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Multi-Scale Interactions Between Augmented Reality and Virtual Reality Users in Mixed Reality Environment

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ABSTRACT

Multi-scale interaction in Mixed Reality (MR) allows the avatars to shrink down themselves into a small size or enlarge into giant size. Multi-scale in MR is important in some situations that required precise avatar's measurements to interact and manipulate with the content. However, the correct or appropriate scaling for multi-scale still remain unsolved in MR, very less people work in Augmented Reality (AR). It is critical to align precisely the way humans perceive the virtual world with the ways perceiving the real world. Therefore, this paper aims to produce a correct multi-scale technique for VR and AR users in MR environment. This paper presents a preliminary study on the previous works multi-scale techniques for MR remote collaboration. Then it explains the development of a multi-scale interaction between VR and AR users for the MR environment. Finally, this paper shows the results and implement the technique into an application. The results used to measure how multi-scale interaction can be leveraged with MR technology. The remote MR application involves AR and VR users with different interaction techniques.

1. Introduction

Developing a multi-scale feature for this project required the correct scaling. Using the correct scaling is important and crucial for an application that required precise measurement such as medical, architecture, and automotive industry. It is critical to align precisely the way humans perceive the virtual world with the ways humans perceive the real world [1]. Humans tend to use natural bodies as the ruler to measure the distance or object size in everyday life. Because of that, a virtual avatar in VR that does not use a proper measurement might cause difficulty to determine distance or object size. The virtual object might seem smaller if the virtual avatar is too big and bigger if the virtual avatar is too small. For example, given a controllable child body instead of an adult body scaled down to the size of a child, participants overestimate object sizes more than in the small adult body and have faster reaction times on an implicit association test for child-like attributes [2]. This concept also applies to object distance where if an avatar is too big the object distance might see as near and if avatar to small object distance might see as far away. Either way, finding the correct

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scaling measurement based on the real world is a must so humans can have the same perception in the virtual world.

An experiment conducted by [1] shows that depth also influences object distance and size. Figure 2.12 shows that the human retina perceives two objects as the same size but in reality, the near object is smaller while the far object is bigger but still have not been explore in virtual environment. [3] also conducted a similar study that used multi-scale interaction in the developed application. Recursively scaling method was used to change the avatar either to a giant or miniature mode. In the application developed, smooth transition was included between scaling the virtual avatar without breaking the continuity to offer users the sense relative to the surrounding. To determine the correct scaling, a fixed avatar of the AR user was used as a placeholder for reference to give a better scaling measurement to the VR user avatar. The trigger method was used in this application in order to change the virtual avatar scaling by using a handheld controller or by entering the snow dome area.

2. Background Study

The collaboration includes sharing real-world details with a remote VR user from local AR users to increase spatial awareness and understanding. The research focuses on improving the collaboration experience between the AR local user and VR remote user. With the remote VR, users keep on teleportation for moving through the work area causing AR users to lose track and out of the field of view (FOV) of the VR user. The adaptive avatar or mini avatar has been used to dynamically emulate the AR user’s gaze, adjust to the surface geometry being projected on in the AR user’s FOV, and imitate the VR user with redirected gaze and movement to consistently gaze and point at the same position in shared room [3] whenever AR user not facing the VR avatar. The Mini-me avatar can disappear or snap back to the original VR avatar if the AR user is facing the VR avatar.

Figure 1 shows an adaptive avatar imitate the VR user with redirected gaze even with AR users cannot see the normal size avatar. Snow Dome application is an extension from the previous research of the Mini-Me adaptive avatar. The research is focusing on increasing collaboration experience between an AR local user and a VR remote user that enables VR users in multi-scale interaction [3] The VR user can scale up into a giant or down into a miniature avatar to view project space from a different perspective. As the avatar of VR user scale down, the perspective of the VR user could snap to the current Mini-Me position. This could be useful if the VR user is to be in front of the task space of the AR user instantly. The Snow Dome application was made to simulate the miniature VR avatar to interact with the small virtual object inside the dome. VR users can become small and teleport inside the virtual dome and interact with the small virtual objects inside the dome or can become bigger into a giant and interact with the reconstructed space [4]. Figure 2 shows the two situations where the VR user in a miniature mode and VR user in a giant mode in helping to experience a different viewing perspective.

