Implementation and Evaluation of a High-presence Interior Layout Simulation System using Mixed Reality

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Abstract

With the recent development of information and communications technology, the furniture sales and interior design fields have begun adopting various simulation systems based on virtual and augmented reality. Here we implement and evaluate a high-presence interior layout simulation system. Using mixed reality technology, the system arranges three-dimensional (3D) objects such as virtual furniture and home appliances in real space, without the visual discomfort caused by occlusion discrepancies between the virtual objects and real space. Accordingly, users can easily simulate home interiors by arranging 3D objects in their own living rooms or bedrooms. To test the effectiveness of the interior layout simulation system, we surveyed 22 university students who rated the presence, operability, functionality, and effectiveness of the system. The subjects' responses were overwhelmingly positive for all five measures.

Keywords: Interior Layout Simulation, Mixed Reality, Head Mounted Display, Real-time Mesh Generate

1 Introduction

With the recent development of information and communications technology, online shopping has become widespread. The furniture sales and interior design arena provides various Internet-based services. However, since many of these Internet service present products through PC monitors and smartphone screens, users must imagine the scale and arrangement of the products. On the other hand, with the development of technologies such as virtual reality (VR) and augmented reality (AR), digital presentations with high realism and immersion have been realized. The AR technology can simulate the image of products placed in real space by superimposing and displaying virtual objects on the real environment. In addition, the VR technology presents a virtual space composed of virtual objects and 3D scenes to users through devices such as HMD. Under these circumstances, interior design systems and interior product presentation systems using new technologies such as VR and AR can deliver high-presence services, providing consumers with realistic interior simulations. For this reason, they are attracting attention as a new product-purchase mechanism.

The rest of the article is organised as follows. Related work is described in Section 2. The research objective is described in Section 3. The system configuration and architecture of our proposed High-presence Interior Layout Simulation System is explained in Sections 4. The prototype system is described in Section 5 and evaluated in Section 6. Finally, we conclude our findings in Section 7.

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2 Related Works

Previously, we developed AR and VR presentation systems focusing on Japanese traditional crafts.

In our VR system for Japanese traditional crafts, consumers acquired a realistic interior simulation through a head mounted display (HMD). However, this system requires a virtual interior space constructed in advance, and incurs a high construction cost. Moreover, consumers cannot freely customize the interior space [10, 11, 9, 20, 19, 4, 3, 5].

On the other hand, the AR system allows consumers to experience Japanese traditional crafts by superimposing virtual objects on real environments through mobile terminals such as smartphones and tablets. However, this system introduces discrepant occluding relationships between the real environment and the virtual objects. In addition, it cannot express the sense of scale and reality of traditional crafts, as the virtual objects are placed on a flat display [7, 8, 6].

Phan et al. [15] developed an interior design application using marker AR technology. This system provides users with simulation of 3D furniture placed in a real environment by using 2D AR markers. The user can interactively change the color and scale of the virtual furniture object by using the control marker band.

Moaresa et al. [12] developed an interior layout application using marker AR technology. This application recognizes the space taken by a smartphone camera by using image processing technology. By placing virtual furniture objects in this recognized space, the user can experience AR interior placement.

Shin et al. [18] developed an AR interior design application that can be shared by multiple people. The user can browse the entire designed room layout in addition to AR presentation of virtual furniture objects by using this application. Also, when an application is used by multiple people, the designed room layout can be shared with each other.

Sandu et al. [17] surveyed several currently available AR interior design applications and analyzed the strengths and weaknesses of each application. Based on the results of the analysis, they proposed a new AR application. The proposed application scans the whole space and identifies real furniture by walking around the room space using the camera of the smartphone. Next, virtual furniture objects are arranged based on the scanned data.

Yan et al. [22] developed a 3D simulation system for room interiors using a 3D model and the VR3ID method. By using this system, users can experience changing the materials of walls and floors in a room interior, adding and moving furniture objects in a 3D simulation space. However, since the 3D simulation space is provided to the user via a PC monitor, the user cannot experience a simulation of the room interior with a high sense of reality.

Pejić et al. [14] developed an augmented and virtual reality application for the presentation of traditional architectural project. This system uses AR technology to reproduce 2D architectural structural drawings with 3D models and provides users with a three-dimensional structure. In addition, this system uses VR technology to enable users to experience real images of architectural interiors as 360-degree panoramic images.

Cruz et al. [1] developed an interactive collaboration application that allows users to experience an architectural interior in a virtual environment by using HMD and VR technology. By using this system, users can move freely inside the virtual architecture and experience the designed interior with a realistic feeling.

Rácz et al. [16] developed an application based on the demands of architects and consumers, allowing them to experience the whole image of the interior and exterior of a house before construction starts. This application uses HMD and VR technology to provide users with a design plan of the same scale as reality. In addition, users can change the interior and furniture, and can modify the design plan in real time.

