Neurorehabilitation in shared virtual reality

[1]Peter NEHILA, [2]Štefan KOREČKO

[1,2]Department of Computers and Informatics, Faculty of Electrical Engineering and Informatics Technical University of Košice, Slovak Republic

[1]peter.nehila@student.tuke.sk, [2]stefan.korecko@tuke.sk

Abstract – **Virtual reality is used for a wide range of applications nowadays. It can also be used for medical purposes, for example in the process of therapy and rehabilitation of patients. The advantage of applying virtual reality to the rehabilitation process is the possibility of creating interesting and immersive virtual environments and scenarios. Based on an analysis of the technology's potential uses and current solution, we have created an application in Unity, that will allow patients and therapists to collaborate in a shared virtual environment. The application includes several simple scenarios that can be expanded and combined into more complex, engaging sequences in the future, as well as interface to communicate with external environments to assess the patient's actions.**

Keywords – **Collaborative virtual environment, Neurorehabilitation, Unity, Virtual reality**

I. Introduction

In the field of therapy, new methods are constantly being tried that could simplify the work for both therapists and patients. In addition, one of the main goals is to improve the results and make treatment of patients more effective. Recently, virtual reality has started to advance rapidly and what we couldn't imagine just a few years ago, we now have right at our fingertips. Advances have also been made in technology used in virtual reality headsets. We have moved from relatively slow and cumbersome devices to devices that can operate independently without the need to be connected to a computer, with sufficient image quality and high precision motion sensors. Virtual reality is not yet something that people encounter on a daily basis, but this trend may gradually change in the future.

Nowadays, there are already several projects that focus on therapy and rehabilitation combined with the use of virtual reality. The nature of these systems varies depending on what they specifically target. There are systems specialised primarily for the treatment of various phobias or for therapy after an unpleasant experience. Most of these systems are more like 3D virtual environments where the patient themselves are not able to intervene much. There are also systems for which various specialised gloves or other assistive devices have been created, the purpose of which is to improve the results of therapy.

We designed and implemented system using virtual reality, that can be used for neurorehabilitation of patients that suffer from loss of movement in their arms. System includes a collaborative environment, which is an environment allowing multiple users to interact with each other in real time. The system is able to communicate with an external device used to sense activity of the patient and to detect whether they are attempting to perform the movement required of him. Subsequently, an animation of the hand movement is displayed in virtual reality.

II. Virtual reality and its use in therapy

A. Virtual Reality

In conjunction with virtual environments, there are three basic divisions based on the technologies they work with:

- **Virtual Reality** (VR) is a system that provides a high level of immersion into the virtual world of [1],
- **Mixed Reality** (MR) provides a fusion of the real world with the virtual world, at the level of displaying computer-generated objects into the real world. Such systems also include the ability to interact with such objects at the same time [2],

- **Augmented Reality** (AR) also represents a connection between the real world and the virtual world, as opposed to mixed reality, AR seeks only to complement the real world with additional information and other computer-generated enhancements[1],
- **Extended Reality** (XR) is an umbrella term, which can be used when talking about any form of computer generated reality.

All of these virtual environments are characterized by, among other things, real-time processing. There are several definitions to explain the concept of virtual reality (VR). Basically, in the case of virtual reality, one can speak of a system that represents a simulated world, with which the user interacts through data gloves or controllers and goggles to view the virtual environment [3]. The image can be displayed either on a computer monitor or directly on goggles designed for stereoscopic display. Virtual reality seeks to model the world as faithfully as possible and to provide the best possible interaction between humans and the simulated world.

B. Collaborative Virtual Environment

By the term Collaborative Virtual Environment (CVE) we can imagine a system that can be used by multiple users at the same time, so they can share its capabilities. Thus, they can collaborate and interact in a virtual environment. The most important part of CVE is information sharing. Collaborative virtual environments can also be defined as distributed virtual reality systems that offer a digital world designed for information sharing and interaction between users using the resources offered by the system[4].

C. Rehabilitation using VR

Within the field of rehabilitation in VR we have to consider several issues, the main one being the quality of rehabilitation and its real outcomes. According to [5], improvements in outcomes can be achieved by improving several aspects. These include:

- naturalness,
- engagement,
- sense of presence,
- affection for the VR app itself.