Fig. 1. Adaptive avatar imitates the VR user with redirected gaze [3]

Fig. 2. VR user in miniature and giant mode [4]

Superman vs Giant research that has been conducted by [5] to study on spatial perception for a multi-scale MR flying telepresence interface. This work was done to address certain issues in MR collaboration such as small-scale collaboration and the solution that has come up with was to enable the user to remotely collaborate at a wider scale like a building construction by using the combination of MR, Unmanned Aerial Vehicles (UAV), and multi-scale collaboration virtual environments. Using the UAV to fly around the building for mapping the 3D reconstruction of the building and place inside the virtual environment. The UAV is an autonomous drone that is synchronized with the VR user head and body movement where the drone can fly at the eye height of the user. The VR user can scale themselves up to giant resulting in the UAV to adjust itself so it can have the same eye height of the giant. The VR user can also change to superman mode used to fly around the building. This helps users can change the view perspective of the environment [5]. Figure 3 shows the superman mode and giant mode with difference view perception. Table 1 shows the chronological of researchers who has worked on remote MR environment especially in remotely combining AR and VR to become MR environment.

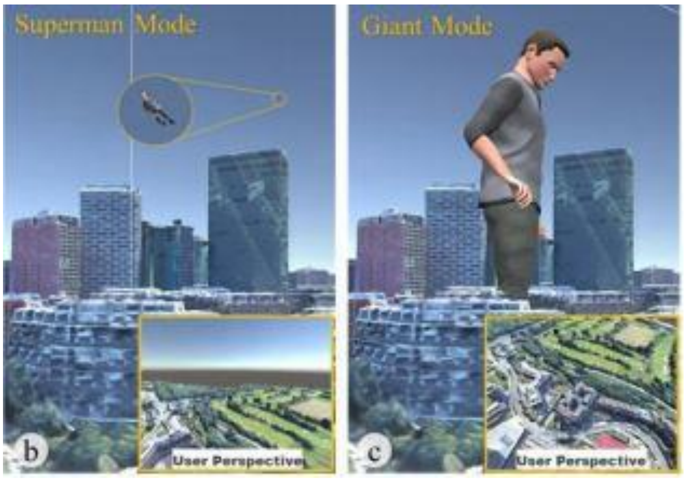


Fig. 3. Superman mode and Giant mode [5]

Another example is “Paint that Object Yellow”. It is an object manipulation system with multiple modalities interaction in a virtual reality environment as shown in Figure 3 [15]. It applied a typical VR visualization method with the use of head-tracked HMD and speech-gestures integration as input. Speech recognition in this system utilizes Microsoft Speech SDK. On the other hand, two oculus touch controllers are used for gesture control.

Table 1 shows the previous works. [16] has a novel remote collaborative platform based on gestures and gaze to support collaboration works during assembly or training tasks. They have motivated by the remote collaboration enables local workers and remote experts to collaborate in real-time without geographic restrictions. Recent works such as BeHere [17] invokes gesture and avatar into collaborative environments. Interaction-attention in XR has been explored [18], multiscale interaction in XR. The user could take on different perspectives in the streamed VR and shrink or enlarge their avatar similar to multiscale [19, 20].

Table 1
Previous Works

Year	Research / Project
2018	Mini-me: An adaptive avatar for mixed reality remote collaboration [6]
2018	Superman vs giant: A study on spatial perception for a multi-scale mixed reality flying telepresence interface [5]
2018	Snow dome: A multi-scale interaction in mixed reality remote collaboration. [3]
2019	On the shoulder of the giant: A multi-scale mixed reality collaboration with 360 video sharing and tangible interaction [7]
2020	A mobile game SDK for remote collaborative between two users [8]
2020	MR-Deco: Mixed Reality Application for Interior Design [9]
2020	3D telepresence for remote collaboration in extended reality (xR) [10]
2021	Manipulating Avatars for Enhanced Communication in Extended Reality [11]
2023	A novel AR remote collaborative platform for sharing 2.5D gestures and gaze [16]
2023	BeHere is a remote collaboration system based on virtual replicas sharing gesture and avatar in a procedural task [17]
2023	SAPIENS in XR: operationalizing interaction-attention in extended reality [18]
2023	User-defined mid-air gestures for multiscale GIS interface interaction [20]

3. Proposed Multi-Scale Interaction

This section explains the multi-scale avatar, user interaction, and multi-scale features uses in this research experiment.

