Virtual Object Placement in MR Space Using a 3D Miniature Model of a Room

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ABSTRACT

In this research, we propose a World in Miniature (WIM) -based technique for object placement in MR space. We considered that this would make it possible to freely place objects in 3D space, and to immediately check the position of objects that have been rearranged. In our prototype, we used the mesh of the room provided to represent the occlusion relationship by the MR device to generate a 3D miniature model of the room. We also made it possible to manipulate the virtual objects in the room by manipulating the miniature objects in the miniature model. In order to obtain a guideline for future system design, we conducted an experiment to investigate the characteristics of the manipulation of miniature objects in MR. The results showed that the manipulation of miniature objects in MR is effective in object searching, moving, and reducing physical workload, but that scaling manipulation is difficult. The results also suggest that these effects are affected by the viewing angle and the accuracy of hand tracking of the MR device, and provide guidelines for future system design.

CCS CONCEPTS

• **Human-centered computing** → *User studies*; *Mixed / augmented reality*.

KEYWORDS

augmented reality, 3D user interaction, distant object placement

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1 INTRODUCTION

Mixed Reality (MR) devices, such as Microsoft's HoloLens2 [10], are capable of displaying virtual objects superimposed on real space. Therefore, users of MR devices can place virtual 2D windows or 3D objects around the room. However, recognizing the exact position of the virtual objects is difficult [6], making the manipulation time-consuming and physically demanding. In order to shorten the manipulation time and reduce the physical workload, previous studies have used a virtual object placement method using real space features (walls and edges) [7, 13] and a room depth scale reduction and restoration method [2]. However, in the former method, virtual objects cannot be placed in places where there are no feature points in 3D space. In the latter, the virtual objects are manipulated with a reduced depth scale of the room, so the position of the virtual objects in the real space cannot be immediately confirmed. In this research, we use the World in Miniature (WIM) technique [15], which allows us to freely place virtual objects at arbitrary locations in 3D space and immediately confirm the placement positions.

The WIM technique is a technique for manipulating virtual objects in Virtual Reality (VR), in which a miniature model of the entire virtual environment is constructed and placed near the user. When the user manipulates a virtual object in the miniature, the corresponding object is manipulated in the real scale virtual environment. In order to use the WIM technique in MR, we use the mesh of the room provided by the MR device to represent the occlusion relationship. We scale this mesh and use it as a miniature model of the room. In addition, we display a miniature objects, and by manipulating the miniature objects, the corresponding virtual objects in the room can be manipulated. An overview of the implemented prototype is shown in Fig. 1. In this paper, we first explain the related research and present the design guidelines of the proposed system based on the findings. Next, we describe the prototype implemented based on the presented design guidelines. Then, we describe an evaluation experiment conducted to investigate the characteristics of manipulation of miniature objects in MR. Finally, based on the results of the experiments, we describe our future system design guidelines.

2 RELATED WORK

In this chapter, we first describe the existing techniques and issues of object manipulation in MR. Next, we describe the WIM technique used in this research. Finally, we describe the design guidelines of our system based on the findings of related studies.

2.1 Object Manipulation Methods in MR

For object manipulation in MR space, which is the focus of this research, ray casting is the most common manipulation method. However, in recent years, research has been conducted to manipulate objects using depth information in order to shorten the manipulation time and reduce the physical workload. Nuernberger et al. used the edges and planes of real objects to position objects [13]. However, placement using the edges and planes of real objects does not allow objects to be placed freely in 3D space. Chae et al. assisted object placement by moving a virtual wall superimposed

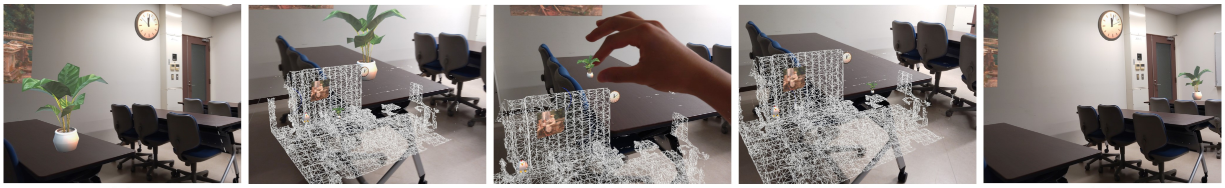

Figure 1: Overview of the prototype. (a) Virtual objects (a flowerpot, a clock, and a painting) are placed in a room. (b) The user view the miniature and check the placement of the virtual objects. (c, d) Changing the position of a miniature object by direct manipulation. (e) The position and size of the miniature objects are reflected on the real scale objects in real time.

on a wall back and forth to virtually reduce and restore the scale of the room [2]. However, when walls are moved, the placement cannot be immediately confirmed.

