University of Basel

Collaborative Virtual Museums

Bachelor thesis

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Abstract

With the current generation of the SteamVR tracking system, it is possible for multiple people to use the same physical space to experience their individual virtual spaces. The primary goal of this project is to link these virtual spaces such that proximity in the physical can be mapped seamlessly to the virtual world. Multiple users should be able to not only interact with entirely virtual but also with tracked physical objects and with each other in the same virtual space despite their individually perceived spaces being rendered by separate machines. A special focus must be the consideration of the disconnect between the physical presence of a user and the position of their virtual avatar, especially in cases where the virtual space exceeds the physical space in size. To enhance the user experience, images, video, audio and 3D models should be displayable in the virtual space. As an extension, dynamic 3D models could be supported.

The result of the project should be a prototype on the basis of which the following questions can be answered:

- What constraints do physical and virtual spaces need to fulfill in order to support multiple users simultaneously?
- What information needs to be exchanged for two or more users to inhabit the same virtual and physical space?
- How can users interact with virtual and tracked physical objects as well as with each other?
- What are the current capabilities of VR systems in terms of displaying multimedia objects?

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1 Introduction

Virtual reality has become a very exciting and popular technology. People already know the experience with 3D movies in cinemas or with 3D television, but virtual reality is something more. It provides a representation of an artificially created world. With the VR head mounted display the virtual world will be simulated directly in front of the eyes. In combination with different sensory such as image and sound, the user gets the feeling, called the immersion effect, of being in a completely different world [1]. The software Unity[1], a runtime and development environment that is involved in this project, enables the development of VR applications and games.

1.1 Foundations of Virtual Reality

Basically it will be distinguished between virtual reality VR, augmented reality AR and mixed reality MR [2].

1.1.1 Virtual Reality

Virtual Reality is a technology, where users can experience in a complete virtual created world, where they can move and interact as they are used to in the real world. The world is a computer-based generated environment [3]. Wikipedia defines virtual as „being something in essence of effect, though not actually or in fact“. In computer-sense the meaning turned into „not physically existing but made to appear by software“[2]. VR is completely differentiated from the real world. On the other hand, augmented reality offers the possibility to show virtual information in the real world.

1.1.2 Augmented Reality

Augmented Reality is a method to represent virtual information in the real world. It can simplify people's needs. For example the head-up display in modern cars, where it is possible

[1] https://unity.com/
[2] https://en.wikipedia.org/wiki/Virtual_reality

to display information like speed and navigation on the front winshield. Many applications are made for smartphones and tablets to use augmented reality. With the app „IKEA place“ users can use the camera to place the desired furniture in the real space to decide if they want to buy it or not[4]. Augmented reality also offers good opportunities for entertainment end education[5]. Many games have the augmented reality function by taking the environment on a smartphone or tablet with the rear camera. The screen shows, how the game figure moves over the dining table for example. The DBIS Group has developed an application called GoFind[6]. It is a augmented reality application, which provides a location-based multimedia retrieval. GoFind uses a content-based multimedia retrieval stack called vitrivr[7]. The user can explore the history of his city by using this application, when there exist the appropriate historic image of it, then the image will be shown on the screen.

1.1.3 Mixed Reality

Mixed Reality, sometimes also called augmented virtuality, merges the experience with the real world and the digital world. What is meant is the mixture of reality and the artificial, computer-generated models. Microsoft[8] calls this technology as the „next evolution in human, computer, and environment interaction“ [3]. The core concept of mixed reality is a combination of computer processing, human input and environment input. In contrast to augmented reality and virtual reality, objects of the real and virtual world can interact with each other in mixed reality[9].

1.2 Historic Perspective

In nineteenth century, people have already encountered the first approaches to virtual reality with their paintings. Charles Wheatstone showed in 1838, that the humans brain will merge two two-dimensional picture into a three-dimensional object by holding each of them in front of an eye[10]. In 1962 Morton Heilig, a cinematographer, received a patent for his sensorama, the first approach of virtual reality, where the user can experience different scenarios with images, smelling and winding system[11] [12]. In 1960 he introduced the Telesphere mask, which was the first invention of a head-mounted display[10]. In 1965 Ivan Sutherland developed the famous Sketchpad, which was the first approach of an interactive graphical application[12]. Three year later together with his student Bob Sproull he constructed a device with appropriate head tracking, which was the first hardware with virtual reality experience[12][10]. In 1985 NASA had running VR-Projects called „Virtual Environment Display System (VIVED)“ and „Virtual Planetary Exploration (VPE)“, which had the aim to train the astronauts behaviour in a virtual created space station, before they were sent into space [13]. In 1989 Jaron Lanier, an American computer scientist, visual artist and composer and the founder of visual programming lab (VPL) has coined the term virtual reality as a „computer-generated environment that stimulates a user's various senses and allows interactions, if possible, in real time“ [4][10]. In 1994 the American company

[3] https://docs.microsoft.com/en-us/windows/mixed-reality/mixed-reality
[4] https://www.vrnerds.de/die-geschichte-der-virtuellen-realitaet

Forte presented in CES Las Vegas the „Forte VFX1 Headgear“, which was a virtual-reality head-mounted display with a head tracking function, a microphone and headphones and supported some games. Some of its functionalities can be found in todays HMD Oculus Rift[5]. Unfortunately this project had no success because of the low display resolution and the expensive price[12]. In 1995 Nintendo made a first try of a 3D gaming console called „Virtual boy“, but it had some errors with the graphics, in the software and was difficult to handle. For this reason, this product was no longer produced[10]. In the 21st century, there were many developments in virtual reality technology. Especially from 2016 to 2017, where Oculus and later HTC introduced their VR-Hardware[12]. Playstation introduced in 2017 their own VR-Hardware, whereupon Microsoft has announced to release a VR hardware for their XBox[12].

1.3 Applications

Virtual reality is used today in many areas. For buisness virtual reality is used for developing products, which was cost effective and enables to test the prototype without develop any versions of the product.[14]. For the same reasons, VR is also used in the construction of buildings. The architects can use the 3D model of the building to test various factors in the exterior as well as in the interior and to recognize any mistakes more easily[14]. In healthcare VR is used for different purposes for example as a VR diagnostic tool or for VR robotic surgery. HumanSim system[15] is a human solution software for medical education and training purposes. Medical personnel will be able by using it to engage in medical scenarios, where they can interact with each other and with the patient in 3D environment[14]. Teachers and students use VR for educational purposes for example Astronomy students can learn about the solar system in represented in VR[14]. VR will also be used in more dangerous professions like military, aviation or for space researches as presented in Section 1.2 to train important maneuvers in a simulator in order to be able to react more properly in difficult situations[1][14].

1.4 Goals

The goal of this thesis is to implement a prototype by expanding the VR exhibition system from the DBIS group of University of Basel, so that two persons can experience in the same exhibition and interact with each other by exchanging an object for example.

[5] https://www.oculus.com/

2 Related Work

This chapter presents a few projects that have the same context and goals as this thesis.