3.1 Multi-Scale Avatar

The multi-scale avatar for VR user has 3 modes, giant, normal, and miniature. The crucial mode is the normal mode to reflect the user real height. The scaling was done by calculating the default height of the virtual avatar with the user real height. The avatar scale for the default size used scaling 1 to avoid complication. After calculating the default height of the virtual avatar with the user real height, the scale ratio then replaced the default avatar scale. Table 2 shows the scaling value used for 3 multi-scale mode.

Table 2
Multi-scale mode in MR

Multi-scale mode	Scaling value
Giant	Multiply 4 times with the original scale
Normal	Based on user real height.
Miniature	Divide 10 times with the original scale

At this stage, the overall progress both on multi-scale interaction and MR collaboration space is integrated together for both parts can be working together. To allow multi-scale to synchronize in MR collaboration space, the scaling synchronization used the Photon Transform View component to sync the transformation of the local client across the network. The Oculus VR composed of three components, the head, left hand, and right hand, the local VR needs to recalculate and reposition the offset of the head object to the new scaled VR body after using the multi-scale feature.

Since the remote VR avatar was automatically synced transformation from the local VR avatar, the remote VR avatar did not recalculate and reposition the new head offset to the newly scaled VR body that made the remote VR body and oculus head component used the previous offset causing the local AR not seeing the remote VR body after VR user used the multi-scale feature. Even though the VR user sees the remote AR user, the AR user not seeing the remote VR user, but the remote VR user is actually present in the AR local client but at a different location. The scaling in the Photon Transform View component was disabled to prevent automatically synced scaling across the network and instead, used Photon RPC to trigger recalculate and reposition the head offset of the remote VR avatar (as in Figure 4).

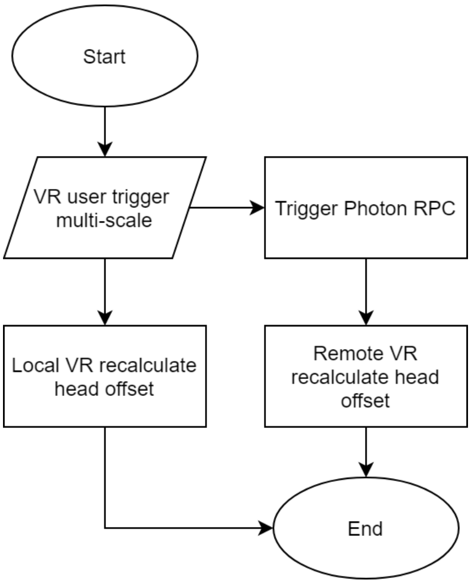


Fig. 4. Multi-scale triggered by VR user

The unit used for this research is in meter. Because the unit was measured in meter, the size of marker was also measured in meter before importing the marker to Vuforia for feature extraction. The size of marker must be the same in both space for achieving same virtual object size. A function was created to resize a specific virtual object to have the same size with the real environment such as physical table and virtual table. This is crucial because the main image target was placed on top of physical table. The marker height from the floor must be the same for both spaces. The physical table first was measured to find the height from the floor until the table surface. The measured height then was used to resize the virtual table to achieve the same height with the physical table. The same concept was used for calculating the virtual avatar size to have the same height with the user real height.

3.2 ZapBox HMD User in AR

ZapBox controller (as Figure 5) allows tracking and interaction with the virtual object for the AR user. Using a 2-Dimentional (2D) flat marker would cause the marker not detected during AR user rotating the marker in all direction. To solve this problem, Vuforia object scanner was used to scan all side of the ZapBox controller for references points to enable tracking from all ZapBox 3-Dimentional (3D) surfaces for more stable tracking. A virtual line or very thin cylinder object was attached to the front end of the virtual ZapBox controller. At the end of the line or cylinder, an invisible collider was attached to enable interaction with the virtual object. Upon contacted with other interactable virtual object, a specific function would trigger such as open door or disabling trap. An invisible virtual collider surrounding the virtual ZapBox controller also was attached to enable AR user for parrying the virtual falling rock object.

The AR user used ZapBox controller for interacting with the virtual object. The ZapBox controller was developed by scanning the controller using the Vuforia Object Scanner. The ZapBox controller is composed of 12 faces where each faces have a unique black and white design for tracking the references points.

Figure 5 shows the ZapBox controller head was scanned using the Vuforia Object Scanner with 309 references points. A 3-Dimensional (3D) cylinder was attached to the ZapBox object target as a rod and at the end of the rod was attached a collider for detecting the virtual object. Figure 6 shows the full ZapBox controller components composed of the ZapBox generated object target, cylinder, and collider in virtual space. AR interaction flowchart to collide the controller with the AR object.