2.2 World in Miniature Technique

One of the object manipulation techniques in VR, the World in Miniature (WIM) technique [15], generates a miniature copy of the virtual environment and manipulates objects in the model to manipulate distant virtual objects. The WIM technique is considered to be less physically demanding because it requires less hand movement. In addition, the WIM method can assist in recognizing the position of objects by adding new viewpoints. The WIM technique has been used not only for object manipulation in VR, but also for navigation [12], IoT manipulation [14], and spatial design [16]. We considered that the WIM technique is also effective for object manipulation in MR. However, the effect of the WIM technique in MR has not been clarified.

2.3 Design Guidelines in this Research

The existing techniques for manipulating objects in MR, such as [2, 13], are effective in shortening the manipulation time and reducing the physical workload, but they have the problem that objects cannot be freely placed in the 3D space or objects cannot be immediately confirmed. In order to solve these problems, this research implements a system that utilizes the WIM technique in MR, which is a method for manipulating objects in VR. The design guidelines for this are as follows:

- Obtain 3D data of the room.
- Create a miniature model of the room using the acquired 3D data.
- Create miniature objects that have a correspondence with the virtual objects in the room and make their positions and sizes work together.

By using these design guidelines, we have developed a system that implements the WIM technique in MR, allowing the user to freely place virtual objects in 3D space and to immediately confirm the position of the rearranged objects. In addition, this system is expected to reduce the manipulation time and the distance of hand movement.

3 PROTOTYPE

This section describes the prototype implemented based on the design guidelines given in the Section 2.3. The hardware we used is the HoloLens2 [10]. The software we used is MixedRealityToolkit (MRTK, version 2.6.2) and Unity (version 2019.4.22.f1) [11].

3.1 Miniature Model of a Room

3.1.1 Creating a miniature model of the room. In MR, occlusion must be taken into account in order to give the user the impression that virtual objects are placed in real space. Therefore, many MR devices use built-in depth sensors to acquire a mesh of the room in real time, and represent the occlusion relationship. For example, HoloLens2 acquires meshes in real time in a function called Spatial Mapping [4] (Fig. 2), and MagicLeap acquires meshes in a function called World Mesh [8]. In this research, since we use HoloLens2, we acquire meshes using Spatial Mapping. In our prototype, we create a miniature model of a room by copying and scaling this mesh and placing it in front of the user (Fig. 3). Therefore, this implementation does not require any additional equipment to be added to the MR device, and can generate a miniature model of the room in real time.

Figure 2: Mesh of a room provided by HoloLens2.

3.1.2 Advantage of using a miniature model of a room. The use of a miniature model has the following advantages. First, by looking at the room from a bird's eye view through the miniature model of the room, the user can see the room from multiple viewpoints. Second, the user can place virtual objects based on real objects, regardless of the presence or absence of feature points, by looking at the miniature model without looking at the room in real space.

Figure 3: 1/10 scale miniature model of a room.

3.2 Miniature Objects

3.2.1 Creating miniature objects. When a virtual object (real scale object) is placed in real space, an object (miniature object) which is a miniature of the virtual object is immediately generated in the miniature model in front of the user. The size of the miniature object is determined by the scaling rate of the model. The position of the miniature object in the miniature model corresponds to the position of the real scale object in the real space. The position and size of the miniature object are updated whenever the real scale object is updated. The real scale object is also updated as the miniature object is updated. For example, if you place a virtual flowerpot on a desk (Fig. 1(a)), a miniature object of the flowerpot will be displayed on the desk of the miniature model in front of the user (Fig. 1(b)). Then, when you move the miniature object to another desk in the miniature model (Fig. 1(c)(d)), the real-scale flowerpot moves to the other desk in the real space (Fig. 1(e)).

