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Visualization Methods for Outdoor See-Through Vision

Takahiro TSUDA[†a], **Haruyoshi YAMAMOTO**[†b], ***Nonmembers***, **Yoshinari KAMEDA**[†c], ***Member***, ***and*** **Yuichi OHTA**[†d], ***Fellow***

SUMMARY Visualizing occluded objects is a useful applications of Mixed Reality (MR), which we call "see-through vision." For this application, it is important to display occluded objects in such a manner that they can be recognized intuitively by the user. Here, we evaluated four visualization methods for see-through vision that can aid the user to recognize occluded objects in outdoor scenes intuitively: "elimination of occluding objects," "ground grid," "overlaying model of occluding object," and "top-down view." As we used a new handheld MR device for outdoor see-through vision, we performed subjective experiments to determine the best combination of methods. The experimental results indicated that a combination of showing the ground grid, overlaying wireframe models of occluding objects, and top-down view to be optimal, while it was not necessary to display occluding objects for outdoor see-through vision with a handheld device, because users can see them with the naked eye.

key words: *mixed reality, augmented reality, subjective evaluation, handheld MR device, occlusion*

1. Introduction

Mixed reality is a technology that superimposes a virtual world onto the real world, enhancing the real world visually by integration of computer graphics to allow users to see useful information that would normally not be available. One useful application of MR is visualization of blind areas occluded by walls, buildings, and other objects in outdoor scenes. Visual information of the occluded area is valuable although it is not ordinarily accessible. This is known by a variety of names, such as "X-ray vision" [6], [15], [16]; in this paper, we call it "see-through vision" [1].

By utilizing see-through vision, the user can determine what exists in the occluded area more easily than by looking at a map. In addition, the user can also observe the situation of the occluded area in real-time. Thus, see-through vision enables the user to see their destination in the next street, to see whether a shop occluded by buildings is open or closed and to determine whether it is crowded, or to see a bus coming to a bus stop just around the corner.

For such applications, it is important for the user to be able to recognize information displayed in see-through vision intuitively. If the information is displayed in a manner that cannot be perceived intuitively, it may confuse the user. As see-through vision is not a familiar technology for ordinary people, the optimal display style should be determined carefully.

In outdoor scenes, a new handheld MR device should not be mounted on the user but held in the hand only when they wish to receive MR service [1]–[3]. As this new style of device has a different modality from conventional MR devices, such as head-mounted display (HMD), it is necessary to investigate adequate visualization functions. For example, with a handheld MR device, It is not necessary for the user to look into the display of the device to see the real world because it can be seen directly with the naked eye.

In the system developed in this study, a handheld MR device was utilized to make use of see-through vision, with moving objects, such as pedestrians and bicycles, in an occluded area hidden by a building in front of the user. We examined four visualization methods for see-through vision to allow the user to recognize what is being seen intuitively and report the best combination of methods based on subjective evaluation experiments.

The rest of the paper is organized as follows. In Sect. 2, pioneering work and the results of previous research into see-through vision are discussed. Then, two problems that must be addressed to achieve well-designed see-through vision are described in Sect. 3. The four visualization methods applied in this study are described in Sect. 4. The results of subjective evaluation experiments are described in Sect. 5, and we conclude the paper in Sect. 6.

2. Related Work

Many systems have been developed using mixed reality technology for see-through vision. These research projects have shown that see-through vision is a promising function implementation of which should soon be feasible.

KARMA [4] uses a rule-based approach to display occluded parts in a laser printer maintenance application. The Architectural Anatomy project [5] displays building architecture by overlaying its wireframe view. X-Ray Window [6] for use on the International Space Station (ISS) is intended to allow astronauts to see through the walls of the station module. In addition, a system that can display the internal structures of objects using X-ray images has been proposed [7].