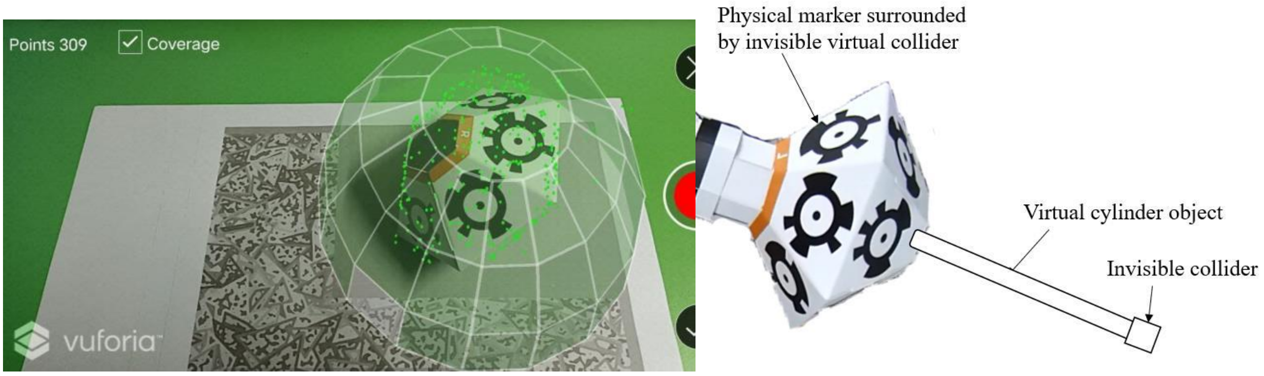


Fig. 5. Zapbox tangible interaction in AR

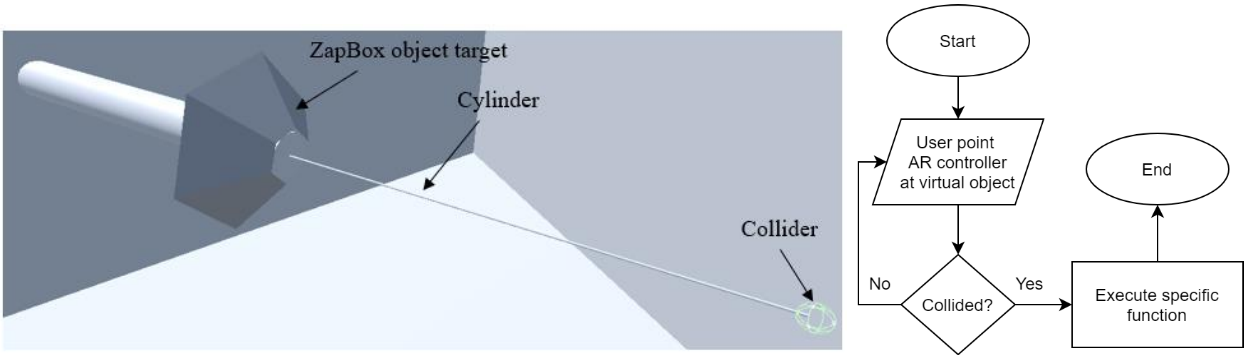


Fig. 6. Zapbox interaction to hit the target object

AR user uses smartphone camera to scan the image target and ZapBox HMD was used as the smartphone holder. Using the physical main image target to anchor the desirable virtual object to the real world. The smartphone also used as processor unit for running the application. Figure 6 shows the workspace setup for AR user. Mobile HMD has been used to place the smartphone inside and the user uses the ZapBox. Insert the earphone into the right hole of the ZapBox HMD to connect with the smartphone. Wear the HMD and put the earphone to both ears. Lastly, look at the physical marker to overlap virtual object on top of the marker. Figure 7 the smartphone with the earphone connected while holding the ZapBox controller for virtual object interaction.