3.2.2 Manipulating miniature objects. In the WIM research of Stoakley et al. [15], they used physical props, a board and a ball, to manipulate miniature objects. As controllers are not used in HoloLens2, we considered that a controller-less manipulation method is appropriate for MR. Therefore, in this research, miniature objects are manipulated by hand using hand tracking. In addition, since miniature objects exist in front of the user, miniature objects are manipulated using direct manipulation. Direct manipulation is a method of interaction similar to interaction with real objects. To press a virtual button, the user presses it with the index finger, and to pinch a virtual object, the user pinches it with the hand. Therefore, the user does not need to memorize the manipulation method as in the case of hand gestures, and it is considered to be easy to use. In this research, we use direct manipulation to move and scale a miniature object. To move a miniature object, users pinch the object with our index finger and thumb, move their hand to a desired location, and release the pinched fingers (Fig. 4). To scale a miniature object, users pinch it with the index fingers and thumbs of both hands, move their hands closer together to scale it, and move them further apart to enlarge it (Fig. 5).

3.2.3 Advantage of using miniature objects. Displaying and manipulating miniature objects in this way has the following advantages. First, by checking the placement of the miniature objects displayed in the miniature model in front of the user, we can check the placement of the real scale object in the room. Secondly, since the miniature objects are displayed in front of the user and manipulation is performed within the limited range of the hand, manipulation is considered to be less burdensome on the arm compared to manipulation by hand ray, and the manipulation time for moving and scaling can be reduced.

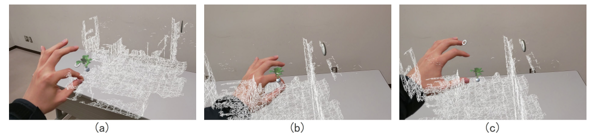

Figure 4: Procedure to move a miniature object (in this example, a flowerpot.) (a) Pinch the virtual object with the thumb and index finger. (b) Move the hand to the desired position. (c) Release the fingers to complete the movement.

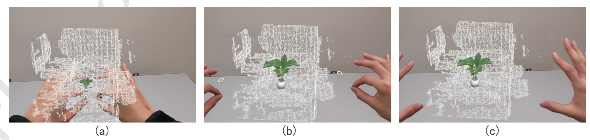

Figure 5: Procedure to scale a miniature object (in this example, a flowerpot.) (a) Pinch the virtual object using the thumb and index finger. (b) By changing the distance between the two hands, the scale is changed. (c) Release the pinched fingers to complete the scaling.

4 EXPERIMENT

In order to obtain guidelines for future system design, we conduct an experiment to investigate the characteristics of the manipulation of miniature objects in MR described in Section 3.2 and the characteristics of MR devices that affect the manipulation, among the functions of the prototype. In the evaluation, there was a possibility that the accuracy of the mesh would affect the manipulation characteristics. Therefore, in this experiment, we did not generate a miniature model as described in Section 3.1, but used a simple miniature model that was generated in advance.

4.1 Participants

We recruited 12 undergraduate and graduate students (10 male, 2 female; age: M = 22.1, SD = 0.90) through an application process in our lab. 11 were right-handed and 1 were left-handed.

4.2 Conditions

In this experiment, we compared the following two conditions.

- **C1.Real-scale condition** participants manipulate real scale objects placed in a room by hand ray manipulation
- **C2.Miniature condition** participants manipulate miniature objects placed in a simple miniature model by directly pinching them

The experimental design was a within-participant arrangement, and each participant performed the task in two conditions.The order of the conditions was counterbalanced, with six participants performing the task in the order of *Real-scale* and *Miniature*, and the remaining six participants performing the task in the order of *Miniature* and *Real-scale*.