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[†]The authors are with the Department of Intelligent Interaction Technologies, Graduate School of Systems and Information Engineering, University of Tsukuba, Tsukuba-shi, 305–8573 Japan.
a) E-mail: tsuda@image.esys.tsukuba.ac.jp
b) E-mail: haruyosh@image.esys.tsukuba.ac.jp
c) E-mail: kameda@image.esys.tsukuba.ac.jp
d) E-mail: ohta@image.esys.tsukuba.ac.jp

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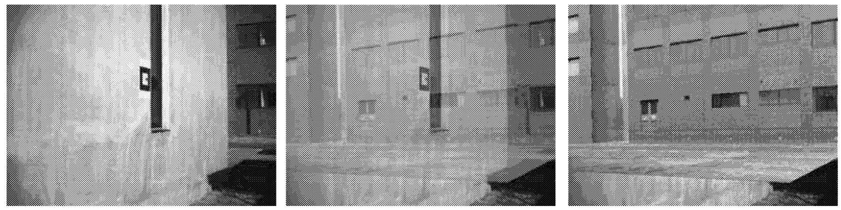

(a) Real world (b) Basic visualization method (c) Occluded area superimposed

	(a)	(b)	(c)
Visibility	Bad	Not bad	Good
Spatial relationship	Good	Not bad	Bad

Fig. 1 Comparison of visualization.

See-through vision is also useful in medical applications, such as volume-rendering of the fetus in pregnant women [8], displaying occluded tumors inside the breast to support ultrasound-guided needle biopsy [9], and displaying the internal structure of the hip using X-ray images in total hip replacement (THR) [10]. For outdoor use, BARS, a military system that can locate occluded objects [11], and a handheld see-through device that can visualize occluded objects in real-time have been proposed [1].

See-through vision is also useful in virtual environments (VE), where utilization of transparent walls can improve navigational support [12]. Thus, see-through vision has been utilized for many applications.

However, displaying information in see-through vision in a manner that the user can recognize intuitively is a nontrivial task. It is necessary to consider visualization methods carefully because see-through vision is an unfamiliar visual stimulus for human beings, and may cause problems related to perception [13].

A number of research projects have focused on how best to visualize occluded objects. Furmanski et al. developed visualization using principles derived from perceptual psychology and cognitive science [14]. Livingston et al. examined drawing styles and opacity settings that enable people to interpret layers of occluded objects accurately [15]. Bane et al. designed a set of interactive tools that enable people to see through walls and buildings, which they call application virtual x-ray vision [16]. The proposed tools allow people to find appropriate information easily. The human depth perception model related to utilization of semitransparency in 3D interactions [17] and psychological effects of stereo, lighting, and background scenes in computer graphics [18] have been investigated. How the brain processes local stimuli during the global sensation of self-motion was examined in view of temporal information processing, and the results indicated judgment biases of temporal order [19].

These studies assumed see-through vision with an HMD and are effective when used with such systems. However, as a handheld MR device [1]–[3] is more useful to realize see-through vision in outdoor environments, a new visualization method associated with use of such MR devices is proposed.

3. See-Through Vision

To achieve intuitively perceptible see-through vision, it is important to enable the user to recognize what and where objects are located in the occluded area. The following two issues are important for this purpose:

A. Visibility of occluded area and objects in the occluded area

B. Correct perception of spatial relationships of occluding objects and occluded area

Most related studies focused mainly on spatial relationships. In contrast, our goal is to develop a visualization method that can achieve these two goals simultaneously. These two issues may be antithetical, but it is necessary to find the best balance between (A) the visibility and (B) the spatial relationships. We discuss these in detail in the following sections. Note that as we assume a handheld MR device to achieve see-through vision, approaches to handle these issues may have different side effects from those that arise in systems making use of an HMD.

3.1 Visibility of Occluded Area

As the main advantage of see-through vision is that it allows the user to see occluded areas, it is important to ensure good visibility of the occluded areas. For this purpose, showing the image of the occluded area directly to the user is a good solution. A sample snapshot is shown in Fig. 1 (c). However, it causes contradictions in occlusion because the order of overlap is inverted on the display. This contradiction is a serious problem related to perception of spatial relationships, which we discuss in the next subsection.