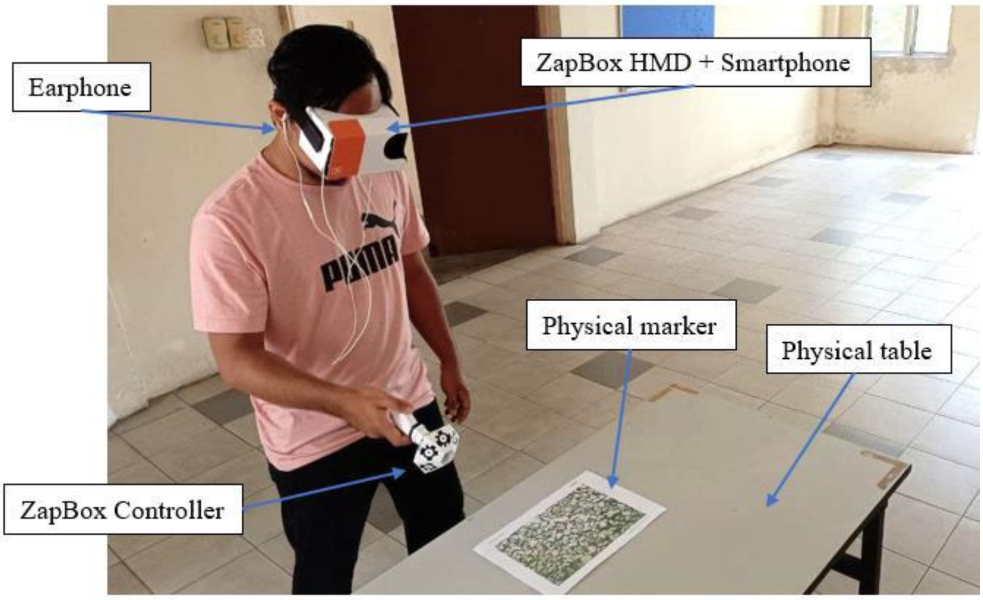


Fig. 7. Zapbox tangible interaction in AR

The AR application was built and pre-install into the smartphone before the testing begin. The printed marker was placed on top of a physical table with a height of 80 centimetres from the floor to reflect the virtual table used in the virtual environment. The ZapBox controller was placed, facing up, on the right hand of the AR user. The AR user is required to input their information and connect to the network before place the smartphone inside the ZapBox HMD. The earphone was connected to the smartphone inside the HMD and place both earphone speakers at both AR user ears. Lastly, the AR user is required to wear the HMD in order to begin the testing.

3.3 HMD User in VR

VR user needs to interact with the interface however the VR user used Oculus Quest 2 device, the touch controller was used for the interaction. Ray pointer was used to interact with UI in 3D space. By overlapping the ray pointer to the UI such as UI button, VR user can interact by clicking the controller button. VR user also can use multi-scale feature by clicking specific controller button.

The VR application was built and pre-install into the Oculus Quest 2 HMD using the Side Quest application. The VR user is required to wear the HMD and place both Quest 2 controllers on both VR user hands, as in Figure 8. The earphone was connected to the Quest 2 HMD and both earphone speakers were placed at both VR user ears. The application was executed, and the VR user would be greeted inside the initial VR lobby scene and wait for further instruction.

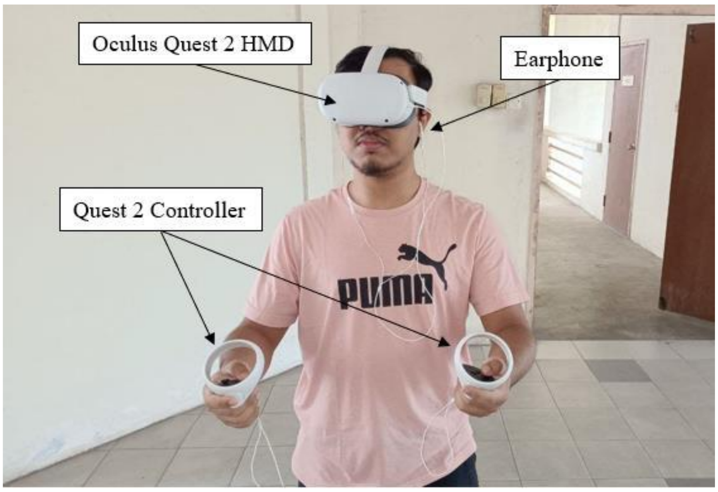


Fig. 8. User interaction in VR

Ray pointer was used to interact with UI in 3D space. By overlapping the ray pointer to the UI such as UI button, VR's user can interact by clicking the controller button. VR's user also can use multi-scale features by clicking a specific controller button. Figure 9 shows the VR interaction flowchart and Table 3 shows the list of buttons used for VR interaction. There are two buttons, Trigger and A. Trigger is used to interact with the UI button and A is used to change the VR avatar scale.