4.3 Task

A white sphere and a red sphere were displayed in the room, and the task was to move and scale the white sphere to match the target red sphere. The experimental environment was a space of 5 m × 5 m × 2.5 m in one part of the room. The white sphere and the red sphere were randomly placed for each task among 48 candidate points (Fig. 6) that divided the entire experimental environment on a grid. The white sphere and the red sphere appeared once in each of the 48 candidate points without overlapping, for a total of 48 trials. The sizes of the white and red balls were (0.5 m, 0.4 m, and 0.3 m), and each of them appeared 16 times. If the center distance between the white and red spheres is less than or equal to the radius of the red sphere and the size of the white sphere is ±10% of the size of the red sphere, the task is considered to be completed and we move on to the next task. To determine the position and size of the miniature objects, we used a miniature model consisting only of the floor, and placed the miniature objects on the model. The miniature model is 1/10 scale of the room and is fixed at the center of the room (the midpoint of the two blue points in Fig. 6(right)). In both the *Real-scale* and *Miniature* conditions, the moving manipulations are performed with one hand and the scaling manipulations are performed with two hands. The manipulations for each condition are shown in Fig. 7.

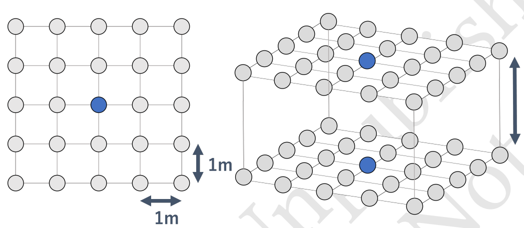

Figure 6: Candidate sphere placement points (blue points are not shown because they are the user's initial positions). (Right) The bottom sphere is located at 0.25m from the floor.

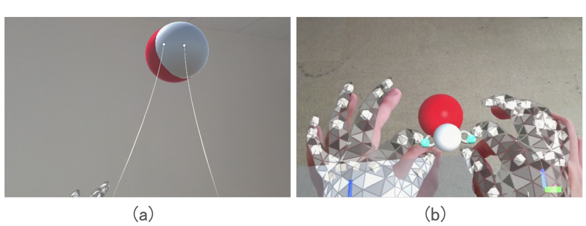

Figure 7: (a) Manipulation in *Real-scale*. (b) Manipulation in *Miniature*.

4.4 Procedure

In the experiment, we first explained the purpose and content of the research in writing, and then obtained the participants' consent. Next, we explained the task contents of this experiment. Then, in order to familiarize the participants with pinch object manipulation, we asked them to practice basic manipulation of the HoloLens Tips [3] and objects until they were satisfied. Then, they performed the task in each condition. The participants were instructed to perform the task faster and more accurately. After the completion of the task, three questionnaires were administered to the participants: a System Usability Scale (SUS) questionnaire [1] for usability research, a NASA-TLX questionnaire [5] for workload research, and a open-ended questionnaire.

4.5 Measurement

We considered that object manipulation can be divided into phases of searching for an object, moving an object, and scaling an object. Therefore, we obtained not only the time from the start to the end of a task (total manipulation time), but also the searching time, moving time, and scaling time. Here, the searching time was calculated as the time from the start of the task to the time when the user grasps the position of the sphere and touches it. We also obtained the log data of the hand position during the task in order to obtain the distance of the hand movement. The hand position was obtained by the hand tracking function of HoloLens2.

4.6 Results

For the total manipulation time, searching time, moving time, and scale time of the task, we first removed the outliers. We discarded values as outliers if they were larger than the third quartile plus 1.5 times the quartile range or smaller than the first quartile minus 1.5 times the quartile range.

4.6.1 Manipulation time. The total manipulation time for each condition is shown in Fig. 8. The searching time, the moving time, and the scaling time for each condition are shown in Fig. 9. The mean total manipulation time, searching time, moving time, and scaling time for each condition were as follows: *Real-scale* was 20.34 minutes (SD = 3.42), 11.21 minutes (SD = 2.23), 7.20 minutes (SD = 1.92), and 1.92 minutes (SD = 0.63), respectively, and *Miniature* was 8.57 minutes (SD = 1.58), 2.93 minutes (SD = 0.73), 3.82 minutes (SD = 1.35), and 1.82 minutes (SD = 0.56), respectively. Results of the Wilcoxon signed rank test showed that the total manipulation time ($V = 78$, $p < 0.01$), searching time ($V = 78$, $p < 0.01$), and moving time ($V = 78$, $p < 0.01$) were significantly different. However, there was no significant difference in scaling time ($V = 46$, $p = 0.622$).