3 Research Objective

In this research, we implement a high-presence interior layout simulation system using mixed reality (MR) technology, which combines the advantages of AR and VR technology, and which uses an HMD with a see-through function. The MR simulation experience resolves the contradiction between the real environment and the virtual objects by placing virtual interior objects in the MR simulation space. In practical applications, users who are considering purchasing furniture and home appliances, or changing the layout of their housing space, can simulate the arrangement of virtual furniture and home appliances in real space.

4 System Configuration and Architecture

The system configuration is shown in Fig. 1. This system consists of MR environment, a see-through HMD (HTC VIVE Pro HMD) [13] and Unity Application [21].

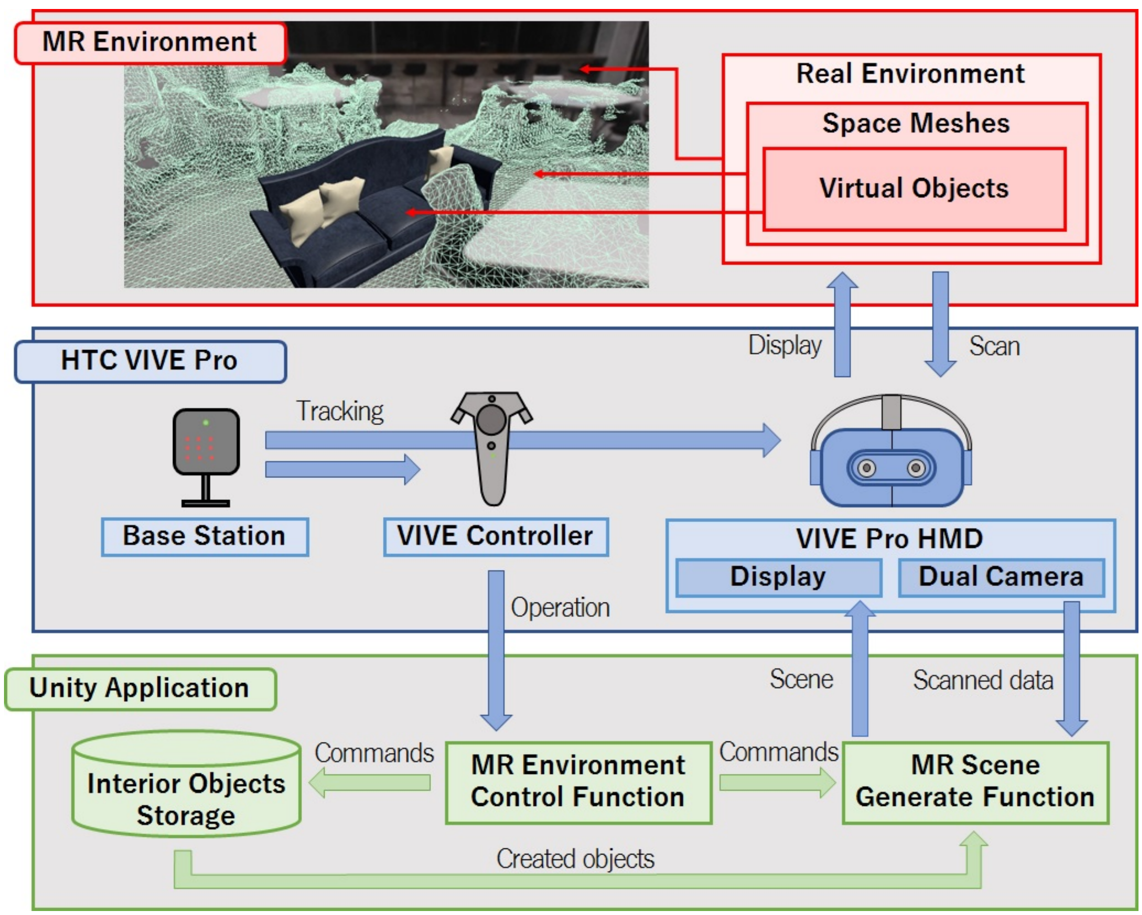

Figure 1: Configuration of the MR-based Simulation System

The system performs three main functions:

1). Captures the location and operation information of the user, and transfers it to the Unity Application that controls the system.

2). Scans the real space with a dual camera installed in the HMD and digitizes the shape of that space.

3). Presents the MR scene generated by Unity Application to the user and provides the MR simulation environment.

Unity Application controls the system functions under the operation commands issued by the user. Based on the space information scanned by the HMD, the MR environment is generated.

MR environment is a simulation environment generated by the cooperation of HMD and Unity Application. It comprises three layers: Virtual Object, Space Meshes, and real environment.