Another important aspect is the feeling of immersion, which brings with it other positive feelings of working in a virtual environment. According to the authors in [6], feelings of immersion and engagement in the virtual environment are important, as both of these feelings are necessary to induce presence in the virtual environment. They named the presence of stimuli for various user activities from within the virtual environment (e.g., in the form of a representation of the patient's hand or haptic response), the comfort of wearing the VR headset, the maintenance of the user's attention, and the isolation from the external environment as the main features enhancing these factors.

Another way we can improve satisfaction and increase patient interest in exercise is the use of game scenarios [7]. Such scenarios can facilitate exercise, as the patient often does not need to feel that they are doing the same boring repetitive activity, instead they are doing something meaningful that moves them further along in the game. One of the advantages of VR is also accessibility. A number of rehabilitations are carried out in specialized facilities under the supervision of doctors [7]. Rehabilitation carried out in VR could in the future be easily accessible over long distances, which could mean much easier access to rehabilitation for many patients, and that ultimately means improving their lives.

D. Simulation Sickness

A significant problem associated with virtual reality is the feeling of nausea when using a VR headset. A particular type of motion sickness, simulation sickness, is referred to in connection with VR. This type of motion sickness is not caused by real movement (compared to motion sickness when travelling, for example), but by a visual sensation depicting movement, even though no physical movement has been made. [8]. This sensation can be caused by several factors. Oculus has created a guide [8] outlining advice on how best to develop applications for VR. From the document, it is possible to list a few main factors that affect the comfort level when using the VR headset, namely:

- **acceleration when moving** - the perception of acceleration without actual acceleration has a negative effect on humans,
- **head movement** - for example, a slight up and down movement when walking is undesirable when using a VR headset,

- **sideways movement** - in real life, people rarely move sideways or backwards, these movements often cause motion sickness,
- **latency of the image** - the delay of the image to the movement we actually make,
- **duration of using VR headset** - prolonged use of the VR headset without a break,
- **user interface** - if it is cluttered or it contains elements that change frequently,
- **avatar** - the presence of an avatar improves the user's feelings, also it is necessary to map the movement of sensors to the movement of limbs such as arms and legs,
- **involuntary movement** - for example, moving the user after a bump can cause a feeling of nausea.

III. Architecture of our system

The system we've designed focuses on allowing users to collaborate in a shared virtual environment. System divides users into different role - therapists and patients. Therapists control significant part of the therapy, they can create training scenarios consisting of multiple steps, change timings for certain parts of movements or even control positions of patient in virtual environment. Patient's role is to simply follow therapists instructions. The system allows for communication with external systems through it's API.

We have created this system using Unity. Our decision was primarily between Unity and A-frame. We chose to use Unity, because it provides more options for future development, easier building of more complex systems and more option for gamification. A-frame is more suitable for fast prototyping and smaller scale projects. One major difference, when developing networked applications using Unity is that usually, the server and client are developed at the same time, as one application. The only difference is that server build uses different settings (application executes different code depending on build type).

We use OpenXR standard to access functionality of VR headsets. This allows us to support wide range of devices. Because we're using OpenXR we lose certain specific functionality of some VR headsets, we do gain ability to uniformly work with multiple different VR headsets. System also allows to use simulated VR on desktop, although using application in this mode is not recommended. Simulated VR has problematic controls as well as low optimization, because in this mode device has to render everything twice, as if it was rendering image on VR headset.

A. Avatars and environment

Traditionally in VR applications the user does not have full-body avatar. The reason being that it's quite demanding to have avatar object in scene and have it be animated. Since we are creating collaborative virtual environment, we can't ignore this functionality[9]. We have implemented avatars created using readyplayer.me[1] platform, animations for avatars come from platform mixamo[2]. It was essential to pay attention to arm and head animations as well, it's important that they follow movement of sensors, such as headset and controllers.

Environment is really important when it comes to VR applications. Pleasant environment can help patients relax and motivate them during rehabilitation[5]. The environment we have created was designed to contain different shelves and other furniture, that would help with filling the room. For the world outside of the room we have used skybox that helps to create cozy atmosphere, which can help with rehabilitation.

B. Network structure

For our system we have decided to use client-server infrastructure. With such an infrastructure, we can easily control what messages are sent, when and to whom. For example, server could simply control which requests are processed and which are ignored based on roles. Another advantage of such infrastructure is delegation of functionality - server can do certain things, while ignoring other, such as calculating animations, animating avatars. In client-server architecture clients are hidden from outside, and only server has access to them. This unfortunately creates single point of contact, which could be prone to overloading.