3.2 Spatial Relationships

Occlusion is a very important clue for recognition of the locations of objects in the depth direction [20]. In MR/AR display, this was evidenced by experiments using perceptual cues [14]. People can usually recognize which of two objects is closer to them by seeing that one is occluded either partially or completely by the other. They recognize 3D locations of objects in a scene in a similar manner.

However, occluded objects, which are normally invisible, are shown in see-through vision, which causes contradiction of occlusion on the display. This results in perceptual ambiguity of spatial relationships between occluding objects and the occluded area.

Examples of occlusion scenes are shown in Fig. 1 (a) and Fig. 2. In this example, the user cannot see the occluded area (lawn, road, and brick-faced building) because the light gray concrete building in front hides them in the real world. The overview of this environment is shown in Fig. 9. If the occluded area is superimposed, the view becomes inconsistent with the order of the objects, as shown in Fig. 1 (c).

One conservative solution is to blend the texture of the occluded area transparently (Fig. 1 (b)) [1]. Although this transparent view by itself still lacks the clues to determine which texture corresponds to the occluded area, people can at least recognize that there are two types of object in the scene and they may understand which is closer by remembering the texture of the occluding object. If the occluding object's texture is simple, such as a uniform tone, it may be easier to determine which is closer. However, it is generally not easy to examine which blended textures correspond to that of the occluding object and which do not. Therefore, supplemental clues that aid in visual recognition of the 3D locations of occluded objects are necessary.

3.3 See-Through Vision with a Handheld Device

Outdoor see-through vision with the handheld MR device used in this study allows the user to easily see the real world directly with the naked eye, without needing to look into the display. This means that the user can see both the MR display and the real world with the naked eye simultaneously. In addition, the user's field of view is not limited. With such a system, we hypothesize that visible objects are less important as visual information in the display of the device, and therefore we can ignore the visibility of occluding objects, and improve visibility of the occluded area and occluded objects.

Here, we take up the transparent view of occluding objects and occluded area as the basic visualization method to realize see-through vision (Fig. 1 (b)) [1]. We call this the "basic visualization method (Fig. 3)." Although this approach is not the best for our final goal, it can provide some visual clues to allow recognition of spatial relationships and it can show the image of the occluded area to some extent. By applying additional functions to the basic visualization method, the most appropriate system to realize see-through vision is discussed in the following sections.

4. Visualization Methods for See-Through Vision

Four visualization methods to enhance the basic visualization method for see-through vision are introduced in this paper. Our goal is to find the most appropriate combination of methods to satisfy the two issues, (A) "visibility of occluded objects" and (B) "spatial relationships of occluding and occluded objects," to achieve intuitively perceptible see-through vision.

Fig. 2 Input image.

Fig. 3 Basic visualization method.

Fig. 4 Elimination of occluding objects.

4.1 Improving Visibility of Occluded Area

To improve the visibility of the occluded area, the texture of occluding objects should be controlled.

Elimination of occluding objects The texture of occluding objects is eliminated completely and that of the occluded area is rendered spatially at the correct position on the image on the handheld MR device. An example is shown in Fig. 4. This method prevents admixture of the occluded area texture and the occluding object texture, and causes problems in that users cannot perceive what the occluding object is like. However, by applying see-through vision with a handheld device, users

Fig. 5 Ground grid.

Fig. 6 Wireframe of occluding object.

can see the occluding object directly in the real world while looking at the information on the display, so this does not matter in this case.

4.2 Improving Recognition of Spatial Relationships

We adopted the following three methods to resolve ambiguity in the spatial relationships between occluding objects and the occluded area.