The proposed system architecture is shown in Fig. 2. The architecture consists of user operation control manager, system function control manager, MR scene generate function, HMD manager, and interior objects storage. The user operation control manager acquires the user's actions from the controller and HMD, and reflects the interaction with the UI and the movement of the camera on the system. The system function control manager controls the functions provided by this system. This manager performs functions such as scanning the real space and adding or moving virtual objects through the UI. The MR scene generate function generates MR simulation scene by merging mesh data of the real environment with elements such as virtual furniture objects, lights, and shadows. The MMD manager manages dual cameras and display attached to the HMD device, and scans the real environment and presents MR simulation scene according to system instructions. The interior objects storage stores virtual furniture and home appliance objects that are presented to the user. The user can reflect the objects stored in interior objects storage on the MR simulation scene.

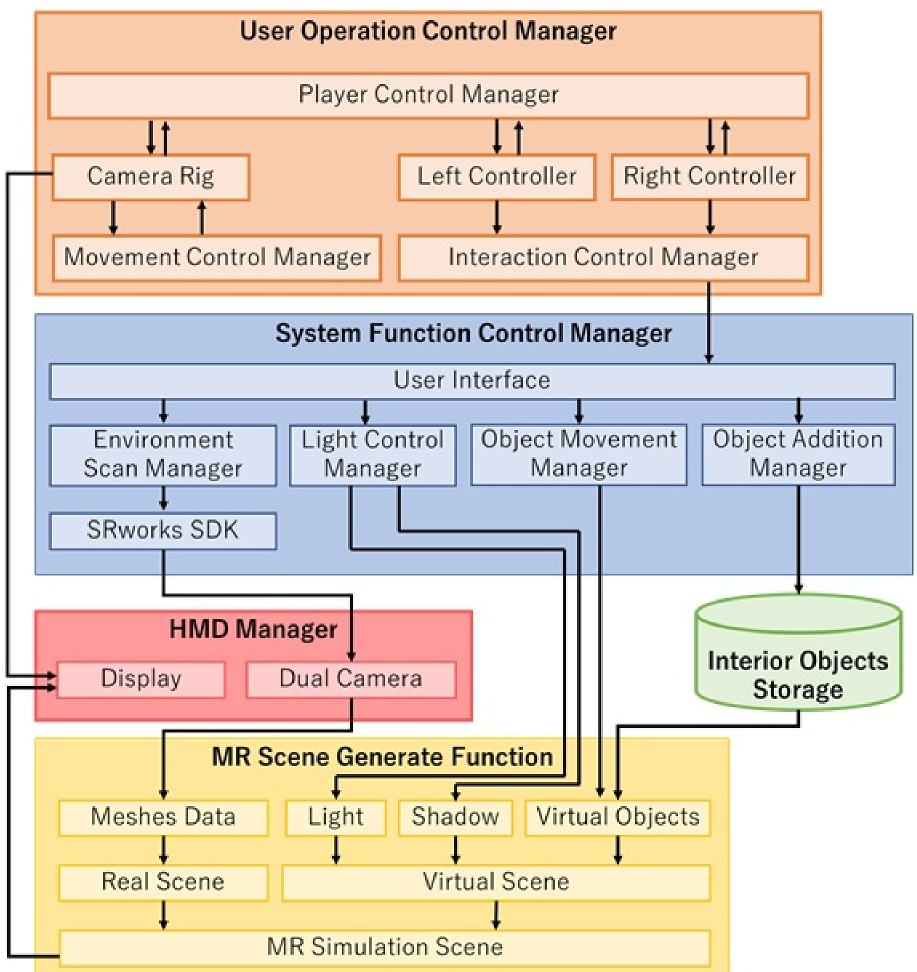

Figure 2: Architecture of the MR-based Simulation System

5 Prototype System

A prototype of the proposed system was implemented in Unity. The see-through HMD scans the real environment and presents the MR space. This prototype system has a space-scanning function, an object-arrangement function, an ambient-light adjustment function, and a mesh display switching function. With these functions, it provides users with a furniture arrangement simulation in the MR environment.

5.1 Space-Scanning Function

The previous AR system superimposed the virtual object directly on the real environment, without capturing the shape information of the real environment. Therefore, contradictions occurred in the occluding relationship between the real environment and the virtual object. The present system removes the contradictions in the occluding relationship by scanning the real environment and generating a mesh holding the shape information of the real environment.

The space-scanning function of this system starts the dual camera of the HMD and scans the real environment using VIVE SRWorks SDK [2]. It then generates a space mesh based on the scanned shape information. The space mesh comprises a triangle mesh set with a side length of 4 cm, which matches the shape of the real environment. It thus resolves the contradictory occluding relationship between the real environment and the virtual object (Fig. 3).

