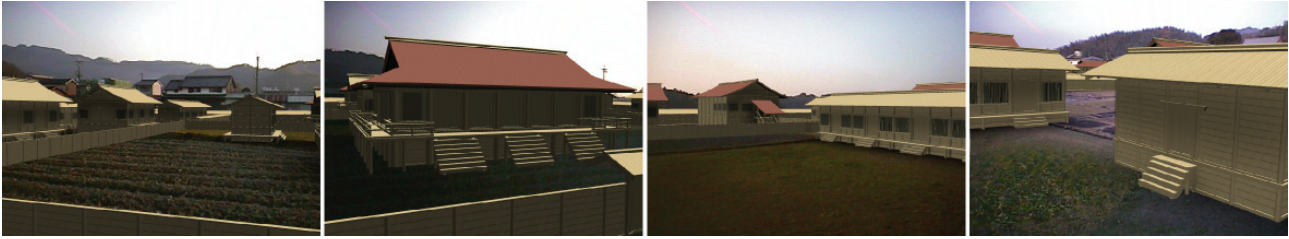
Figure 7: Synthesized image of Asuka-Kiyomiharanomiya palace on MR system

End points	Question
1. Raising interest in Asuka-Kyo and local community.	Q1. Do you want to know the history and the culture in the Asuka Period?
	Q2. Do you want to visit other archaeological sites in Asuka village?
2. Acquisition of new knowledge of the history and culture of the Asuka Period.	Q3. Do you feel as if the ancient Asuka-Kyo were here?
	Q4. Do you know what the buildings of the Asuka Period were?
	Q5. Can you imagine people's livelihood in the Asuka Period?
	Q6. Can you imagine how large the Asuka-Kyo was?
3. Getting the importance of the preservation of cultural properties.	Q7. Do you think that the preservation of cultural heritage is important?
	Q8. Do you think the reconstruction using Mixed Reality is meaningful?
4. Getting the mechanism and property of CG and MR.	Q9. Do you understand the relation between display and viewpoint?
	Q10. Do you understand the mechanism of Mixed Reality?

Table 1: Relation of end points of education effect and questions
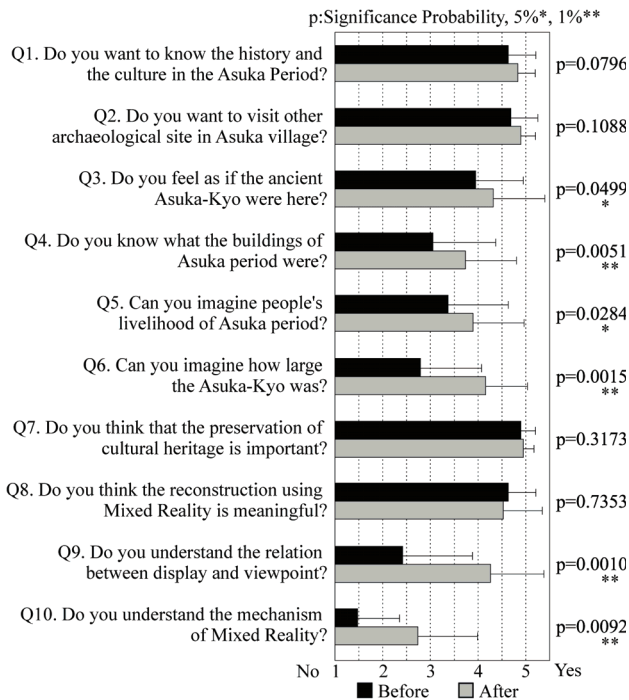

Figure 8: Average score of educational effects before and after experiencing the contents

the palace as shown in Figure 6. We installed the MR system on a northeast direction of the main temple because there are no real buildings and the users could take a look around the site. The camera for illumination acquisition was placed 5 meters away from the MR system to avoid capturing users and equipment. Figure 7 shows the synthesized images on HMD. Natural soft shadows and real-time image synthesis were achieved by application of the fast shadowing method.

3. EVALUATION EXPERIMENT FOR EDUCATIONAL EFFECT

First we performed an experiment to evaluate the educational effect of the proposed contents by comparing the attitudes of subjects before and after experiencing the contents. We wanted to investigate how the test subjects were affected by the contents in respect to their interest in and concerns about the history of Asuka Period.