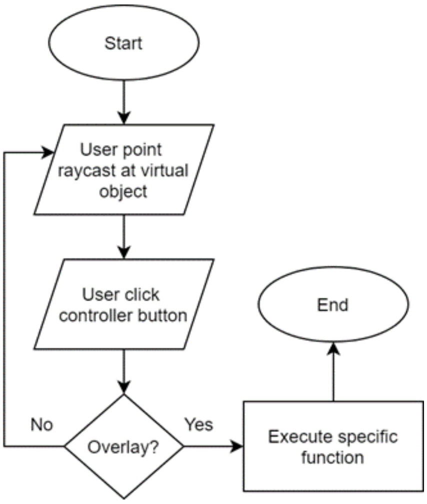


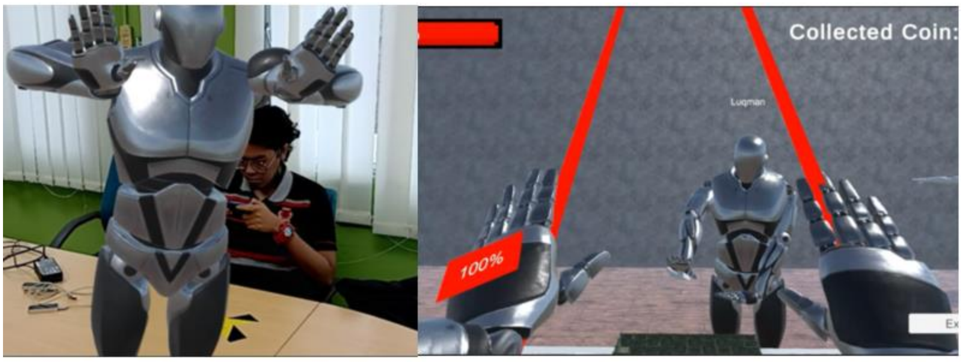
Fig. 9. VR interaction flowchart

Table 3
List of Buttons

List of buttons	Explanation
Trigger	Interact with UI button
A	Change the VR avatar scale

4. Test MR Application

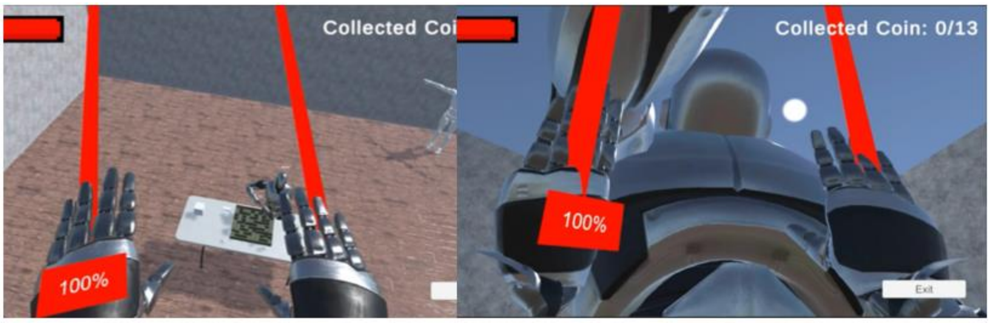
To allow remote collaboration between two users, MR maze has been developed, both users need to be in the same shared interface. Two users from different interfaces were connecting into the same space, MR maze. Once the player in the room equal to 2, both users would be transfer to the main scene. Figure 10(a) shows the shared space for AR user and Figure 10(b) shows the shared space VR user, in normal mode, after successfully connected into the same network room. Figure 8(b) shows the VR user, in giant mode, and VR user can see the AR user in miniature mode.



(a) (b)

Fig. 10. (a) AR space (b) VR space

The object is first created using Blende. Shape keys are added to the cylinder object (pottery object) during object modeling in Blender to enable deformation. Then, a simple cylinder (cylinder collider) is modeled using Blender, which will be used as collider for each Shape Key. Both 3D objects were imported into Unity. Figure 11 AR user will see the VR user in giant mode. Figure 11(a) shows the AR user help VR user open the hidden door and Figure 11(b) shows the VR user sees the AR user hand open the hidden door.