5.1.1 Object-Arrangement Function

In an interior arrangement simulation, the most important requirement is arrangement of the virtual furniture objects. The proposed system allows users to arrange virtual furniture objects through simple operations. Virtual furniture objects in the MR environment are simply moved by pressing the furniture button displayed on the menu panel, as shown in Fig. 4.

5.1.2 Ambient-Light Adjustment Function

In a real environment, all objects are shadowed. Therefore, arranging a non-shadowed virtual object in a real environment is visually discomfiting. To avoid this problem, the proposed system adds shadows to virtual objects through the ambient-light adjustment function (Fig. 5).

By default, this function creates a directional light perpendicular to the ground, which generates a shadow directly below the virtual object. The user can adjust the direction of the shadow by manipulating the controller, until the shadow of a virtual object matches the shadows in the real environment.

5.1.3 Experience of MR Environment

The proposed system simulates the interior layout with high presence by the space-scanning function, the object-arrangement function, and the ambient-light adjustment function. First, the user is presented with a simulation space based on the real environment captured through the dual cameras of the HMD. The user then selects each function from the 3D menu panel displayed on the simulation space. When the user selects the space-scanning function, a mesh is generated that molds to the real environment. Finally, the user arranges the virtual furniture object on the simulation space and switches the mesh to transparent (Fig. 6).