Ground grid A grid on the ground is presented virtually in the occluded area to clarify the horizontal relationships between occluding objects and the occluded area. An example is shown in Fig. 5. By looking at the grid, the user can determine the size and location of the occluded area hidden by an occluding object. On the other hand, the grid may degrade visibility of the occluded area.

Overlaying model of occluding object Overlaying a CG model of the occluding object clarifies the 3D shape and the area of the occluding object. By understanding the shapes of occluding objects precisely in a scene with the help of CG model information, the user can easily recognize which texture in the image belongs to the occluding object. Hence, they can also recognize which texture in the image corresponds to the occluded area.

In this paper, two kinds of CG model visualization are presented.

"Wireframe" The first method involves the overlay of a wireframe model of the occluding object. As a wireframe drawing is very simple, it does not spoil the visibility of the occluded area. An example of this method with overlay of a wireframe model of an occluding object is presented in Fig. 6.

"Wireframe+surface" The other method involves overlaying a colored transparent surface in addition to the wireframe model. Although seeing the occluded area through the colored virtual surface may degrade visibility, it can resolve ambiguities in depth relationships between the occluding object and the occluded area. The effects of the CG visualization method on human perception of transparent surfaces have been reported [17], and it has also been shown to be effective in augmented reality [15]. An example of overlaying wireframe+surface model of an occluding object is presented in Fig. 7.

Fig. 7 Wireframe+surface of occluding object.

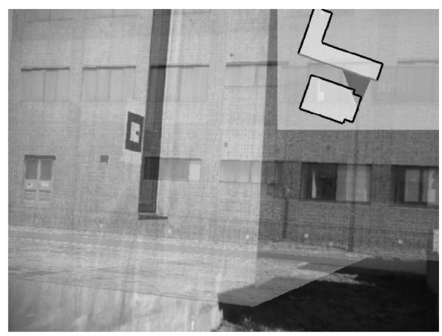

Fig. 8 Top-down view.

Top-down view A top-down view provides good clues to allow recognition the spatial relationships among the user, occluding objects, and occluded areas. The disadvantage of the top-down view is that it does not provide any visual information regarding the occluded objects in the occluded area. Therefore, this method is thought to be supplemental for realizing see-through vision. A snapshot showing the top-down view is presented in Fig. 8. As the top-down view is a view of the scene from another view point, it is sometimes difficult to de-

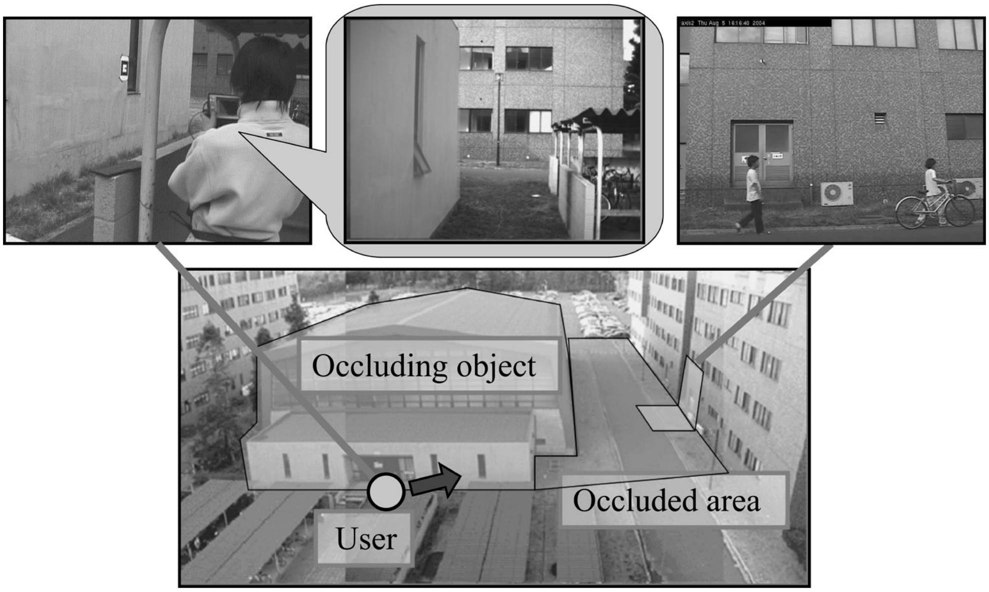

Fig. 9 Experiment field overview. User see through occluding object and see pedestrians in occluded area.

termine the correspondence between the objects in the view and the image on the see-through vision device.