4.6.2 Distance of the hand movement. Distance of the hand movement for each condition is shown in Fig. 10. The mean distance of the hand movement in each condition was 223.7 m (SD = 49.4) for *Real-scale* and 86.1 m (SD = 13.3) for *Miniature* (Fig. 10). A paired t-test showed a significant difference (t(12) = 11.34, p < 0.01).

4.6.3 SUS. The mean SUS scores for each condition were 67.7 (SD = 15.94) for *Real-scale* and 77.7 (SD = 9.85) for *Miniature*. A paired t-test showed no significant difference (t(12) = -1.97, $p = 0.074$).

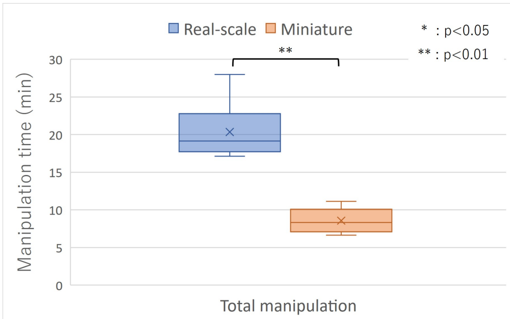

Figure 8: Total manipulation time for each condition.

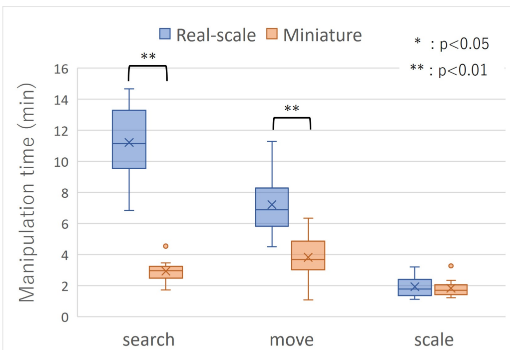

Figure 9: Searching time, moving time, and scaling time for each condition.

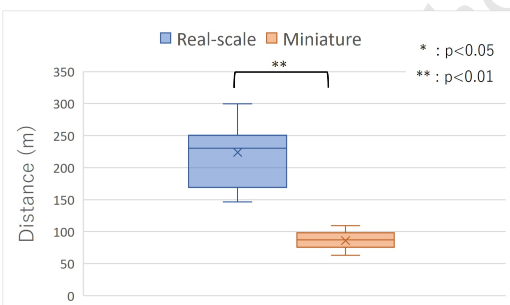

Figure 10: Distance of the hand movement in each condition.

4.6.4 NASA-TLX. The mean overall workload for each condition was 72.5 (SD = 17.7) for *Real-scale* and 39.9 (SD = 15.3) for *Miniature*. A Wilcoxon signed rank test revealed a significant difference (V = 78, p < 0.01). The mean workloads for the physical demands of each condition were 84.6 (SD = 17.2) for *Real-scale* and 36.3 (SD = 25.1) for *Miniature*. Wilcoxon's signed rank test showed a significant difference (V = 78, p < 0.01).

4.6.5 Open-ended questionnaires. For the searching in *Real-scale*, we received the following comments: "It was difficult to find the objects because the range of the objects was so wide in relation to the field of view" (P10), and "It was necessary to walk around to grasp the position of the objects because of the narrow angle of view" (P12). On the other hand, for the searching in *Miniature*, participants commented that "it was very easy to use because you could observe the entire room from a bird's eye view, so it was easy to concentrate on the operation"(P4). For the scaling manipulation in *Miniature* , participants commented that "It was difficult to grasp an already small object with both hands and scale it. I think it would have been easier if there was a handle such as a frame" (P3), "When scaling, the fingers of both hands collided and it took a little time. I felt that there was a trade-off between the accuracy of hand tracking and the size of the miniature"(P12).