(a) (b)

Fig. 11. (a) Miniature AR user (b) Giant size of VR user

AR user as in Figure 12 (a) sees VR user in the maze game in the miniature mode. To start the game, VR user need to change to miniature mode (as in Figure 12 (b)). After changing to miniature mode, the VR user would automatically be teleported into the maze and the game timer would start. VR user must protect himself from the enemy by shooting at the enemy. As in Figure 13 (a), AR user, in a normal scale size, must help VR user by disabling trap, open hidden door, parry falling rock, and give direction to the VR user through verbal communication. The game would end if the VR user health reach zero and automatically force out of the maze or after complete collecting all the hidden chest or simply by toggling the multi-scale feature. The chest can be collected by colliding VR user with the chest as in Figure 13 (b).

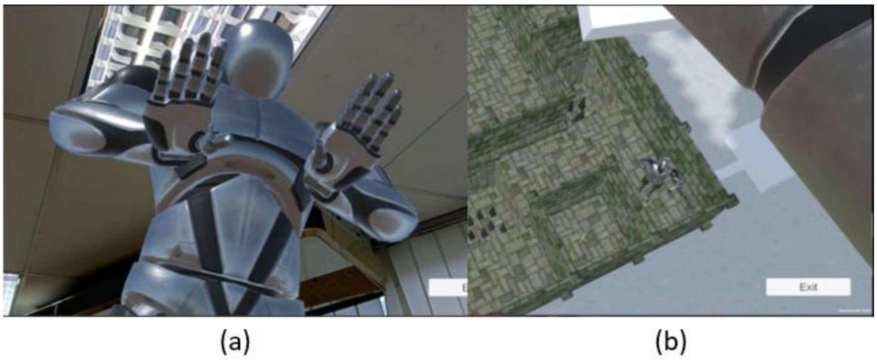


Fig. 12. AR user sees VR user in real world

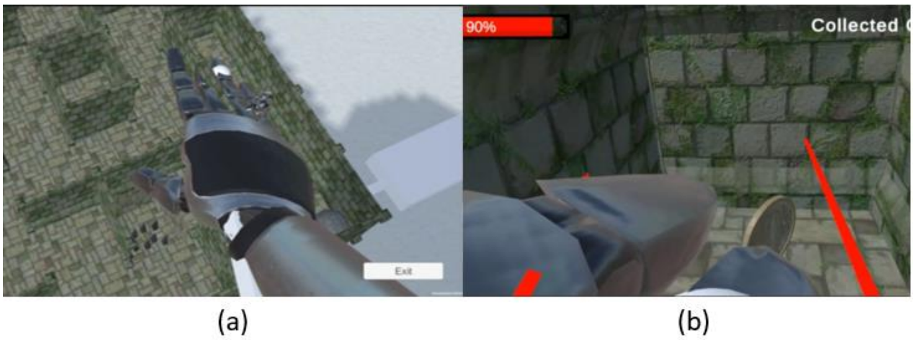


Fig. 13. AR user using ray pointing using Zapbox

In the maze, three walls one door covered all side of the chest. The chest is hidden from the VR user and only AR user know the chest position by looking the maze from above. AR user must point and touch using the ZapBox controller, 1 of the 4 walls to open the door to give access to VR user. Figure 14(a) shows the chest hidden by wall and Figure 14(b) shows the door open to uncover the chest behind it. Similar approached was used for disabling the spike trap. By pointing the ZapBox controller at the spike trap, it would disable and give ways to VR user. Figure 15(a) shows the spike trap before disable and Figure 15(b) shows the spike trap after disable. VR user would receive damage if triggered the spike trap.