5. Experiment

We have conducted subjective evaluation experiments to determine the most effective visualization method for outdoor see-through vision. First, each visualization method proposed in the previous section was examined by comparing it to the basic visualization method. Then, combinations of the methods were examined to determine the best combination for see-through vision.

5.1 Experimental Environment

We developed the basic visualization method based on outdoor see-through vision [1]. The layout of the experimental field is shown in Fig. 9 and the handheld MR device used, a Sony VAIO type U VGN-U70P, is shown at the top left in Fig. 9. Video capture was performed using a Point Grey Research Dragonfly camera mounted on the device. Subjects were asked to remain standing in the same position shown in Fig. 9, and were allowed to direct the handheld device in any direction to see through the building in front of them.

The camera mounted on the device captured the image seen by the user, which is shown in the upper-middle part of Fig. 9. The resolution of the image was 640×480 pixels.

We utilized ARToolKit [21] to align the camera in this environment. Our system can estimate the position of the camera of the handheld device by referring to the position of the ARToolKit marker that was measured in advance. As the shapes of the buildings were also determined in advance, the system could render CG 3D objects of the buildings in the camera image in real-time. The system is also capable of superimposing the on-line video of the occluded area taken by remote cameras and transmitted via wireless LAN. The live texture of the video is aligned geometrically and blended to the camera of the handheld device so that it fits precisely to the CG 3D objects. The details of the rendering algorithm were described previously [1].

Although the system can render the occluded area in real-time, we used recorded videos and associated textures in the experiment so that all subjects could experience the same situation. We recorded a typical situation of the occluded area with pedestrians and bicycles and they were visualized dynamically in the display of the handheld device. The displacement of the CG objects in the image was about 10 pixels throughout the experiment.

We conducted the experiment in 14 subjects, all of whom knew about the system. However, most had had little time to actually use the system. The subjects received instruction on how to use the system for about 5 minutes before the experiment. All of the subjects were male and they all knew the spatial relationships among their standing point, the occluding object, and the occluded area.

5.2 Evaluation of Each Visualization Method

We examined each visualization method by subjective evaluation experiments to ascertain whether they were effective when applied to the basic visualization method.

5.2.1 Methodology

Each of the first four visualization methods was applied to the basic visualization method. The subjects' task was to compare the enhanced see-through vision with the basic visualization method and give scores for the following two

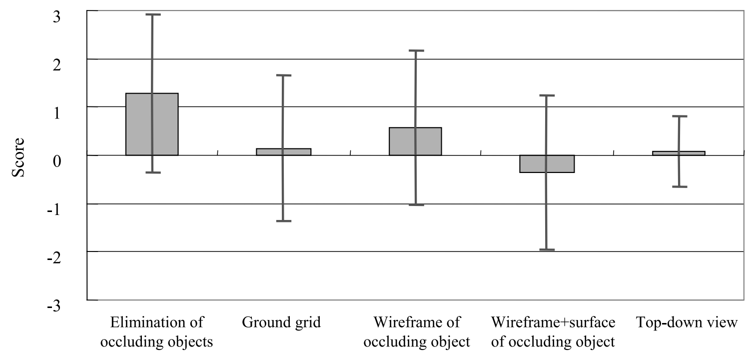

Fig. 10 Evaluation of visibility of occluded area.