2.1 VIRTUE

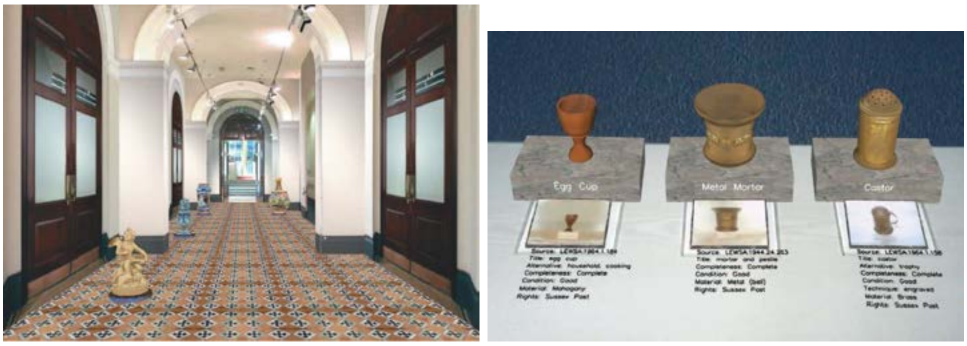
The DBIS group of University Basel has created a prototype of a virtual museum experience, where the user will be able to go through virtual rooms and see the paintings. In reality the rooms has a finite size and they can only exhibit a limited number of artworks. With this VR system, it is possible to enlarge the rooms for the exhibition as desired. This thesis is based on this research project. They released on github a virtual exhibition project, where the user can easily build an own exhibition.[16]

(a) (b)

Figure 2.1: Virtual Exhibition Hall[17]

2.2 ARCO - Virtual museum exhibitions

The VIRTUE project is similar the project ARCO (Augmented Representation of Cultural Objects project). Similar to VIRTUE, ARCO has the aim with virtual reality and augmented reality to exhibit artifacts in a non-limited space. It provides a technology to design and manage a virtual exhibition. The cultural objects are stored in a database. ARCO offers several tools and parameters, by which an exhibition designer create a a virtual exhibition in no time. ARCOs architecture is built up on three components: content production, content management, content visualization. It uses a high-level XML-based language called X-VRML[6] to create parameterized templates for virtual exhibition. It is a file format for 3-dimensional interactive computer graphics [18]. Exhibitions created with ARCO can be displayed on different platforms, e.g. as local Web, remote Web, AR scene and so on. Finally, museums visitors should use a intuitive human-computer interface based on well-known metaphors to experience the exhibtion, just as they are used to in real life [19].



(a) Web browser displaying virtual exhibition (b) Virtual exhibitions as AR representations

Figure 2.2: Illustrations of ARCO[19]

2.3 DIVE

DIVE (Distributed Interactive Virtual Environment) was a VR-related research project at the Swedish Institute of computer science. It is a distributed VR system based on UNIX and Internet networking protocols. This system is a dynamic virtual environment, which allows users or applications to visit the environment. The purpose of this project was to develop a virtual reality system with the focus on distribution, collaboration, interaction and muli-user aspects. The goal was, similar to this thesis, to enable user or application to participate the DIVE world. Users should be able to see, meet and collaborate with other users and applications. To represent the user in virtual space, DIVE draws a simple 3D object called body-icons. The body-icon is a part of user interface abstractions. The interface called visualizer, by which the eyes are built as a part of the body-icon, renders the world, which can be set up to accommodate a wide range if I/O devices. Several physical input devices are used to do actions in the virtual world, which is calles as vehicules. One example is the mouse vehicle, which enables the user to move around, send messages and graps objects. [20]

[6] https://en.wikipedia.org/wiki/XVRML

3 Architecture

In this chapter, the entire architecture and concepts are described to realize the goals, which have been shown in Section 1.4

3.1 Equipment

The DBIS group provided two HTC VIVE Pro devices. There were two HMDs, each wired to a separate computer. Each device had two controllers to hold them in the hand. Four base stations were available to track the devices position.

3.1.1 HTC Vive Pro

This device gives the user an experience of the VR environment with its excellent graphics and precise tracking. The HMD has been designed with optimized ergonomics so that the user can wear it easily and for a longer period of time with its improved weight distribution. The spacial scale is constructed so that the user can move more freely in the physical space[21]. The controller provides wireless gaming experience and interacting in the virtual world. It is equipped with a multifunctional trackpad and a two-stage trigger. The HMD device and the controller contain multiple sensors, which receive signals from the base stations for computing the current position.

3.1.2 Vive Tracker

The Vive Tracker can integrate the common objects from the physical world into the VIVE system. The tracker is attached to a physical object, the object must then be accurately modeled in the VR world. Like the HMD and controllers, the tracker contains also sensors. [22]

3.2 SteamVR Tracking System

The SteamVR Tracking System is a hardware and software system, which determines the objects location in the tracking space. The system consists of three components: the base stations, the objects, e.g. the HMD, controller and tracker[23]. A base station send high frequencies of laser light through the room , much like a lighthouse. The sensors on the devices in the tracking room are waiting to be scanned by the laser light. In combination with at least two base stations, SteamVR calculates the positon, orientation, movement and angular velocity of the tracked object[24].

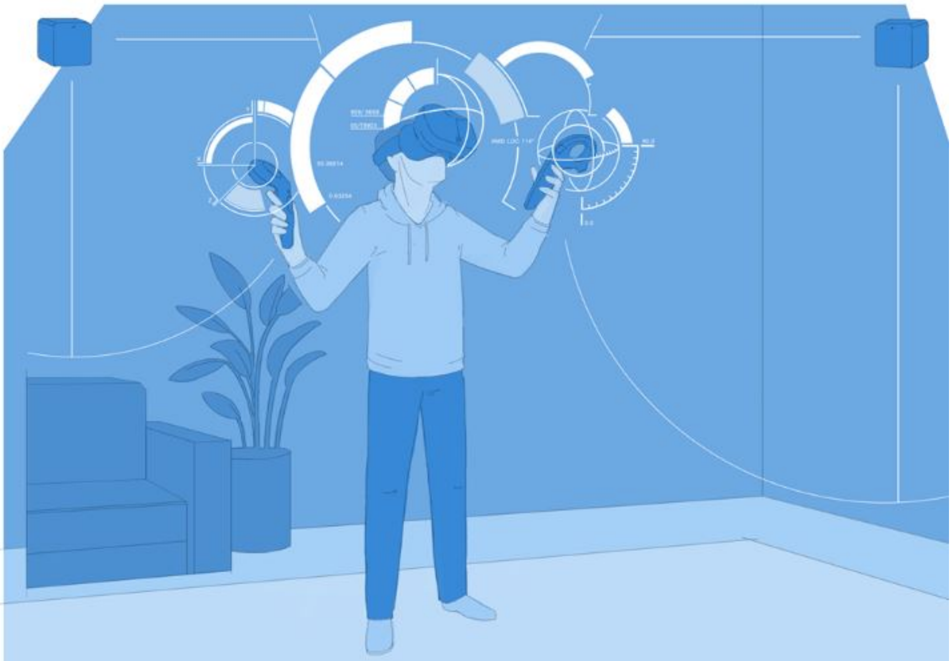


Figure 3.1: Illustration of tracking[25]

3.3 System Architecture

In this section the individual goals are shown.