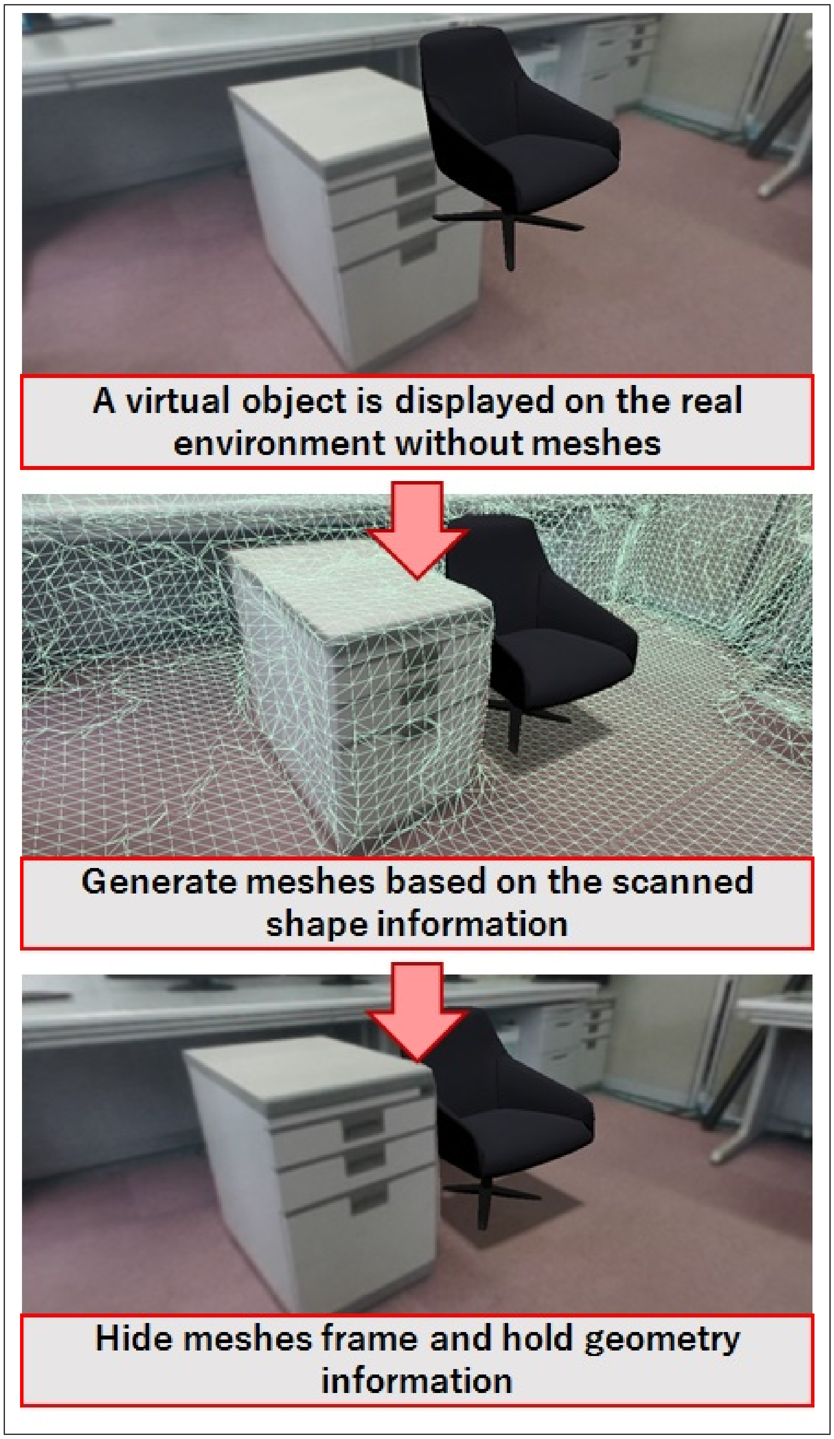

Figure 3: How the space-scanning function solves the occlusion contradiction

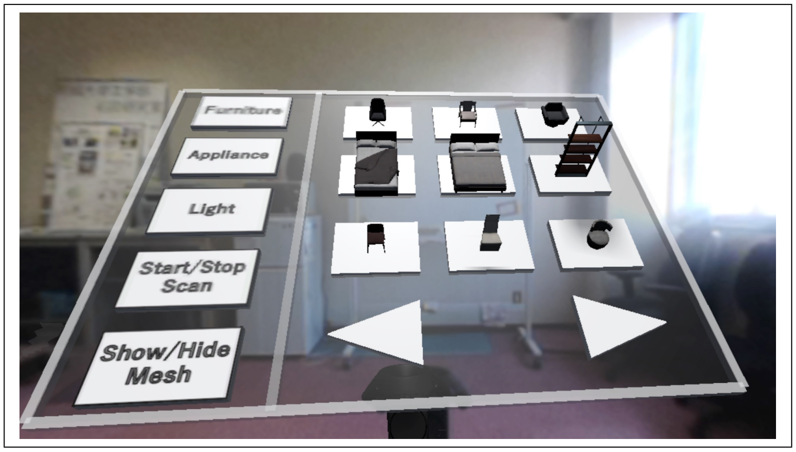

Figure 4: Menu Panel

Figure 5: Improving the Virtual Reality by Generating Shadows of a Virtual Object