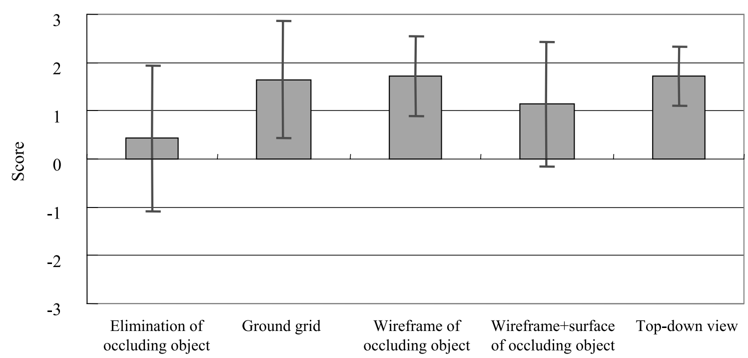

Fig. 11 Evaluation of spatial relationship.

Table 1 *P*-value of each methods at question 1 (Visibility) and 2 (Spatial relationship).

	Elimination of occluding objects	Ground Grid	Wireframe model	Wireframe+surface model	Top-down view
Question 1	0.012	0.73	0.21	0.42	0.72
Question 2	0.31	0.00022	0.0000031	0.0057	0.00000010

questions on a 7-point scale:

1. How good is the visibility of the occluded area?
2. How perceptible are the spatial relationships of the occluding objects and the occluded area?

The 7-point scale was interpreted as follows: the enhanced method is much better (+3), the same (0), the basic visualization method is much better (−3). We useed the t-test for evaluation of the results, with 5% taken to indicate significance.

5.2.2 Results and Discussion

The results of question 1 are presented in Fig. 10 and those of question 2 are presented in Fig. 11. Rectangular bars indicate the average of the score, and the lines indicate the standard deviation.

The results of t-tests are shown in Table 1. In this case, if $p \leq 0.05$ the result indicates that the effect of the method was statistically significant and if $p > 0.05$ the effect of the method was not statistically significant. Therefore, the effect of "elimination of occluding objects" was statistically significant for question 1. The effects of all the proposed methods except "elimination of occluding object" were statistically significant for question 2. These results indicate that the methods show the expected effects.

First, we discuss the results of question 1. In the experiment to examine "elimination of the occluding objects," some subjects reported that it was difficult to recognize the occluded area shown in the display because of a paucity of clues. This may have caused large standard deviation. However, the total score was markedly high, in agreement with our expectations. "Overlaying wireframe+surface model of occluding object" received a low score. We feel that this was because the occluded area covered with a colored semi-transparent surface caused a subjective feeling of poor visibility. Although the effect of the wireframe+surface model for determination of depth relationship has been reported [15], it appears not to be useful when it is necessary to think of the visibility of the occluded area with depth determination.

Second, we discuss the results of question 2. The best score was obtained by the "top-down view." Although the top-down view lacks the visual information of the occluded objects, it is useful to locate the user's position in the scene and to recognize the location of the occluded area. It was reported that alternate perspectives, such as the top-down view, are useful perceptual factors derived from perceptual psychology and cognitive science [14]. This conclusion was supported by the present results.

The results indicated that the wireframe model was better than the wireframe+surface model. Users appear to feel that the 3D shape of the occluding object is more important than the depth relationship between the occluding object and the occluded area. Although the wireframe+surface model is useful to guess the depth relationship, it may degrade the visibility of the wireframes that are valuable to recognize the 3D shape of the occluding object. Therefore, we think they use the visibility of the wireframes to recognize the 3D shape rather than the combined visualization of wireframe and surface for easier estimation of depth relationships. The visibility of the wireframes is more important when users think of the shape of the far side of the occluding object. In addition, users appeared to understand the 3D shape of its near side more easily with the wireframe model because the additional surface rendering may degrade the visibility of the texture of its frontal side. Some of the subjects' comments supported this suggestion. Some subjects noted that the surface of the occluding object is unnecessary for recognition of spatial relationships. This may cause large standard deviation of the evaluation of "overlaying wireframe+surface model of occluding object." It was reported previously that the wireframe+surface model was better than the wireframe model [15]. However, we feel that this was not true in our see-through vision system because we utilized a handheld device that can be pointed in any direction.