3.3.1 Virtual Exhibition

The prototype was developed on the application VR exhibition provided by the DBIS Group of University Basel. This application consists of a frontend and a backend. The frontend is a Unity project[7]. It has a room with only image frames hanging on the walls. To display images, a backend must be running in parallel[8]. This is a tool which allows for configuration, storage of and access to VR exhibition definitions. An exhibition can be defined in a JSON file[9]. The images where stored locally on the computer. To specify the images in the definition, the paths to them must be inserted. The JSON-File was used to create a database on MongoDB[10]. The backend supports a dockerized mongo instance very

[7] https://github.com/dbisUnibas/virtual-exhibition-presenter
[8] https://github.com/dbisUnibas/virtual-exhibition-manager
[9] https://www.json.org/
[10] https://www.mongodb.com/

well, so Docker[11] was used here. The backend then establish a connection to the mongo object instance to access the images. To display the images in the application, the host and port number must be and the object id of the mongo instance must be added.

3.3.2 Multiuser Synchronization

In order to build the multiuser synchronization, the additional player must be drawn in the VR environment. The position of the player must be determined correctly so that the distance to the first player in VR is equal as in the physical world. The position and rotation of the player's HMD from the physical environment must be determined first, then its position and rotation in the VR world will be calculated, although the rotation in both worlds is the same. All these data will be transmitted via a separate server to the other player.

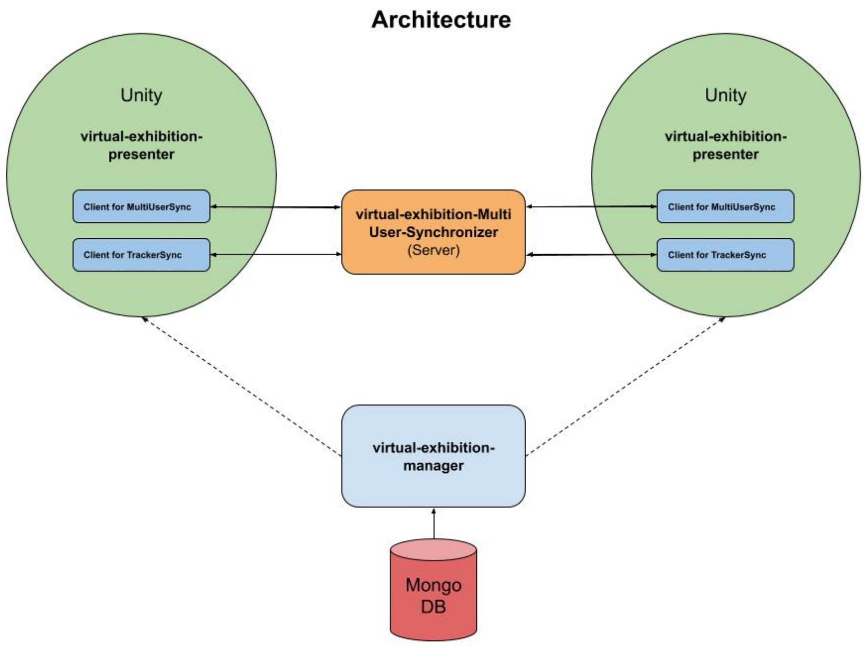


Figure 3.2: Multiuser Synchronization concept.

Figure 3.2 shows how the multiuser synchronization works. The client don't need to care how many players are available. It gets the data of the players and draws them in the VR world. In this thesis, there were two computers, so the prototype was built for two players, but it can be extended for multiple players. To exchange the data, several functions were implemented on the server side that were responsible for sending and receiving players data. Let's see a scenario of two players using the VR application. The second player sends its physical position and rotation data of the HMD to the server and will be stored there. In

[11] https://www.docker.com/

order for the first player to draw the partner, the data of the second player are retrieved from the server, the corresponding VR position will be calculated. In exactly the same way, the second player retrieves the data from the first player and calculates its corresponding position in VR world. The exchanging of data for multiuser synchronization happens in an own client as shown in Figure 3.2.

3.3.3 Carrying Objects

The aim was here to carry physical objects in the virtual world. As described in Section 3.1.2 the physical object will be tracked by the VIVE tracker. The tracked object will also be synchronized by the mutiuser synchronizer. The position and rotation of the tracker will be exchanged between the clients shown in Figure 3.2 exactly in the same way as described in Section 3.3.2. The player can get the object with the hands, carry it around or pass it to the partner.

Now lets see again the scenario with two players. After establishing the multiuser synchronization, two players can now see each other in the VR exhibition. A tracker is now connected to the first computer to the SteamVR system. Then a new client will be started to transmit the trackers physical position and rotation data to the same server. In the VR Exhibition running on the second computer, the object, on which the tracker is attached to, will be instantiated. Now both players can see the box and can pick it up.

4
Implementation

The implementation chapter describes how the project concepts and architecture presented in Chapter 3 are implemented.

4.1 Technologies

4.1.1 Unity

The VR exhibition museum runs in Unity. Unity is a game development platform to create 2D, 3D and since Unity 5.1 it supports VR headsets for VR applications. The first version of it was released in 2005 as an OS X game engine, which was written in C++. Unity supports several platforms. A simple VR environment can be created within minutes by creating predefined objects and placing them in the VR world. To adjust the behaviours are needed for each object, a script can be programmed in C# and can be added to the specific object.

4.1.2 SteamVR

SteamVR is a plugin for Unity maintained by the Valve Corporation, a software company in Bellevue in Washington in USA. This plugin is responsible to manage three things: loading 3D models of VR controllers, handling input from those controllers, and estimating how the players hands looks like while using the controllers[26]. For the prototype SteamVR was specifically used to get the HMDs physical position and rotation data. For the tracker a new game object was created and put it to the players game object as a child. A predefined script called „Steam VR_Tracked Object“, was included to the tracker game object as a component, which enables to get its physical position and rotation data. The corresponding devices must be selected in the component. Section 3.2 describes what a SteamVR Tracking System is. Basically SteamVR distinguish between „Tracking Space“ and „Play Area“ as shown in Figure 4.1. The tracking space is the space available to the player in the physical space whose boundaries are marked with the so-called „Chaperones“. These are the blue grids the player can see in the VR world. The tracking space can have any shape. For the VR application, however, it is cumbersome to consider each position. That's why there exist still the „Play Area“. This is the largest possible rectangle, in Figure 4.1 shown as a green rectangle, that fits in the tracking space. The VR application assumes that the player can reach every position in the play area [3].