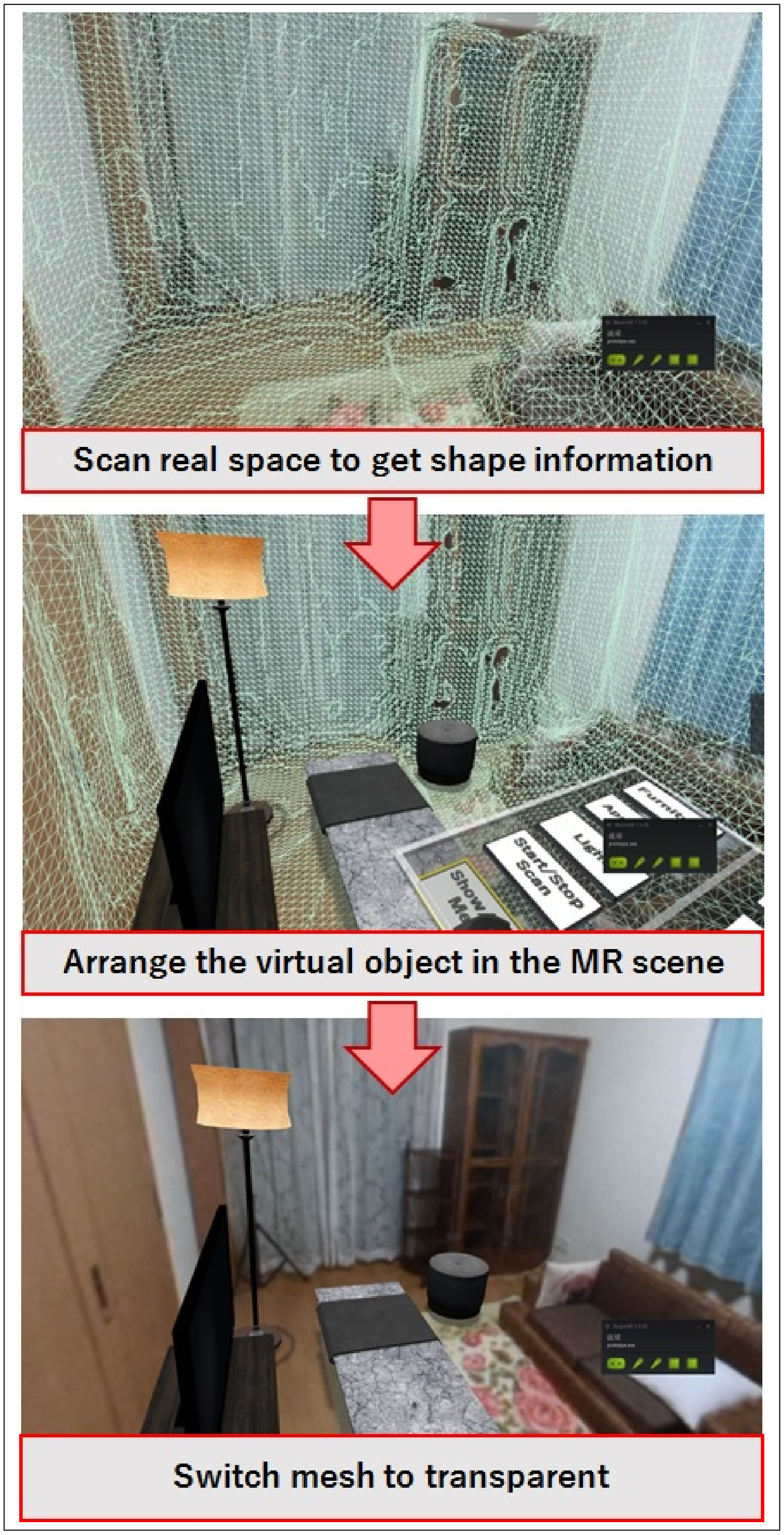

Figure 6: Example of an Interior Layout Simulation

6 Evaluation and Discussion

In the evaluation experiment, subjects were asked to consider a furniture-purchasing scenario in the simulation environment, in which virtual objects were arranged in the real space. The subjects (22 university students) evaluated the system by answering the questionnaire. The evaluation assessed the presence, operability, functionality, and effectiveness of the system. The survey results are presented below.

6.1 Evaluation results

The subjects' responses to the presence evaluation of our system are shown in Figure 7. As 95% of the subjects answered "high" or "somewhat high," a high sense of presence was confirmed.

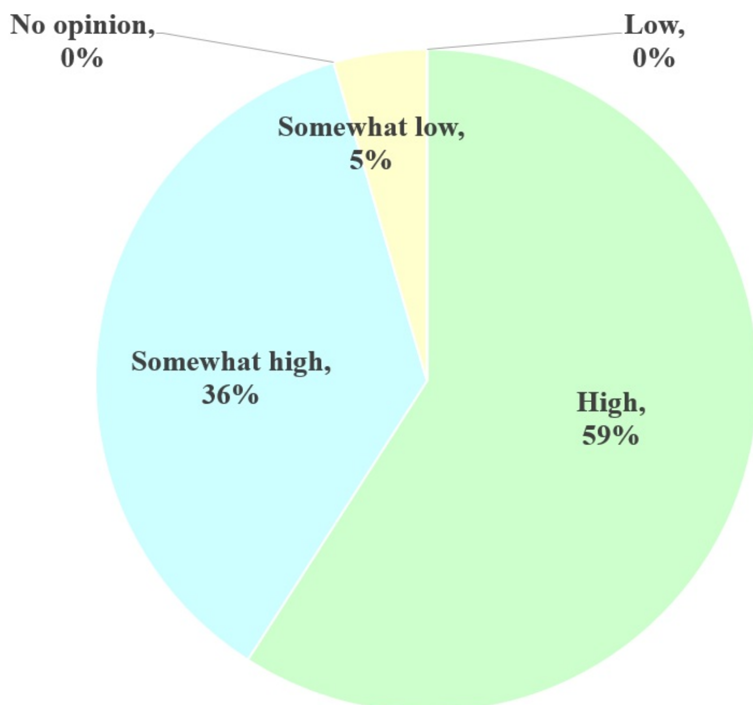

Figure 7: Presence responses of the high-presence interior layout simulation system (n=22)

Figure 8 shows the responses to the operability questions of our system. As 91% of the subjects answered "easy" or "somewhat easy," we confirmed the high operability of the system.

Figure 9 shows the responses to the functionality questions of our system. As 73% of the subjects answered "satisfied" or "somewhat satisfied," we confirmed the high functionality of the system.

Finally, the effectiveness responses to our system evaluation are shown in Figure 10. As 90% of the subjects answered "effective" or "somewhat effective," we confirmed the high effectiveness of the system.