The use of "ground grid" was also highly evaluated in present study. It was also reported previously that size-scaling gradients, such as grids are perceptual factors [15], which was supported by out results. However, some subjects noted that the texture of the ground of the occluded area was sufficient to recognize the spatial relationships, and that a grid was unnecessary. This may have been responsible for the large standard deviation.

5.3 Evaluation of Combination of Visualization Methods

As the four visualization methods can be combined to enhance outdoor see-through vision, we conducted subjective evaluation experiments for combinations of "elimination of occluding objects," "ground grid," and "overlaying model of occluding object." The remaining method ("top-down view") was not used for combination tests because it was felt to be independent from the other three.

Figure 12 shows an example of a combination of all three methods: "elimination of occluding objects," "ground grid," and "overlaying wireframe+surface model of occluding object."

5.3.1 Methodology

As there are two types of model (wireframe and wireframe+surface) in "overlaying models of occluding object," it was necessary to examine twelve patterns. The patterns are shown in the left table in Fig. 13. In the table, letters in the pattern column are assigned to indicate each pattern. The other columns in the table show which visualization methods were applied to the patterns. We used the rank method for subjective evaluation. The subjects ranked all twelve patterns in consideration of the two questions presented in the previous experiment, with the best given a score of 1, and the worst a score of 12. We used the Kramer rank sum test [22] at a significance level of 5% and examined the significance of differences.

Fig. 12 A visualization example of a combination. "Elimination of occluding objects," "ground grid," and "overlaying wireframe+surface model of occluding object" are applied.

5.3.2 Results and Discussion

The results are shown in the right graph in Fig. 13. The horizontal axis of the graph indicates the sum of the ranks. Bars correspond to the patterns shown in the left table. A smaller sum, indicates a better evaluation. In this case, Kramer rank sum test indicated that the effect of the method was statistically significant if the sum of ranks ≤ 57, and not statistically significant if the sum of ranks ≥ 125. Thus, pattern J was significantly better and patterns A and B were significantly poorer than the others. The results indicated that intuitively perceptible see-through vision was realized by applying the three methods (pattern J).

These results, in addition to the observation that "elimination of occluding object," "ground grid," and "overlaying model of occluding object" each received high scores, indicated that the combination of these three methods was also useful to realize outdoor see-through vision. These methods are effective with any combination of other methods. With regard to the overlaying model, the wireframe model received higher scores than the wireframe+surface model when integrated with the other methods (e.g., pattern J was better than pattern L).

In conclusion, the combination of all four methods was good for achieving outdoor see-through vision on a handheld MR device.

Pattern	Ground grid	Overlaying model	Occluding object
A	No	None	Blended
B	No	None	Eliminated
C	No	Wireframe	Blended
D	No	Wireframe	Eliminated
E	No	Wireframe+surface	Blended
F	No	Wireframe+surface	Eliminated
G	Yes	None	Blended
H	Yes	None	Eliminated
I	Yes	Wireframe	Blended
J	Yes	Wireframe	Eliminated
K	Yes	Wireframe+surface	Blended
L	Yes	Wireframe+surface	Eliminated