Figure 4.1: Lightblue: Tracking Space, Green: Play Area [3]

4.1.3 gRPC

To implement the client-server connection as presented in Section 3.3.2, the gRPC framework was used here. gRPC is a modern open source high performance RPC framework. It enables to simply connect devices in distributed systems and provides services, which will be defined by using Protocol buffers[12]. gRPC can be used in several platforms and languages, it automatically generates client and server stubs in a variety of languages[27]. In the multiuser synchronization, the server is implemented in Java and the clients in Unity in C#. The gRPC framework in server was provided with Gradle[13]. The messages and services, see section 4.2, were provided by the generated gRPC classes, which were built with Gradle.

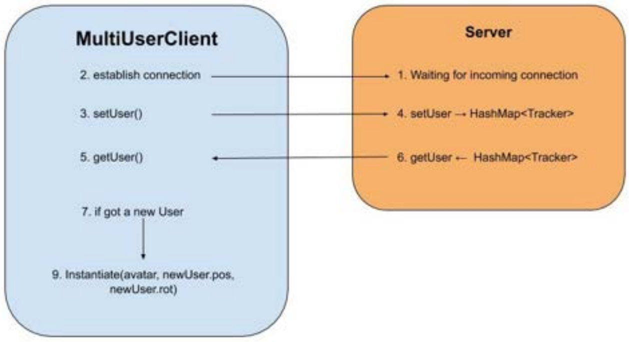
4.2 API Specification

The functions, which were implemented on the server, were defined in a proto file, see in Appendix A. The messages „User“ and „Tracker“ were used in the implementation to specify the player and tracker. The properties were a unique object id, the physical and virtual position, which were 3-dimensional vectors, and lastly the rotation, which was a vector with four elements, defined as quadrublet. After the proto file was generated, instances „User“ and „Tracker“ could be instantiated in Unity to save all the data. The function getUser() retrieves the User instance from the hashmap according to the RequestUsers Id, which is used as key. So also the function getTracker() to retrieve Tracker instance. SetUser() and SetTracker() puts the received instances in the appropriate hashmaps.

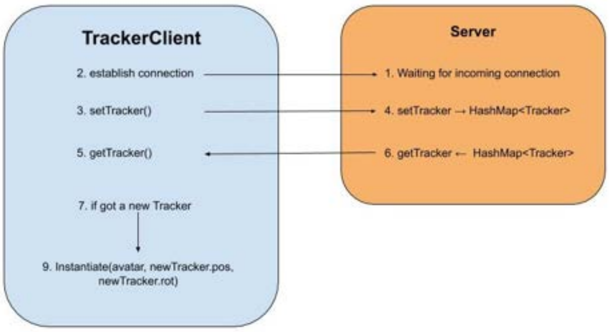
[12] https://developers.google.com/protocol-buffers/
[13] https://gradle.org/

4.3 Implementation Structure

The multiuser synchronization is based on a client-server architecture as explained in Section 3.3.2. Figure 4.2 shows how a client communicates with the server.



(a) Implementation structure user synchronization



(b) Implementation structure tracker synchronization

Figure 4.2: Synchronization structure

First, the client tries to establish a connection to the server. If it was successfull, then it sends its players physical position and rotation data to the server. The server stores these data in a HashMap. The client meanwhile tries to get data from a possible new player from the server, which is also be stored in the HashMap. If such an instance exists, then the client instantiate in Unity a new gameObject to represent the new player. The client continuously gets data from the server, to update the virtual position and rotation of the new player.

4.4 Multi-User Synchronization

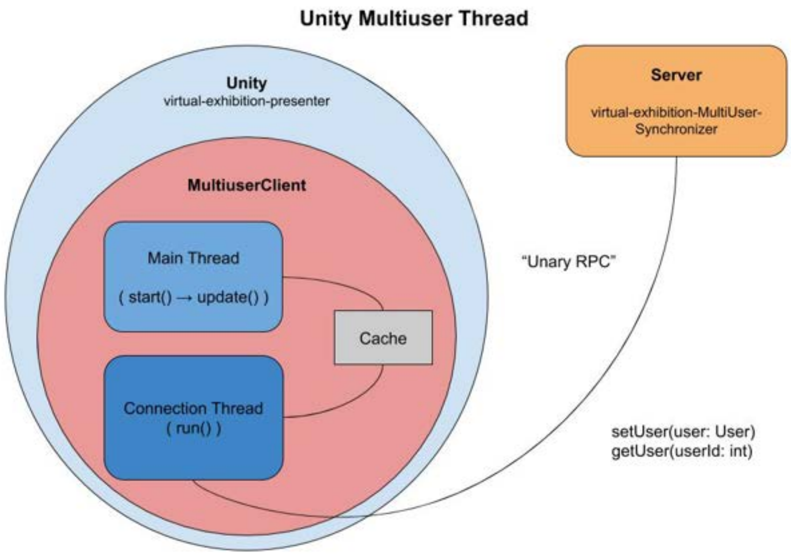


Figure 4.3: Multi-User Synchronization concept.

4.4.1 Client-Server connection

The client-server communication is realized with the gRPC framework. As already explained in Section 4.3, the server waits for incoming connections. The client is implemented in Unity and tries to establish a connection to server. It is running in a separate thread, to establish a continuous connection to the server. The server implements all services, which are defined in a proto file. In the thread, a while loop runs over time to ensure a constant exchange of data. The client stores the data from the server in separate variables, which is shown in Figure 4.3 as cache, because from a thread it's not possible to assign data directly to the game objects.