3.1 Experimental Design

Nineteen observers (12 male, 7 female, average age 49.63, range 28-77) volunteered to participate in the experiment. Evaluation items were determined from the learning goals of Geography, History, and Information subjects in the ministry's curriculum guidelines for high schools. Specifically, we presumed four end points of 1) Interests in the remains, 2) Historical knowledge, 3) Conservation awareness of cultural heritage objects, and 4) Understanding of MR technologies, which were expected to increase by experiencing the MR contents. Ten questions were prepared from these end points. The corresponding relation of questions and end points is shown in Table 1. These questions were randomly arranged on the survey forms, and observers were asked to rate them using a scale from one to five before and after experiencing the contents. The experience time of each observer was two minutes.
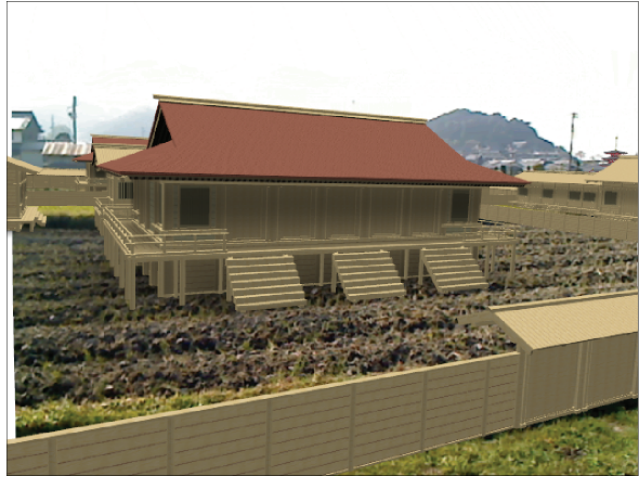
3.2 Result and Discussion

As a result, we confirmed the score had been increased for almost all question areas. Figure 8 shows the average score of every question before and after going through the contents. The p-values in Figure 8 indicate the significance probability calculated by the Wilcoxon signed-rank test, and they represent the probability of obtaining the score by chance (two-sided test). The symbols of * and ** indicate a significance level less than 5% ($p<0.05$) and 1% ($p<0.01$) respectively. We found a statistically significant improvement of less than 1% in Q4, Q6, Q9, and Q10, and less than 5% in Q3 and Q5.

The result shows the proposed contents had an educational effect on learning goals 2) Historical knowledge, and 4) Understanding of MR technologies, previously assumed. Q3 and Q6 showed how users increased their recognition of the scale of ancient Asuka-Kyo and its spatial corresponding relationship with current remains and landscape. Especially the score of Q6 regarding size is remarkably increased and we might guess it is because the observers could physically

(a) Synthesized image without shading and shadowing   (b) Synthesized image with shading and shadowing

Figure 10: Synthesized images for evaluation experiment for user's impression with and without shading and shadowing
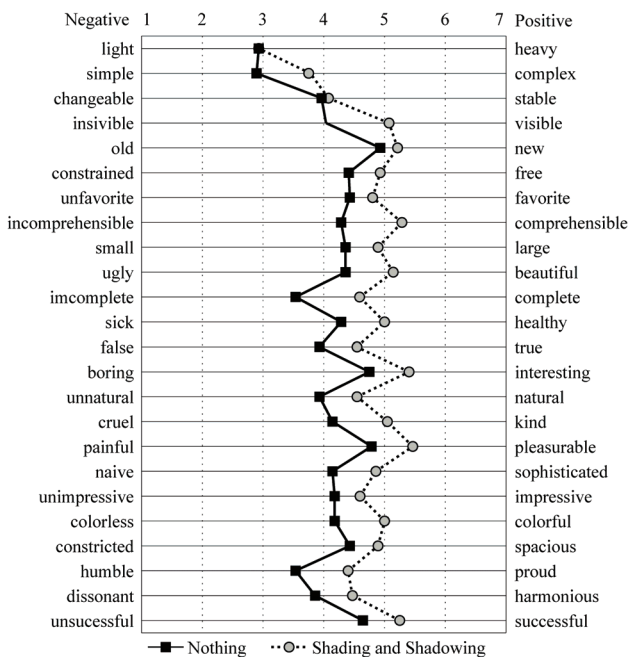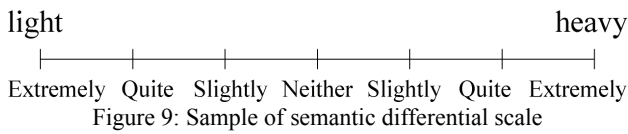