5 DISCUSSION

5.1 Searching Objects

In searching objects, the searching time was shorter in *Miniature* than in *Real-scale*. In addition, in the open-ended questionnaire, the participants commented that it was difficult to search with *Real-scale* due to the narrow viewing angle of the MR device, while *Miniature* was easy to manipulate due to the bird's eye view of the room. Therefore, it is possible that the narrow viewing angle of the MR device affected the search. Relatedly, many VR devices have a viewing angle of about 120 degrees, while MR devices currently on the market have a viewing angle of less than 60 degrees (HoloLens2: 52 degrees). Therefore, it is more difficult to search for objects in a wide space in MR than in VR, and the approach of this research using miniatures is considered to be valid. On the other hand, considering the narrow viewing angle inherent to MR devices, it is necessary to consider the size and position of miniatures when using them.

5.2 Moving Objects

In moving objects, the moving time was shorter in *Miniature* than in *Real-scale*. Also, the distance of the hand movement was shorter in *Miniature* than in *Real-scale*. Therefore, it is possible that the difference in the distance of the hand movement caused the difference in the moving time. As for the physical workload, the results of NASA-TLX showed that the workload of *Miniature* was smaller than that of *Real-scale*. It is possible that the difference in the physical workload was caused by the difference in the distance of the hand movement.

5.3 Scaling Objects

In scaling objects, there was no difference in the scaling time between *Real-scale* and *Miniature*. In addition, in the open-ended questionnaire, there were comments about the collision of the fingers of both hands in *Miniature* and the possibility that the accuracy of the hand tracking affects the manipulation of the miniature object. In our implementation, when trying to manipulate a miniature object, the effective area for manipulation (the area that accepts touch events) was also reduced by the same magnification as the miniature object. This may have affected the accuracy of hand tracking when performing scaling that requires complex manipulations using both hands simultaneously. In the future, it will be necessary to expand the effective area for manipulating objects in the miniature, or to adopt a different manipulation method that does not require both hands.

5.4 Design Guidelines For Future Systems

Based on the discussion of this experiment, we formulate design guidelines for future systems:

- In order to maintain the usefulness of miniature objects in searching, it is necessary to design the system so that the size and position of the miniature model can be kept within the viewing angle as much as possible.
- In order to assist the scaling manipulation of miniature objects, it is necessary to determine the lower limit of the scaling rate of miniature models or to improve the manipulation interface of miniature objects.

5.5 Limitation

In this experiment, a simple miniature model was used. This was a necessary choice for the evaluation of the interaction system, but may also affect the usability and workload measurements in the experiment.

In addition, the participants in the experiment were all students, resulting in a very narrow demographic of participants. To reduce bias, experiments should be conducted with participants recruited from a wider age range.

5.6 Future Work

This experiment clarified the characteristics of the manipulation of miniature objects and the characteristics of the MR device that affect it, and provided guidelines for the design of future systems.Therefore, we will first improve the manipulation interface based on the design guidelines. In addition, in the prototype, the miniature model was represented by a white wire frame, but it is necessary to consider whether to use a surface model or whether RGB information of the room is necessary. Then, using the improved manipulation system and a miniature model of the room, we will implement applications specialized for specific uses, such as office environment enhancement and AR authoring, and verify the effects of using these applications.

Moreover, the current system allows only one user at a time and uses only a HMD (head-mounted display) as the display. Therefore, as described by Memmesheimer and Achim [9], the system could be used for further applications by extending the system to allow multiple people to use the system simultaneously and to use not only HMDs but also HHDs (handheld displays) simultaneously.

6 CONCLUSION

We proposed a World in Miniature (WIM)-based technique for object placement in MR space to make it possible to freely place objects in 3D space, and to immediately check the position of objects that have been rearranged. In this prototype, we used the mesh of the room provided to represent the occlusion relationship by the MR device to generate a 3D miniature model of the room. We also made it possible to manipulate the virtual objects in the room by manipulating the miniature objects in the miniature model. After that, we investigated the characteristics of the manipulation of miniature objects and the characteristics of MR devices that affect the direct manipulation of the miniature object in order to obtain guidelines for future system design. The results showed that the manipulation of miniature objects is effective in searching objects, moving manipulation, and the physical workload, but that scaling manipulation is difficult. In the future, based on the guidelines obtained from the experiments, we will complete the system design by adding functions to complement the shortcomings shown. In addition, we will develop applications using the system and conduct evaluation experiments.

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