4.4.2 Synchronization Players Position

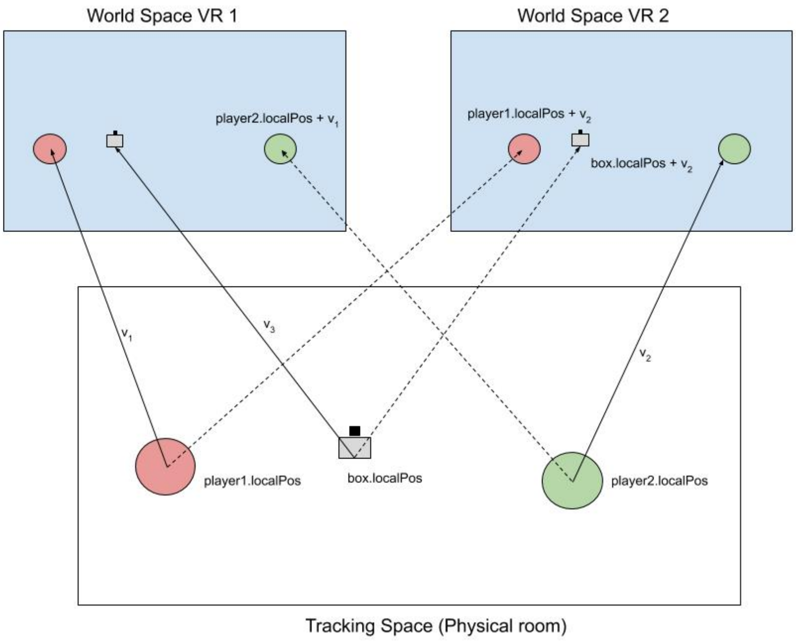


Figure 4.4: Synchronization physical position to virtual position

Once the client receives physical position and rotation data from a new player, a new game object will be instantiated in Unity at runtime. The client retrieves the data from the server via the getUser() function, which is updated in the Update Method per frame and transferred to the game object. Figure 4.4 shows how the player will be placed correctly in the virtual world. Unity defines a world space in VR and a tracking space, which will be specified by SteamVR shown in Section 3.2. The coordinates of the game object in the world space and the corresponding tracking object in the physical space are different.
Now lets see again the scenario with two players to explain this concept. The VR world on the left side in Figure 4.4 is running on the fist computer and the VR world on the right side is running on the second computer. The red object called „player1“ in the physical space is the HMD and the red object in the VR world is a game object, which represents the players head. The difference between the player1's physical and virtual position will be defined as a vector v_1. When the client is active on the first computer and tries to retrieve the the second players „player2“, represented by the green object in Figure 4.4, physical position and rotation data from the server. This player must be placed correctly in relation to the VR environment running on the first computer. To ensure that, the vector v_1 will be added to the physical position player2.localPos of the player2. This concept was conceived so that not only the player, but all physical objects in the physical space drawn in the VR environment have the same distance vector. For example the box from Figure 4.4 is connected to the first computer and is vector v_2 is the same as the vector v_1. This concept has the advantage that the second player and the box also comes along with when the first

player teleports.

Figure 4.5: Limited physical area

At the first test of the prototype, there were a little offset in the placement of the avatar. To minimize this, the tracking space of the SteamVR system must be configured as exactly the same as possible on both computers. To achieve that, the tracking space was marked with a tape, see Figure 4.5. Then on both computers the room setup in SteamVR was done again considering that both computers room-scale was exactly the same. After that, the offset could be minimized, it was possible to touch the avatar and to take the box with the hands much better as before.

4.4.3 Avatar

To represent the second player in the VR world, an avatar must be included in the project. This prototype uses an avatar from the Unity asset store called the „Sci-Fi Engineer“[14].

Figure 4.6: Sci-Fi Engineer Avatar to represent the second user

This avatar comes with several animations. For this prototype, it was enough to use the walk and stay animation. To switch between the animations, a script was implemented to determine, when to change the animation. To enable to use this avatar, this has to be saved as a prefab and must be included to the gRPC-Client game object as Player 2, which is responsible for the multiuser synchronization.

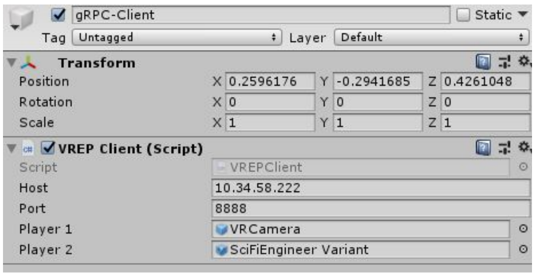
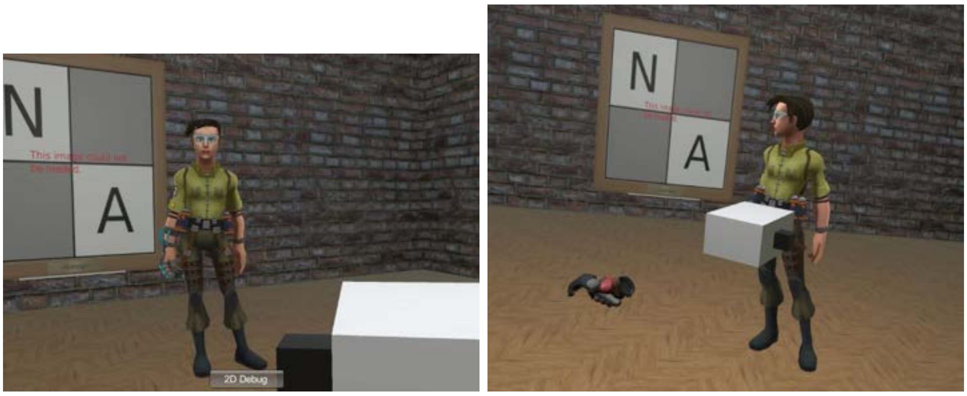


Figure 4.7: SciFi-Engineer prefab attached to the game object gRPC-Client1 as player 2

In the implementation, this prefab and the second players VR position and rotation were passes to Unitys „Instantiate()“[15] function to instantiate the avatar. The player itself is not represented as an avatar, because the player should get the experience to be in the VR world as itself and not as a virtual figure.

[14] https://assetstore.unity.com/packages/3d/characters/humanoids/sci-fi-engineer-29165
[15] https://docs.unity3d.com/ScriptReference/Object.Instantiate.html



(a) First players view (b) Second players view

Figure 4.8: Players view

4.5 Carrying Objects

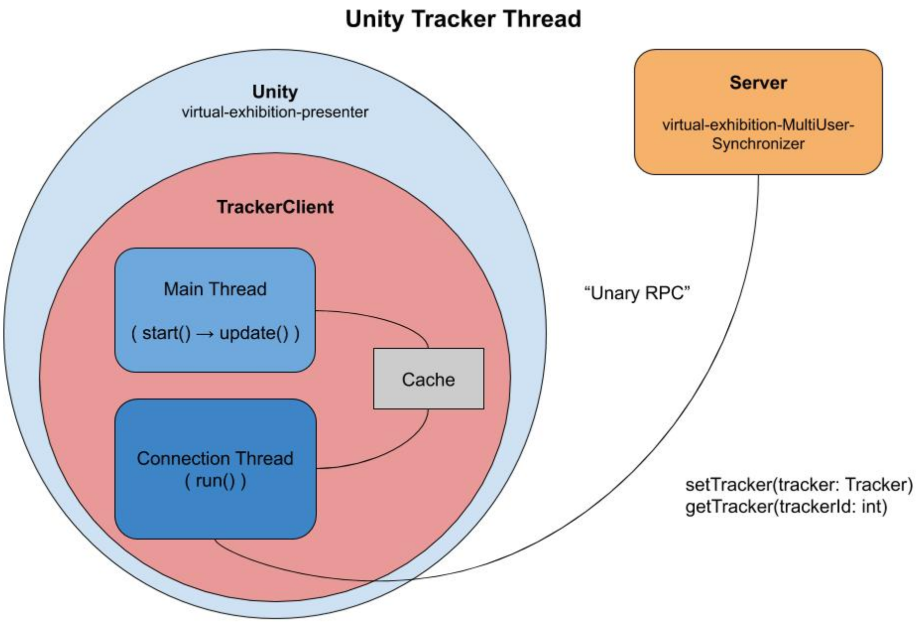
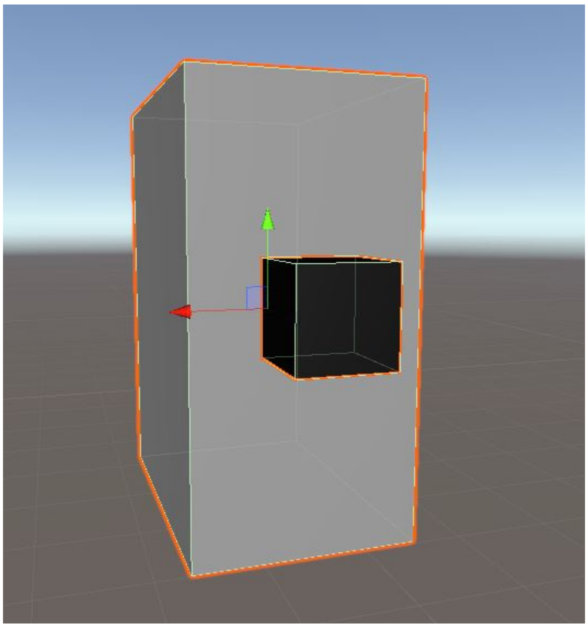