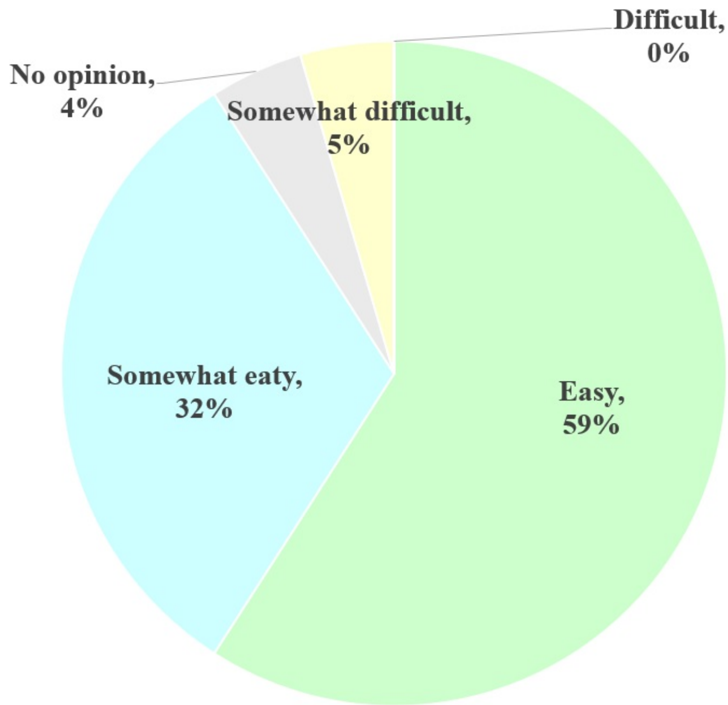

Figure 8: Operability responses of the high-presence interior layout simulation system (n=22)

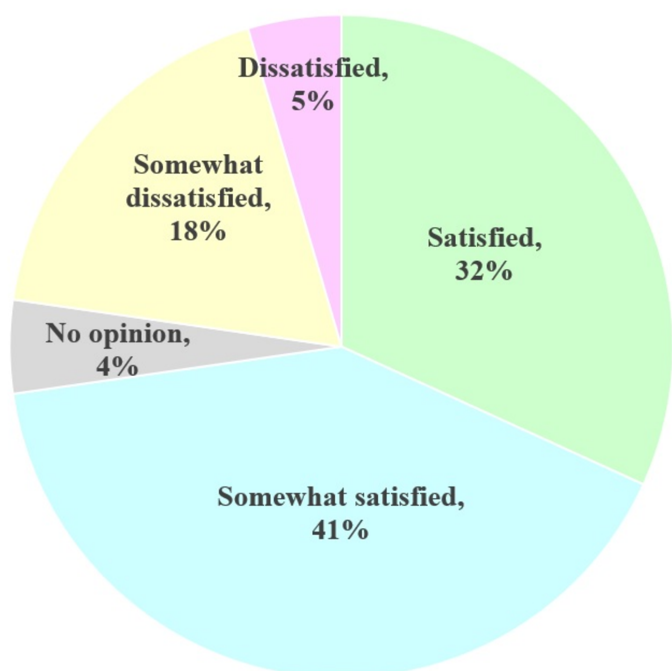

Figure 9: Functionality responses of the high-presence interior layout simulation system (n=22)

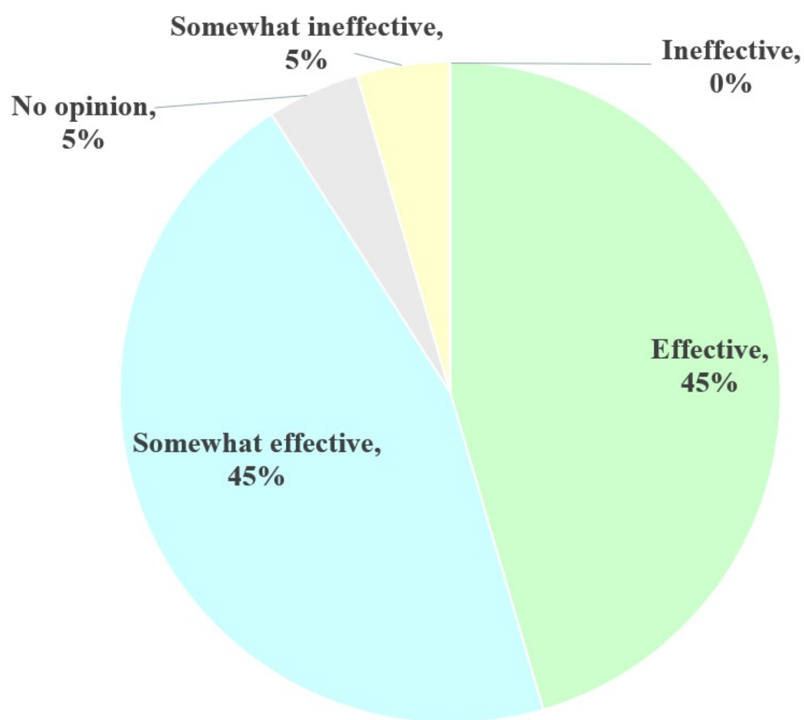

Figure 10: Effectiveness responses of the high-presence interior layout simulation system (*n*=22)

6.2 Discussion

Although the space-scanning function of this system generates meshes in real time, a single scan cannot generate an accurate mesh because the scanning is performed only within the visible range of the dual cameras. To obtain a highly accurate mesh of the entire real environment, multiple scans are required (Fig. 11). Therefore, improving the accuracy and speed of the space-scanning function is the next step for refining the system.