Figure 9: Sample of semantic differential scale

Figure 11: Average score of adjective pairs

Adjective pairs	Factor loading		
	Factor 1	Factor 2	Factor 3
Factor 1: "Realistic"			
false – true	**0.947**	0.075	-0.171
incomplete – complete	**0.677**	-0.060	0.316
dissonant – harmonious	**0.628**	0.052	0.095
humble – proud	**0.619**	0.079	0.287
unnatural – natural	**0.546**	0.134	0.287
sick – healthy	**0.535**	0.204	0.206
Factor 2: "Spectaculer"			
colorless – colorful	0.057	**0.840**	0.034
unimpressive – impressive	0.187	**0.815**	-0.064
unsuccessful - successful	-0.108	**0.706**	0.228
naïve – sophisticated	0.489	**0.551**	-0.090
constricted – spacious	0.190	**0.517**	0.041
Factor 3: "Entertaining"			
incomprehensible – comprehensible	-0.096	0.175	**0.868**
constrained – free	0.140	-0.093	**0.629**
unfavorite - favorite	0.065	0.236	**0.545**

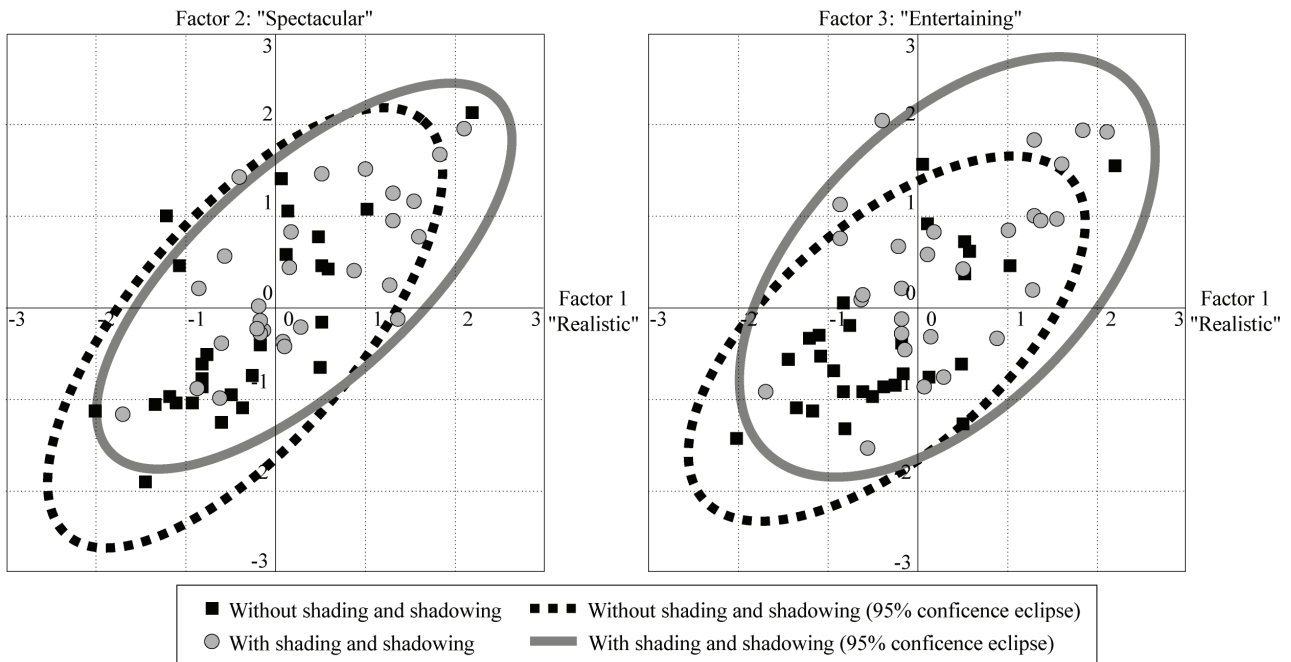Table 2: Factor loadings of adjective pairs

observer. Especially, the average score of Q7, preservation of cultural heritage, was originally higher than that for other questions. Meanwhile the score of Q8, the value of mixed reality, decreased, but this might be because of random error (p=0.7353).

4. EVALUATION EXPERIMENT FOR USERS' IMPRESSION WITH AND WITHOUT SHADING AND SHADOWING

In the next experiment, we conducted a subjective evaluation test to measure the users' impressions of the MR contents and clear up the potential psychological factors that affected evaluation of the synthesized image. Then we studied whether significant differences came about by adding correct shade and shadow.

