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Visualization Methods for Outdoor See-Through Vision

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Abstract

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 five visualization methods for see-through vision that help the user to intuitively recognize occluded objects in outdoor scenes: "elimination of occluding object," "ground grid," "overlaying model of occluding object," "top-down view," and "on-off switching of MR display." As we applied a new handheld MR device for outdoor see-through vision, we conducted subjective experiments to determine the best combination of methods. The experimental results indicated the combination of showing the ground grid, overlaying the wire-frame models of occluding objects, and top-down view to be optimal, while it is not necessary to display occluding objects for outdoor see-through vision with a handheld device, because users can see them with the naked eye.

Keywords: Mixed Reality, Augmented Reality, See-Through, Outdoor, Subjective Evaluation

1. Introduction

Mixed reality is a technology that superimposes a virtual world onto the real world. It enhances the real world visually by integrating computer graphics into the real world so that users can see useful information that normally would not be available in the real world. One useful application of MR is to visualize the blind area occluded by walls, buildings, and other objects in outdoor scenes. Visual information of the occluded area is valuable although it is not ordinarily accessible. We call this application see-through vision [1].

By utilizing see-through vision, the user can determine what exists in occluded area around them more easily than 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 intuitively recognize information displayed in see-through vision. If the information is displayed in a manner that cannot be perceived intuitively, it will 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][2][3]. As this new style of device has a different modality from conventional MR devices, such as HMD, it is necessary to investigate adequate visualization function that is suitable. For example, with the handheld MR device, the user does not need to look into the display of the device to see the real world because it can be seen directly with the naked eye.

In this study, the user made use of see-through vision function with a handheld MR device, with moving objects, such as pedestrians and bicycles, in an occluded area hidden by a building in front of the user. We examined five 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 formed as follows. In section 2, pioneering work and the results of previous research into see-through vision are discussed. Then, two problems that should be addressed to achieve well-designed see-through vision are described in section 3. The five visualization methods applied in this study are described in section 4. The results of subjective evaluation experiments are shown in section 5, and we conclude the paper in section 6.

2. Related work

In recent and advanced research projects, 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 to be implemented in the near future.

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 wire-frame view. X-Ray Window [6] for use on the International Space Station (ISS) is intended 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].

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 inside 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). See-through vision utilizing transparent walls could improve navigational support for people in VE [12]. Thus, see-through vision has been utilized for many applications.

However, it is a non-trivial task to display information in see-through vision in a manner that the user can intuitively recognize. 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 through the use of 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]. People can find appropriate information easily with the proposed tools. The human depth perception model related to utilization of semitransparency in 3D interaction [17] and psychological effects of stereo, lighting, and background scenes in computer graphics [18] have been investigated.

These research projects assume see-through vision with HMD and are effective when people use HMD. However, as a handheld MR device [1][2][3] is more useful to realize see-through vision in outdoor environments, a new visualization method that is associated with the handheld MR device should be 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 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

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 realize see-through vision, approaches to handle these issues may have different side effects from those that arise when HMD is used.

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 assure 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 Figure 1(c). However, it causes contradiction of occlusion because the order of overlapping 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 to recognize the locations of objects in the depth direction [19]. In MR/AR display, this was evidenced by experiments using perceptual cues [14]. When there are two objects, people usually recognize which object is closer to them by seeing that one object is partially or completely occluding 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.

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

One conservative solution is to blend the texture of the occluded area transparently (Figure 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 kinds of object in the scene and they may finally 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 easy for people to understand which texture 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 help in visual recognition of the 3D locations of occluded objects are necessary.

3.3. See-through vision with handheld device

Outdoor see-through vision with the handheld MR device used in this study has the feature that the user can easily see the real world directly with the naked eye, and do not need to look into the display. This means that the user can see both MR display and the real world with the naked eye at the same time. In addition, the user's field of view is not limited. With such a system, we can hypothesize that visible objects are less important as visual information in the display of the device. By taking this hypothesis into account, 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 (Figure 1(b)) [1]. We call this view the "basic visualization method." 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.