Figure 4.9: Tracker Synchronization concept.

In this thesis, a box was used to demonstrate the usage of the VIVE tracker, see Figure 4.10. This box was modeled exactly in the same size in Unity. To ensure, that the player knows that the box is tracked with a VIVE tracker, a small black cube was also modelled to represent the tracker. The box was assigned to the tracker as a child element in Unity. So that the tracker can be correctly recognized and placed by SteamVR. The tracker was also be included in the multiuser synchronization. The concept is exactly the same as explained in Section 4.4.

(a) Physical box with tracker attached to it



(b) Virtual model of the box

Figure 4.10: Physical and virtual box

5 Evaluation

This chapter describes the evaluation of the prototype, the result and the these results are discussed at the end. The purpose of this evaluation was to let some people test the prototype and to evaluate their experience and possible improvements and suggestions for extension. Seven persons participated in the evaluation.

5.1 Preperation

For the evaluation some people were invited to test the prototype and then they had to write down their experience on an evaluation form.

5.1.1 Setup

Two computers were available. On each a HTC Vive Pro was connected and the tracker attached to the box was configured on a computer. On both computers, the virtual-exhibition-presenter[16] was loaded with the prototype and on one computer was the server[17] running. In addition, a simple exhibition was generated with four images and then loaded on the backend virtual-exhibition-manager[18]. Each application has running its own backend.

5.1.2 Questionnaire

The prototype was developed so far that two persons can test it. In order to evaluate their experience, some questions were asked about it in an evaluation form, they all are attached in Appendix B. The first part with two questions was about the experience of the VR exhibition. They were asked about how the difference was between a exhibition in VR world and in the real world and how realistic the painting were. In the second part with, there were five questions about the prototype. They were asked about how the expectation was to the new person, who suddenly appears in the VR world. Then what they have to pay attention when they teleport. Then a box was standing on the floor, if they were able

[16] https://github.com/GowthamanG/virtual-exhibition-presenter
[17] https://github.com/GowthamanG/virtual-exhibition-MultiUser-Synchronizer
[18] https://github.com/GowthamanG/virtual-exhibition-manager

to pick it up and how hard it was to hand over it to the partner. The last part with two questions was if they had any suggestions for any improvements of the prototype and how the prototype and the VR exhibition application could be further developed, i.E. which additional functionalities are desired. And how they felt after testing to be back to the real world.

5.2 Results

5.2.1 VR Exhibition

The first two questions concerning the VR Exhibition were answered on a scale of 1 to 5.

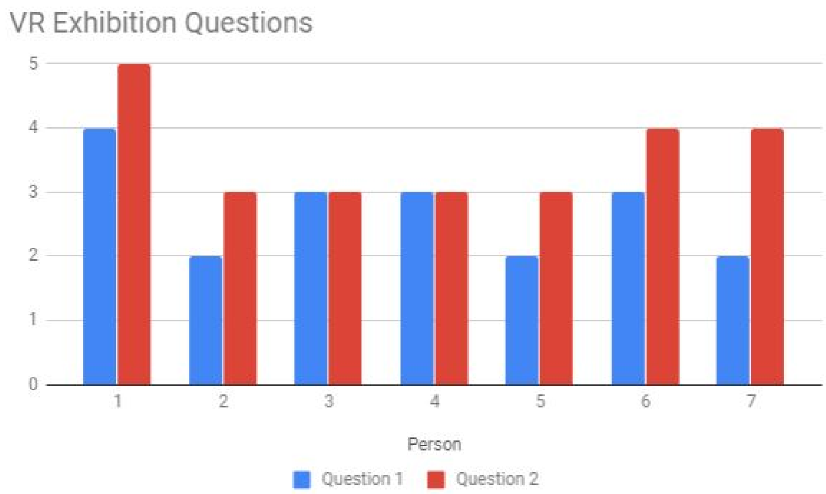


Figure 5.1: Evaluation of questions concerning VR Exhibition

In the first question, six out of seven people answered in scale between 2-3. In the real world, they have a slightly different perception of an exhibition than in the virtual world.

5.2.2 Prototype

In the first question, two out of seven persons thought, that the new appeared avatar was a human. Other people thought, that it was just a virtual figure in the VR world and it's not possible to interact and to communicate with it. In the second question, many persons didn't expect, that the other person will come with after teleporting. Some people had to pay attention do not walk into walls, as well as in the virtual world and in the physical world. For question regarding the box, all, except one person, thought that was not possible to pick the box up. One person thought that it would be possible to move the box with the controller by pointing at it, others had some difficulty keeping the box with the controllers, they would rather have done it by hand. Passing the box to the second person was easy for the most people.

5.2.3 Improvements and Future Development

The second last question was to find out what people have ideas for improvements and for further developments. One person would like to have the functionality to teleport with when the other person is teleporting. Two persons wished to get the box with the hands. One person wanted more room perspective. Another wanted more realistic representation of the VR exhibition. One thought that the physical engine could be improved, e.g. the player can hang a large painting off the wall and throw it away, which is not possible in the physical world. Many had wished to have more space, several rooms and several floors. More activities were also desired in the VR exhibition such as a tour of the exhibition guided a virtual figure. The description of the individual pictures should be read aloud and not only show paintings, also play videos. An improvement of the prototype might be to represent the player itself as an avatar.