4.1 Experimental Design

Fifty-six observers (28 male, 28 female, average age 51.88, range 12-81) who were not engaged in the experiment of Section 3 volunteered to participate to this experiment. We asked them to report the impression of the synthesized images on the MR system. The semantic differential method was used

experience the spaciousness of Asuka-Kyo through the MR system. The scores of Q9 and Q10 show that the contents contributed to users' understanding of the MR technologies and devices. The average scores of these questions were 2.42 and 1.47 respectively. These scores were relatively low compared to other questions, but they dramatically increased after experiencing the MR system. Getting hands-on experience should be recognized as a means of increasing understanding of MR technologies.

On the other hand, the scores of Q1, Q2, Q7, and Q8 showed no significant educational effect. We might assume this is because the interest and concerns of examinees were high enough from the beginning so that the average scores for these questions were positive and the contents had a very small effect on the

(a) Factor scores in the axes of factors 1 and 2　　　　　(b) Factor scores in the axes of factors 1 and 3

Figure 12: Factor score of examinees with and without shading and shadowing
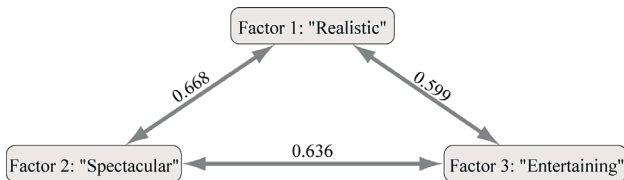

Figure 13: Correlation coefficient among factors

to analyze the result, and we began with 24 pairs of adjectives that were considered to adequately describe the impression of a synthesized image based on (Osgood et al., 1967). The examinees were asked to rate the images using a scale from one to six. The example of the assessment measure is shown in Figure 9. The observers were divided into two groups and were shown two types of synthesized images on the MR system with and without shading and shadowing for each group (Figure 10). Note that we did not inform each group about the difference. The experience was performed under a clear sky within an hour to minimize the change of illumination condition. The experience time of each group was two minutes, like the experiment in Section 3.

4.2 Result and Discussion

Figure 11 shows the average score of each adjective pair with and without shade and shadow. The left side of the figure contains negative adjectives, and the right side contains positive adjectives. When we compared each average score, the group "with shading and shadowing" clearly moved to the right (positive) side. In particular, there was significant difference over 1.0 in the adjective pairs, "invisible – visible" and "incomplete – complete." This could be due to the fact that the shade and shadow emphasized the appearance of solidity and the models seemed to be authentic. By contrast, there was little difference in "light - heavy" and "changeable – stable." It would appear that the shade and shadow had an insignificant effect on the model's projection of stability.

The factor analysis reveals the potential common factors related to the contents evaluation as shown in Table 2. In the

calculation process, we extracted the initial factors by the principal factor method and adopted a promax rotation. The adjective pairs in Table 2 are sorted by their absolute value of factor loadings. The result shows that the three extracted factors explain almost all the adjective pairs.

In the first factor, the factor loading of "false – true" pair is especially high (0.947) and it contains "dissonant – harmonious" and "unnatural - natural" pairs. Therefore, we assume this factor is related to the harmony and consistency of the image and it can be said to represent the "Realistic" aspect. In the second factor, the factor loadings of "colorless – colorful" and "unimpressive – impressive" are high; we assume this means the appeal and power that is "Spectacular." In the third factor, the factor loadings of "incomprehensible – comprehensible", "constrained - free" and "unfavorite - favorite" are high, so we consider this means an acceptance and appeal of the contents, in other words "Entertaining."

The factor scores of three factors described above for each group are plotted in Figure 12. The ellipses in this figure mean the 95% confidence region given a 2-dimension normal distribution of factor scores. When we compare the distribution of each group, "with shading and shadowing" group has a higher score than the other. Particularly, there is a great difference between two groups in the axis of the "Entertaining" factor as shown in Figure 12 (b).

Figure 13 shows the coefficient of correlation of the three factors. There are fairly high correlations among these factors, so we can consider the correct shading and shadowing in MR are important to improve not only the reality and consistency of the synthesized image but also the sharpness and punch of models, as well as the entertainment value and interactivity of the contents.

5. CONCLUSION

In this paper, we developed and evaluated MR contents of the Japanese ancient capital Asuka-Kyo. We successfully improved

the reality of the synthesized image in this content by applying the fast shading and shadowing method (Kakuta et al. 2007). Our first subjective evaluation experiment shows the educational effect of the contents. MR applications that reconstruct lost remains on historical sites are shown to increase the interests and concerns of the subjects. The result of the second experiment regarding users' impressions reveals three common factors in evaluating MR contents, "Realistic," "Spectacular," and "Entertaining." We confirmed that the shading and shadowing of virtual objects improved these evaluating factors and the illuminant consistency is essential for the subjective evaluation. Correct shading and shadowing are also important to increase the entertainment value of the contents in addition to the reality and consistency. Improving the educational effect of the Asuka-Kyo MR contents is our task for the future. Especially the end points of "Historical knowledge" and "Conservation awareness for cultural heritage" are minimally affected by the MR contents as described in Section 3. Multiple information service such as text and audio commentary might improve these aspects.