	(a) Real world	(b) Basic visualization method	(c) Occluded area superimposed
Visibility	×	△	○
Spatial relationship	○	△	×

Figure 1: Comparison of visualization.

4. Visualization methods for see-through vision

Five visualization methods are introduced in this paper to enhance the basic visualization method for see-through vision. 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.

4.1. Improving visibility of the occluded area

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

elimination of occluding object The texture of occluding objects is eliminated completely and that of the occluded area is rendered spatially precisely on the image on the handheld MR device. An example is shown in Figure 4. This method prevents admixture of the occluded area texture and the occluding object texture, and causes the problem that users cannot perceive what the occluding object is like. However, by applying see-through vision with a handheld device, users 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 dissolve ambiguity in the spatial relationships between occluding objects and the occluded area.

ground grid A grid on the ground is virtually presented in the occluded area to clarify the horizontal relationships between occluding objects and the occluded area. An example is shown in Figure 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 shape 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.

"wire-frame" One is to overlay the wire-frame model of the occluding object. As a wire-frame drawing is very simple, it does not spoil the visibility of the occluded area. An example of overlaying a wire-frame model of an occluding object is presented in Figure 6.

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

top-down view A top-down view is a good clue to recognize the spatial relationships of the user, occluding objects, and occluded areas. The disadvantage of the top-down view is that it does not provide any visual information of the occluded objects in the occluded area. Therefore, this method is thought to be supplemental for realizing see-through vision. A snapshot with top-down view is shown in Figure 8. As the top-down view is a view of the scene from another view point, it is sometimes difficult to determine the correspondence between the objects on the view and the image on the see-through vision device.

4.3. Additional function

We also prepared an auxiliary function to enhance the usability of the handheld see-through vision device.

on-off switching of MR display This function enables users to switch MR information on and off. If the

Figure 2: Input image.

Figure 3: Basic visualization method.

Figure 4: Elimination of occluding object.

Figure 5: Ground grid.

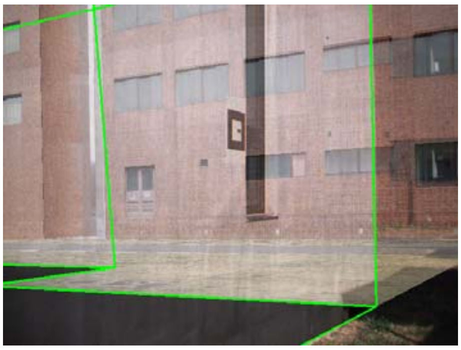

Figure 6: Wire-frame of occluding object.

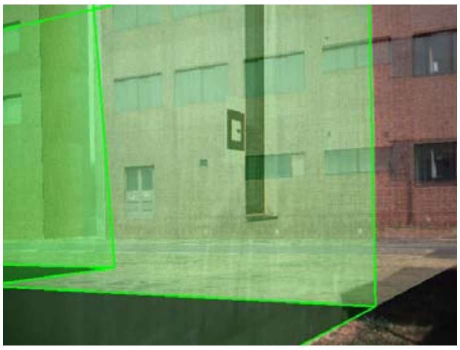

Figure 7: Wire-frame+surface of occluding object.

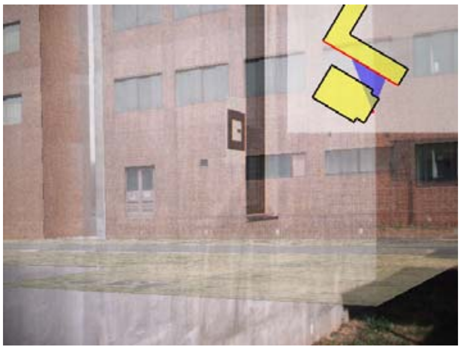

Figure 8: Top-down view.