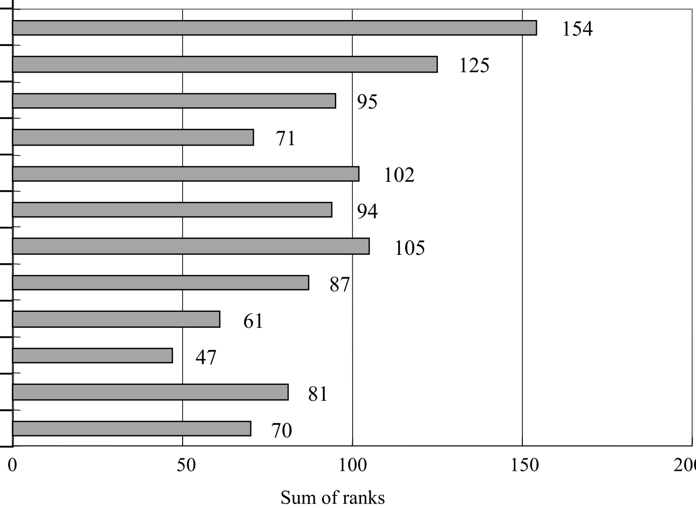

Fig. 13 Combinations of the visualization methods and evaluation of them. Left table indicates combination of methods of each pattern. Right graph shows their evaluation by the sum of ranks.

6. Conclusions

We examined four visualization methods for achieving intuitively perceptible see-through vision for outdoor scenes on a handheld MR device. Subjective evaluation experiments were conducted to investigate the effects of the methods by comparison with the basic visualization method proposed previously [1]. The experimental results indicated that the combination of "ground grid," "overlaying wireframe model of occluding objects," and "top-down view" was the best, while it was not necessary to display occluding objects for outdoor see-through vision.

Extensive experiments under various conditions are required to verify our conclusions. In this study, we conducted a subjective evaluation by counting subject's preferences. In future studies, it will also be important to evaluate how precisely users recognize the situation by subjective evaluation as future studies. For example, it is valuable to evaluate the accuracy of depth determination of objects in the occluded area. It is also valuable to estimate the visibility of the model and the occluded objects by calculating the contrast of their regions on the display.

In addition, further experiments are needed to validate our conclusions. The results described here were derived from a typical situation of the occluded area recorded for the experiments. Although we selected the situation carefully, the results may differ according to the situation in different scenarios, color variations in the scene, distortion of the cameras, system delay time, subject's a priori knowledge of the relationship between the occluding buildings and the occluded area, etc. It is also important to address visualization of multiple occluded areas with multiple occluding objects.

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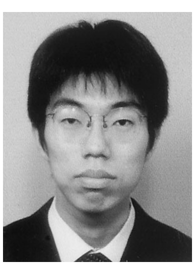
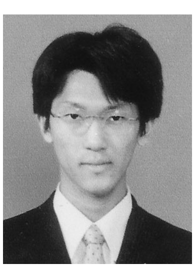


Takahiro Tsuda received B.Eng. from University of Tsukuba in 2005. He is currently M.E. student in the Graduate School of Systems and Information Engineering, University of Tsukuba.



Haruyoshi Yamamoto received B.Eng. from University of Tsukuba in 2004. He is currently M.E. student in the Graduate School of Systems and Information Engineering, University of Tsukuba. He is a student member of IPSJ.

Yoshinari Kameda received his B.Eng., M.Eng, and D.Eng. (Ph.D.) from Kyoto University in 1992, 1994, and 1999. He is now working as an associate professor at Graduate School of Systems and Information Engineering, University of Tsukuba, Japan. His research interests include Mixed Reality and its application, multimodal sensor fusion (massive sensing), visualization and understanding of human motion, ITS, and multimedia processing. He is a member of IPSJ, and IEEE.

Yuichi Ohta received the B.E. degree in electronics and the M.Sc. and Ph.D. degrees in information science, all from Kyoto University in 1972, 1974, and 1980, respectively. From 1978 to 1981 he was on the faculty at the Department of Information Science, Kyoto University. In 1981, he joined the faculty at University of Tsukuba, where he is currently a Professor of the Graduate School of Systems and Information Engineering, and the chair of the Department of Intelligent Interaction Technologies. He was a Visiting Scientist at the Computer Science Department, Carnegie Mellon University from 1982 to 1983.