7 Conclusion

We implemented a high-presence interior layout simulation system through MR technology. This system arranges virtual objects on the real space using MR technology, simulating the interior layout and presenting it to users. Furthermore, by generating a mesh that captures the shape of the real environment, we remove the contradictions in the occluding relationship, providing a high-presence simulation system. In a questionnaire survey, we received feedback on the presence, operability, functionality, and effectiveness of the system. The responses to all features were overwhelmingly positive.

In future work, we will plan a function that allows multiple users in remote locations to share the same simulation space. This function will be developed in the prototype system. Specifically, the MR simulation environment experienced by the main user will be converted to a VR environment and shared with remote users via the Internet. The remote users will be able to experience the simulation environment on various VR devices. In this way, the user can coordinate the interior layout while consulting with remote store clerks or interior designers.

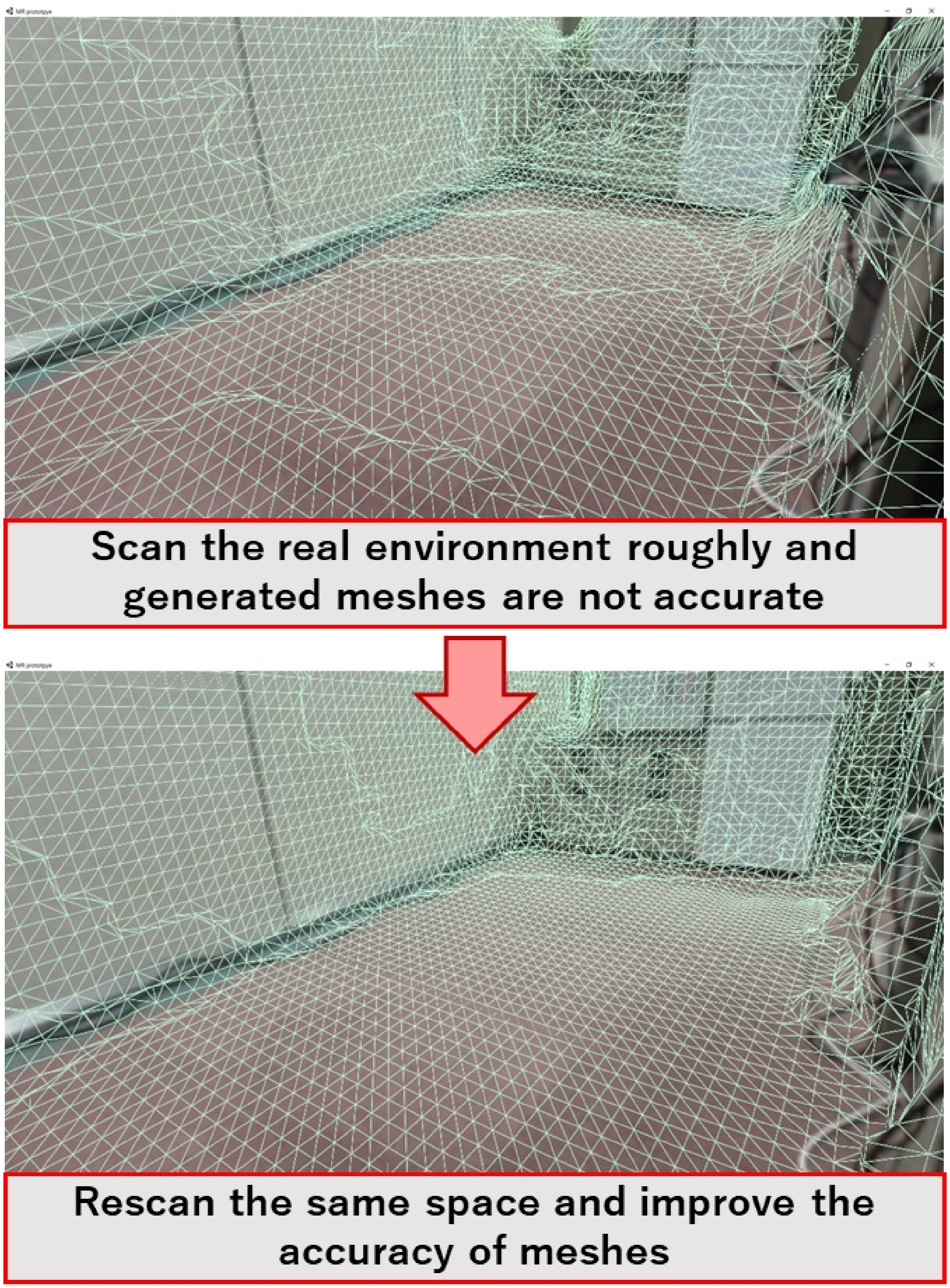

Figure 11: Improving the mesh accuracy by multiple scans

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