MR information is turned off, the display simply shows the video image taken by the camera mounted on the handheld MR device (Figure 2). This makes it easy for users to compare see-through vision images with real world images.

As described above, the handheld MR device used in this study to realize basic visualization does not cover the eyes of the users. People do not need to see the real world though the display because they can see the world directly. In this sense, this is considered a re-

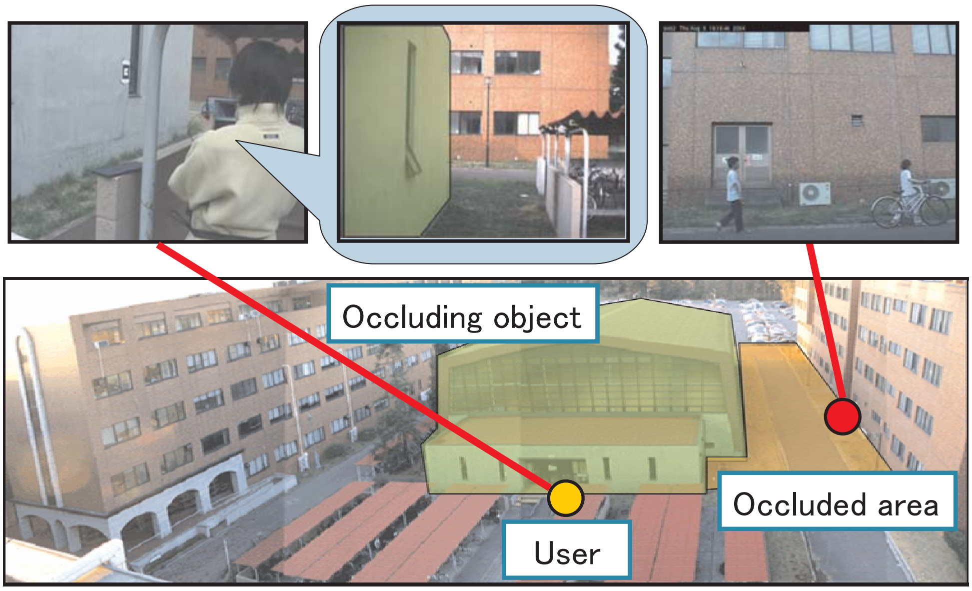

Figure 9: Experiment field overview. User see through occluding object and see pedestrians in occluded area.

dundant function. However, this is still useful because the view of the real world on the device is different from that seen through the naked eye.

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 prepared the basic visualization method based on the outdoor see-through vision [1]. The layout of the experimental field is shown in Figure 9 and the handheld MR device used is shown in the top left in Figure 9. The MR device used in the experiment was a Sony VAIO type U VGN-U70P. Video capture was performed using a Point Grey Research Dragonfly camera, mounted on the device. Subjects were asked to stand in the same position shown in the figure, but 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 captures the image seen by the user, which is shown in the upper-middle part of Figure 9. The resolution of the image was 640×480 pixels. The texture of the occluded area was geometrically aligned and blended in the captured image. During the experiment, there were pedestrians and bicycles in the occluded area and they were visualized dynamically in the display of the device. We utilized ARToolKit [20] to align the camera in this environment. Displacement of the CG objects in the image was about 10 pixels throughout the experiment.

We conducted the experiment in 10 subjects, all of whom were students in our laboratory and 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 befor the experiment.

5.2. Visualization methods

We examined each visualization method by subjective evaluation experiments to ascertain whether each visualization method is 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 questions on a 7-point scale.

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

With regard to "on-off switching of MR display," the question is:

- Which is better with or without the switch?

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 questions 1 and 2 are presented in Figures 10 and 11, respectively.Rectangular bars indicate the average score, and the lines indicate the standard deviation.