5.3 Discussion

The aim of the VR exhibition is to easily design an exhibition from a large ever growing collection and enable people to experience the exhibition in a novel way[28]. Many people wanted to have more space to explore the exhibition, but also more rooms and floors, as they are used to from the real world. Not only in the virtual world, but also in the physical world, they would have had more space to move freely. Some people thought that the exhibition was not realistic enough and that images didn't look like an original work of art. It also depends a bit on how they are used to in the real world. People, who often visit museums have a clear expectation of an exhibition in the virtual world and can criticize better. Some people said that the images had good quality, but it could be more three-dimensional to make it look more realistic, fore example make the frame a bit thicker. The room perspective could also be improved because they found the perspective in the VR room somewhat sterile. As for the prototype, the person was initially unaware that the avatar, who suddenly appeared in the VR world, was a human. The person was fixed at the beginning to be alone in the virtual world. To make it immediately clear that the avatar is also a human, it must be designed more realistic and the movement of the human body must be simulated. When they first saw the box, they first thought that it was a virtual object and that they could use the controller to point on it and to move it. In hindsight, when they were told that it was possible to pick it up with the hands, they realized that it is also a physical object. The prototype did not support the hands being simulated, but many wished it to be possible, so that they could pick the box up easily. To achieve this, not only coordinates of the hand position, but also of individual fingers, the elbow and the shoulder position must be determined and transmitted to the SteamVR so that the hand movement can be simulated realistically on the avatar. There exist such VRGluv gloves[29], that simulate the hand, finger movements and can be used together with HTC Vive Pro[19]. To simulate not only the hand, but various body movements, trackers could be attached in places such as elbows, shoulders, hips and feet and so transmit the physical position and

[19] https://www.youtube.com/watch?v=dVJhTsp5ilM

rotation. There is a project called IKinema Project Orion[30], which realizes such body movements with trackers[20]. Finally, it can generally be concluded from this review that people using a VR application have no idea what they can do. It has to be taught to them what they can do, they do not come for themselves, whether they can now take the box with their hands. Although it is a digitized world, many still want a realistic representation of the VR world. When a person uses the VR, it may happen that he gets overworked, gets a headache, becomes tired, becomes dizzy, feels unstable. These symptoms are known as VR-sickness[31], which can occur, much like seasickness. VR-sickness occurs when the body's self-perception (proprioception) deviates from what the visual cortex perceives. Such a deviation perceives the organ of balance as a fundamental disorder and creates a physical defensive posture. None of these people felt this in this evaluation.

[20] https://www.youtube.com/watch?v=Khoer5DpQkE

6
Conclusion

In this thesis, a prototype was developed that allows two people to interact with each other in the virtual world and to include physical objects in the virtual world. This chapter includes a summary of the thesis, what has been developed, and opportunities exist for further development of the prototype, but also for the VR exhibition.

6.1 Conclusion

The main aim of this thesis was to extend the virtual exhibition application, which was developed by the research group DBIS of the University of Basel. The aim was to develop a prototype that allows two people to stand in the same way in the virtual world as in the physical world. In addition, the users should be able to carry virtual objects, which are a representation of the physical objects, with their hands, carry them around and hand over them to the partner. There were two HTC Vive Pro devices available, so the prototype for the first was designed for two people. To track a physical object, a Vive Tracker had to be attached. It was used for the first time one tracker, two trackers would also be possible if the second tracker would be connected to the other machine.

6.2 Future Work

This prototype can be extended in many ways. This section presents possible enhancements and improvements to the individual goals of this projects.

6.2.1 Improvement of Multiuser Synchronization

The multiuser synchronization can be further improved. To represent the distribution of the objects in the physical space exactly in the VR environment, the space configuration of the physical space in the SteamVR should be done on the server side. The position and rotation of each object and the distribution of all objects in the physical space should be stored on the server. Then the concept of synchronization should be changed so that instead of multiuser synchronization, there would be a synchronization between the physical and VR space. Most likely, the server would run on a high-performance machine, if one intends to have several players in the room, then the server would have to manage several connections.

6.2.2 Illustration of the Avatar

The second player is represented in the VR environment as an avatar. In this project, an avatar was downloaded from the Unity assets store and the animation was adjusted to mimic the movements in space and the movement of the hand. A possible improvement would be a better representation of the animation so that the player could also flex, sit, lie and simulate so that the player takes the tracked object with the hands without using the controller and even simulate small details of face movements. For example, eye gaze and blinking can be simulated using the VIVE Pro Eye[32]. This has the so-called eye-tracking technology, which allows the tracking and analysis of the eyes. With the forveated rendering, the perception of the VR environment could be improved, which in turn makes it possible to sharpen the objects on which they eyes focus.[32]

6.2.3 Physical Objects in VR

In this thesis, a box was used to demonstrate the usage of tracker. This was modeled in Unity and saved as prefab. The prototype can be improved in such a way that an interface exists, which makes it possible to transfer objects to the tracker via drag&drop. This should enable to quickly integrate new physical objects in VR.

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A
Proto File

This proto file was used to develop the multiuser and tracker synchronization.

```
syntax = "proto3";

message User{
    int32 id = 1;
    Vector userPhysicalPosition = 2;
    Vector userVRPosition = 3;
    Quadrublet userRotation = 4;
}

message Tracker{
    int32 id = 1;
    Vector trackerPhysicalPosition = 2;
    Vector trackerVRPositon = 3;
    Quadrublet trackerRotation = 4;
}

message Vector{
    float x = 1;
    float y = 2;
    float z = 3;
}

message Quadrublet{
    float x = 1;
    float y = 2;
    float z = 3;
    float w = 4;
}
```

```
message RequestUser{
    int32 requestUserID = 1;
}

message RequestTracker{
    int32 requestTrackerID = 1;
}

message Response{
    string response = 1;
}


service multiUserSync{
    rpc getUser (RequestUser) returns (User){}
    rpc setUser (User) returns (Response){}
    rpc getTracker (RequestTracker) returns (Tracker){}
    rpc setTracker (Tracker) returns (Response){}

}
```

B
Evaluations

The following pages contain evaluation forms filled out by people who tested the prototype.

Sripaan Sadalingam
08.05.2019.

Bachelor Thesis Collaborative Virtual Museums: Evaluation

Questions about the exhibition:

1) You were in a virtual environment that represented an exhibition. How was the difference between this exhibition and the exhibitions where you were in the real world?

Scale: 1 (completely different perception) to 5 (Same as usual in reality) : 4

2) How realistic were the pictures hung on the wall?

Scale: 1 (unrealistic) to 5 (Like real works of art) : 4-5

Questions about the prototype:

1) You were first alone in the museum, later the a new person appears. What were the expectations of being able to interact with the partner?

Comment: ~~Expecting~~ Expected it to be a human

2) You wanted to teleport somewhere else, what did you have to pay attention to?

Comment: Expected him to stay at his place

3) You saw the box on the floor, what did you think?

Comment: Not expected to be able to pick it up.

4) How hard was it to pick the box up?

Comment: ~~Sup~~ Surprised that it was so easy

5) How hard was it to hand over the box to the partner?

Comment: simple

Last question for the future work:

1) You tested the prototype of of my bachelor thesis. What else would you like to change about the system or what kind of additional functionalities would you have desired?

Comment: More rooms, more activities, museum tour through a virtual person, Painting description should be read aloud, play videos, ~~teleport~~ also teleport when the partner is teleporting.