REFERENCE

Azuma R., Baillot Y., Behringer R., Feiner S., Julier S., and MacIntyre B., 2001. Recent advances in augmented reality, *IEEE Computer Graphics and Applications*, Vol. 21, No. 6, pp. 34-47.

Callieri M., Debevec P., Pair J., and Scopigno R., 2006. A realtime immersive application with realistic lighting: the Parthenon, *Computer & Graphics*, Vol. 30, No. 3, pp. 368-376.

Haller M., Drab S., Hartmann W., 2003. A real-time shadow approach for an augmented reality application using shadow volumes, *Proc. Symp. on ACM Virtual Reality Software and Technology (VRST 2003)*, pp. 56-65.

Jacobs K. and Loscos C., 2004. Classification of illumination methods for mixed reality, *Proc. Eurographics State of the Art Report (STAR)*, pp. 95-118.

Jacobs K., Nahmias J. D., Angus C., Reche A., Loscos C., Steed A., 2005. Automatic generation of consistent shadows for augmented reality, *Proc. Graphics Interface 2005*, pp. 113-120.

Kakuta T., Oishi T, and Ikeuchi K., 2004. Virtual kawaradera: fast shadow texture for augmented reality., *Proc. Int. Society on Virtual Systems and Multimedia (VSMM 2004)*, pp. 141-150.

Kakuta T., Oishi T., and Ikeuchi K., 2007. Real-time soft shadows in mixed reality using shadowing planes, *Proc. IAPR Conference on Machine Vision Application (MVA 2007)*, pp. 195-198.

Osgood C. E., Suci G. J., Tannenbaum P., 1967. *The measurement of meaning*, University of Illinois Press, Urbana and Chicago.

Papagiannakis, G., Ponder, M., Molet, T., Kshirsagar, S., Cordier, F., Magnenat-Thalmann, N., and Thalmann, D., 2002. LIFEPLUS: Revival of life in ancient Pompeii, *Proc. Int. Conf. on Virtual Systems and Multimedia (VSMM 2002)*, pp.19-26.

Sato I., Sato Y., and Ikeuchi K. 2003. Illumination from shadows, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, Vol. 25, No. 3, pp. 290-300.

Sugano N., Kato H., and Tachibana K. 2003. The effects of shadow representation of virtual objects in augmented reality, *Proc. Int. Symp. on Mixed and Augmented Reality (ISMAR 2003)*, pp.76-83.

Takemura M., Kitahara I., Ohta Y., 2006. Photometric Inconsistency on a Mixed-Reality Face, *Proc. Int. Symp. on Mixed and Augmented Reality (ISMAR 2006)*, pp.129-138.

Tanikawa T., Ando M., Wang Y., Yoshida K., Yamashita J., Kuzuoka H., and Hirose M., 2004. A case study of museum exhibition: historical learning in Copan ruins of Mayan civilization-, *Proc. IEEE Virtual Reality Conf. (VR 2004)*, pp.257-258.

Tenmoku R., Nakazato Y., Anabuk A., Kanbara M., and Yokoya N., 2004. Nara palace site navigator: device-independent human navigation using a networked shared database, *Proc. Int. Conf. on Virtual Systems and Multimedia (VSMM 2004)*, pp. 1234-1242.

Uchiyama S., Takemoto K., Satoh K., Yamamoto H., and Tamura H., 2002. MR Platform: a basic body on which mixed reality applications are built, *Proc. Int. Symp. on Mixed and Augmented Reality (ISMAR 2002)*, pp. 246-253.

Utsugi K., Moriya T., and Takeda H., 2001. Making of a virtual world of heijokyo from historical knowledge, *Proc. Int. Conf. on Virtual Systems and Multimedia (VSMM 2001)*, pp. 455-462.

Vlahakis V., Ioannidis N., Karigiannis J., Tsotros M., Gounaris M., Stricker D., Gleue T., Daehne P., and Almeida L., 2002. Archeoguide: an augmented reality guide for archaeological sites, *IEEE Computer Graphics and Applications*, Vol. 22, No. 5, pp. 52-60.