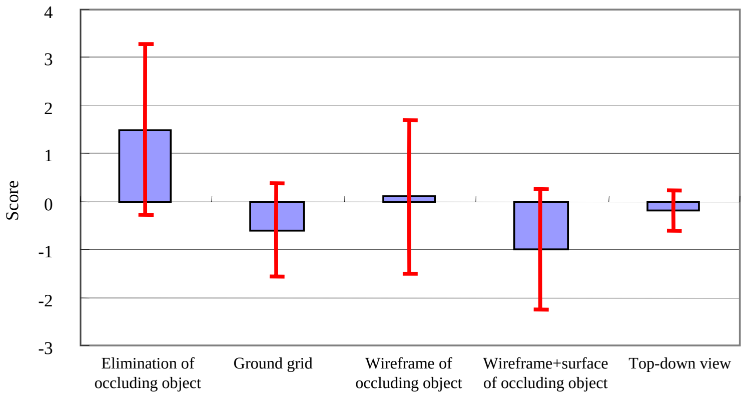

Figure 10: Evaluation of visibility of occluded area.

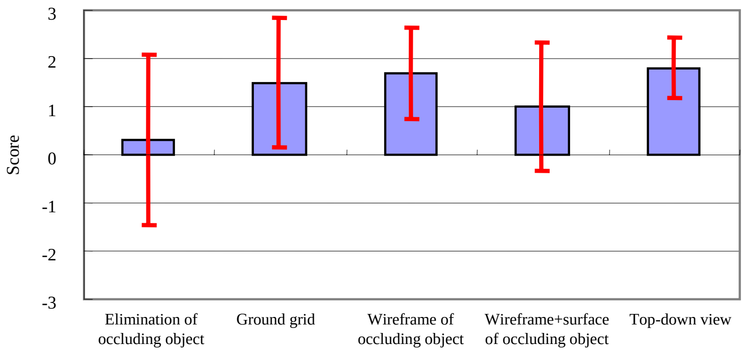

Figure 11: Evaluation of spatial relationship.

	Elimination of occluding object	Ground Grid	Wire-frame model	Wire-frame+surface model	Top-down view
Question 1	2.666	-1.964	0.198	-2.535	-1.50
Question 2	0.537	3.503	5.667	2.372	9.0

Table 1: T-value of each moehods at question 1(Visibility) and 2(Spatial relationship).

The results of t-tests are shown in Table 1. In this case, if t $\geq$ 2.262 the result indicates that the effect of the method was statistically significant and if t $\leq$ -2.262 the result indicates that the effect of the method was not statistically significant. So, the effect of “elimination of occluding object” was statistically significant and that of “overlaying wire-frame+surface model of occluding object” was not 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 effect.

First, we discuss the results of question 1. In the experiment to examine “elimination of the occluding object,” some subjects pointed out 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 marked high, in agreement with our expectations. “Overlaying wire-frame+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 cause a subjective feeling of poor visibility.

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. “Overlaying wire-frame model of occluding object” obtained a score as high as the “top-down view.”

The results indicate that the wire-frame model was better than the wire-frame+surface model. We feel that the users could understand the 3D shapes of occluding objects more easily with the wire-frame model because the additional surface rendering may degrade the visibility of the texture of the occluding objects. In fact, some subjects pointed out that the surface of the occluding object is not needed to recognize the spatial relationships. This may cause large standard deviation of the evaluation of “overlaying wire-frame+surface model of occluding object.” However, the effects of these methods may be concerned with observable angle, size, and shape of the occluding object. Therefore, it is necessary to investigate their effects in these methods.

“Ground grid” was also highly evaluated. However, some subjects pointed out that the texture of the ground of the occluded area was sufficient to recognize the spatial relationships, and they did not need the grid. This may have caused the large standard deviation.

The results of question 3, “on-off switching of MR display,” are presented in Figure 12. The t-value of the method

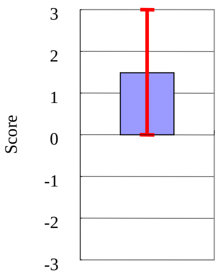

Figure 12: Evaluation of on-off switching MR display.

for this question was $3.143 \geq 2.262$. Thus, the t-test showed the method to be significantly effective. Subjects reported that the switch was useful to compare see-through vision and the image of the real world on the display of the handheld device easily.