2) Did you have any complaints like dizziness or nausea after testing the prototype?

Comment: nothing.

- Amit
- Jeenda

Bachelor Thesis Collaborative Virtual Museums: Evaluation 08.05.19.

Questions about the exhibition:

1) You were in a virtual environment that represented an exhibition. How was the difference between this exhibition and the exhibitions where you were in the real world?

Scale: 1 (completely different perception) to 5 (Same as usual in reality) : 2 / 3

2) How realistic were the pictures hung on the wall?

Scale: 1 (unrealistic) to 5 (Like real works of art) : 3 / 3

Questions about the prototype:

1) You were first alone in the museum, later the a new person appears. What were the expectations of being able to interact with the partner?

Comment: Am Anfang virtuelle Figur später realisiert

2) You wanted to teleport somewhere else, what did you have to pay attention to?

Comment: Dachte sie bleibt an ihrer Stelle

3) You saw the box on the floor, what did you think?

Comment: Kann man aufnehmen

4) How hard was it to pick the box up?

Comment: Einfach

~~5) How hard was it to hand over the box to the partner?~~

~~*Comment:*~~

Last question for the future work:

1) You tested the prototype of of my bachelor thesis. What else would you like to change about the system or what kind of additional functionalities would you have desired?

Comment: realitätsgetreuer gestalten

2) Did you have any complaints like dizziness or nausea after testing the prototype?

Comment: Nein

Pio Lucas
09.05.19.

Bachelor Thesis Collaborative Virtual Museums: Evaluation

Questions about the exhibition:

1) You were in a virtual environment that represented an exhibition. How was the difference between this exhibition and the exhibitions where you were in the real world?

Scale: 1 (completely different perception) to 5 (Same as usual in reality) : 3

2) How realistic were the pictures hung on the wall?

Scale: 1 (unrealistic) to 5 (Like real works of art) : 3

Questions about the prototype:

1) You were first alone in the museum, later the a new person appears. What were the expectations of being able to interact with the partner?

Comment: Thought it was a person

2) You wanted to teleport somewhere else, what did you have to pay attention to?

Comment: Not walk into walls,

3) You saw the box on the floor, what did you think?

Comment: ~~sia~~ First thought I can paint and get the box with controller, not with hands

4) How hard was it to pick the box up?

Comment: Simple

5) How hard was it to hand over the box to the partner?

Comment: simple

Last question for the future work:

1) You tested the prototype of of my bachelor thesis. What else would you like to change about the system or what kind of additional functionalities would you have desired?

Comment: Better Physic engine, get box with hands,

2) Did you have any complaints like dizziness or nausea after testing the prototype?

Comment: nothing

Saarujaan Sachalingam
09.5.19

Bachelor Thesis Collaborative Virtual Museums: Evaluation

Questions about the exhibition:

1) You were in a virtual environment that represented an exhibition. How was the difference between this exhibition and the exhibitions where you were in the real world?

Scale: 1 (completely different perception) to 5 (Same as usual in reality) : 2

2) How realistic were the pictures hung on the wall?

Scale: 1 (unrealistic) to 5 (Like real works of art) : 3

Questions about the prototype:

1) You were first alone in the museum, later the a new person appears. What were the expectations of being able to interact with the partner?

Comment: I thought, it was just a random AI in the game.

2) You wanted to teleport somewhere else, what did you have to pay attention to?

Comment: Not crashing into a wall in real life.

3) You saw the box on the floor, what did you think?

Comment: Didn't expect to be able to pick it up and interact with it.

4) How hard was it to pick the box up?

Comment: wasn't really hard, just picking up a normal box

5) How hard was it to hand over the box to the partner?

Comment: wasn't hard at all

Last question for the future work:

1) You tested the prototype of of my bachelor thesis. What else would you like to change about the system or what kind of additional functionalities would you have desired?

Comment: more space to teleport, more interactions with objects.

2) Did you have any complaints like dizziness or nausea after testing the prototype?

Comment: not really

Pascal Häfli
09.05.19.

Bachelor Thesis Collaborative Virtual Museums: Evaluation

Questions about the exhibition:

1) You were in a virtual environment that represented an exhibition. How was the difference between this exhibition and the exhibitions where you were in the real world?

Scale: 1 (completely different perception) to 5 (Same as usual in reality) : 3

2) How realistic were the pictures hung on the wall?

Scale: 1 (unrealistic) to 5 (Like real works of art) : 4

Questions about the prototype:

1) You were first alone in the museum, later the a new person appears. What were the expectations of being able to interact with the partner?

Comment: Not walking into them, but in real life → collision

2) You wanted to teleport somewhere else, what did you have to pay attention to?

Comment: Other people stay in the relative position where they were before.

3) You saw the box on the floor, what did you think?

Comment:

4) How hard was it to pick the box up?

Comment: No grip possible with fingers (due to the controllers)

5) How hard was it to hand over the box to the partner?

Comment: Receiving the box was easy

Last question for the future work:

1) You tested the prototype of of my bachelor thesis. What else would you like to change about the system or what kind of additional functionalities would you have desired?

Comment: Maybe 3D Movement (More floors / climbing stairs)

2) Did you have any complaints like dizziness or nausea after testing the prototype?

Comment: Adjustment phase for some seconds

Jonas
09.05.19

Bachelor Thesis Collaborative Virtual Museums: Evaluation

Questions about the exhibition:

1) You were in a virtual environment that represented an exhibition. How was the difference between this exhibition and the exhibitions where you were in the real world?

Scale: 1 (completely different perception) to 5 (Same as usual in reality) : 2

2) How realistic were the pictures hung on the wall?

Scale: 1 (unrealistic) to 5 (Like real works of art) : 4

Questions about the prototype:

1) You were first alone in the museum, later the a new person appears. What were the expectations of being able to interact with the partner?

Comment: - no communication possible (verbal or fine gestures)
- irritating to not seeing myself

2) You wanted to teleport somewhere else, what did you have to pay attention to?

Comment: - no special requirements, was quite handy
- didn't expect to teleport together

3) You saw the box on the floor, what did you think?

Comment: /

4) How hard was it to pick the box up?

Comment: - was hard to grab with together with the controllers
- was hard becaus the hands are not animatet (own and partner)

5) How hard was it to hand over the box to the partner?

Comment: (see above)

Last question for the future work:

1) You tested the prototype of of my bachelor thesis. What else would you like to change about the system or what kind of additional functionalities would you have desired?

Comment: - perspective was a bit steril, everything rectangle

2) Did you have any complaints like dizziness or nausea after testing the prototype?

Comment: - No

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Collaborative Virtual Museums

Type of work — Typ der Arbeit
Bachelor thesis

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I hereby declare that this submission is my own work and that I have fully acknowledged the assistance received in completing this work and that it contains no material that has not been formally acknowledged. I have mentioned all source materials used and have cited these in accordance with recognised scientific rules.

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Basel, 10-05-2019

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