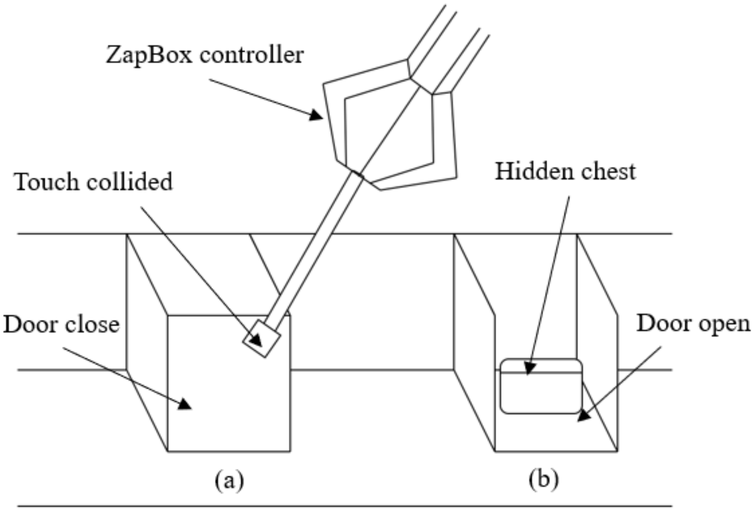


Fig. 14. Hidden chest hit using ZapBox controller

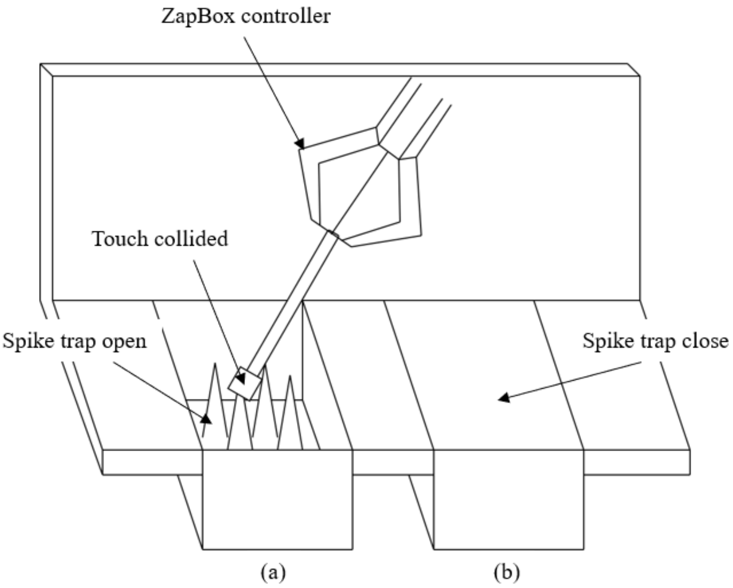


Fig. 15. Hidden chest open to enable obstables using ZapBox controller

During Maze application gameplay the VR user is in miniature mode, AR user have no type of indicator to know the current health of the VR user. UI was placed at the wall outside of the maze showing the amount of chest collect, best time, timer, and health of the VR user to allow AR user to be aware of the game and collaboration information. The best time would be updated if the timer is less than the last best time. After VR user exiting the Maze game by toggling the multi-scale, lose because health reach zero, or have successfully collected all chests, the timer, VR health, and total chests would be reset. The timer would automatically start after VR user enter the maze. If the VR user collect chests, the total chests UI would also be updated showing the current collected chests. VR user also can view his current health by looking at the left hand of the avatar.

5. Results

The main physical marker was imported into the Vuforia for feature extraction. After finish, the database was downloaded and imported into Unity. The physical marker was placed on top of the physical table, as shown in Figure 16(a). In the virtual space, the virtual marker was placed on top of a virtual table. Figure 16(b) shows the virtual marker on top of the virtual table.


(a) (b)

Fig. 16. (a) Real environment and (b) VR shared space environment

After the user was loaded into the main scene, the input name would be shown above the virtual avatar. Figure 17 shows the user's name above the virtual avatar.

(a) (b)

Fig. 17. (a) Avatar and (b) Shared space

From pre-experiment questionnaire result, only 60% of testers has experience in using LMC, while 50% of testers has experience with using speech commands in interacting with digital content.

From the post-experiment questionnaire result, up to 70% of testers strongly agree that the instruction provided in user menu is clear and easy to interact with. This shows that most of the testers are satisfied and do not face difficulty in interacting with the user interface. For hand gestures recognition part, up to 60% of the testers strongly agree that the application can recognize the predetermined gestures easily, and the gestures are intuitive. While 40% of the testers agree with that statement. For speech recognition, up to 70% testers strongly agree that the application can respond to the command in a short time, understand the speech command in natural language and perform the respective action. This shows that most of the testers can interact with the application using speech commands in natural language, and the application able to respond with the respective events.

As for black box testing, the average of recognition for all 15 gestures interaction recognition achieved 92%. While for a total of 80 speech command phrases recognition rate is 83%. Overall, the recognition accuracy for both gestures and speech command are within satisfaction of the tested users.

6. Conclusions

This paper presented an application that support hand gesture and speech recognition in 3D object manipulation in virtual environment. The testing results also shown that the intuitive hand gestures interaction, and natural language recognition, speech and gesture can become well-coordinate input in HCI.

Even though the results also indicate that some of the testers required some time to get used on interaction using mid-air gestures, however, after some time of practice, most of the testers still able to perform well and interact naturally with the computer. Hence, it is suggested for future works that the commands can be more intuitive and intelligent without having specifically set the speech phrases or gesture command which will help in shorten user learning curve.

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