5.3. Combination of visualization methods

As the five visualization methods can be combined to enhance outdoor see-through vision, we conducted subjective evaluation experiments for the combinations of "elimination of occluding object," "ground grid," and "overlaying model of occluding object." The remaining two methods ("top-down view" and "on-off switching of MR display") were not used for combination tests because we feel these two are independent from the other four.

Figure 13 shows an example of a combination of all three methods: "elimination of occluding object," "ground grid," and "overlaying wire-frame+surface model of occluding object".

5.3.1. Methodology

As there are two kinds of model (wire-frame and wire-frame+surface) in "overlaying models of occluding object," twelve patterns had to be examined. The patterns are shown in the left table in Figure 14. 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 the twelve patterns in consideration of the two questions presented in the previous experiment. The best pattern was scored as 1, and the worst as 12. We used the Kramer rank sum test [21] at a significance level of 5% and examined the significance of differences.

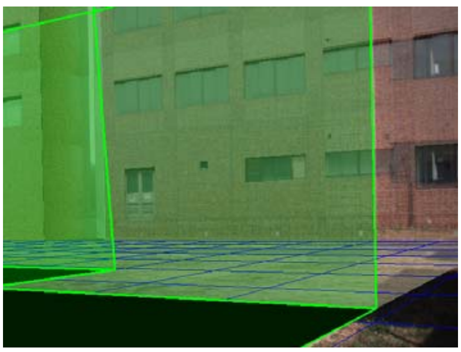

Figure 13: A visualization example of a combination. "Elimination of occluding object," "ground grid," and "overlaying wire-frame+surface model of occluding object" are applied.

5.3.2. Results and discussion

The results are shown in the right graph in Figure 14. 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 $\leq$ 37, and not statistically significant if the sum of ranks $\geq$ 93. Thus, patterns J and A were significantly better and significantly poorer than the others, respectively. The results indicated that intuitively perceptible see-through vision was realized by applying the three methods (pattern J).

According to these results, in addition to the fact that "elimination of occluding object," "ground grid," and "overlaying model of occluding object" each received high scores, 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 wire-frame model received higher scores than the wire-frame+surface model when integrated with other methods (e.g., pattern J was better than pattern L).

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

6. Conclusions

We examined five 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 wire-frame 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. It is also important address visualization of multiple occluded areas with multiple occluding objects.

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

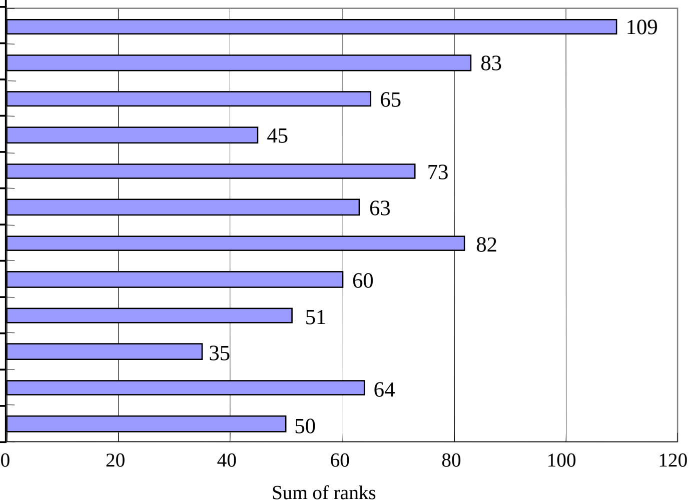

Figure 14: Combinations of the visualization methods and evaluation of them. Left table indicates combination of methods of each pattern. Right graph shows their evaluation by the sum of ranks

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