C. Process of rehabilitation

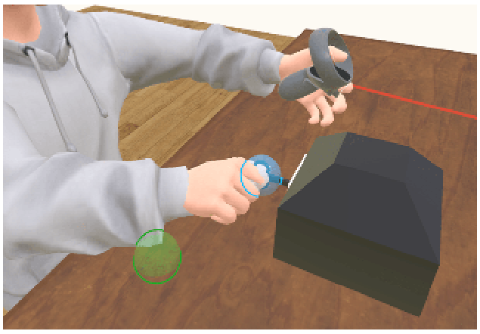
Rehabilitation in our system consists of multiple shorter moves, that are defined at the beginning. After therapist has finished setting up all parameters and positions for moves, he can start the training. Every move has wait period, during which Patient is supposed to imagine the movement

[1] https://www.readyplayer.me/
[2] https://www.mixamo.com/#/

(a) Block animation

(b) Cube animation

(c) Cup animation



(d) Key animation

Fig. 1: Showcase of different types of animations

in his head. Using electroencephalogram we can measure their brain activity. Using OpenVibe software used for computer-brain interaction, we can determine whether movement was correct. After that OpenVibe can send request to our server informing us about the move that was executed. That's why we need API, that is accessible from outside our system.

D. *Configurable training*

The training sessions can be configured in many ways. Therapist can define parameters such as length of movements, number of movements and key positions for animations. Positions can be set by moving the object in 3D space and defining intermediate steps. Therapists can also choose from multiple scenarios. On figure 1, you can see different types of animations. These scenarios involve differ in object used in movement, difficulty of movement, as well as the way hand is moving while animation is playing. All these scenarios were created to help stimulate patients.

E. *Animations*

Because we allow therapists to change positions for training, it would be impossible to use traditional animations to move objects. These animations are hard to create and are usually hard to adapt. In order to achieve animations, that can be configured, we use dynamic animations. In order to create these dynamic animations, we use inverse kinematics. Inverse kinematics allows us to dynamically calculate needed rotations of bones in arm in order to get to the desired position. Inverse kinematics can be power hungry, when it comes to a lot of calculations, but because we don't expect big number of users in one scene at once, even when being used on weaker hardware, they can be used to create immersive and god animations. The only problem is the fact that they can sometimes produce moves, that are unnatural (moves that are not doable in real life). In order to solve this issue we have to set up different limitations and boundaries, when the moves are being calculated.

F. *Hardware constraints*

System is primarily developed for VR headset Oculus Quest 2. The application also supports other standard VR headsets, that are traditionally connected to computer via cable. We chose Oculus Quest 2 as our primary target, because of it's availability and the ability to work independent without the need to be connected to computer. We have also created a desktop client, that can be used by therapists. Because we use client-server architecture, we also need server to be running, in order to be able to use application. In order to achieve smooth run we had to pay

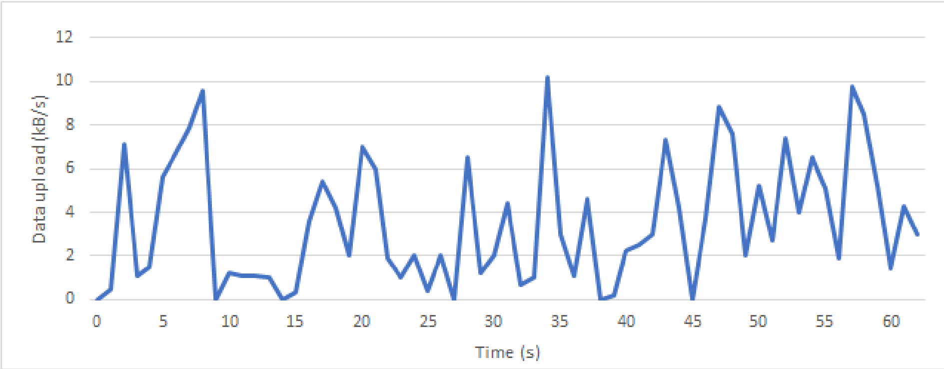


Fig. 2: Network usage - uploaded data

attention to optimization, especially when using VR headset. Because we plan to further develop the system and create more, rich scenarios, it's important to find a good trade off between level of details that we aim for and the amount of processing power required to create a satisfying experience.

IV. Evaluation

Because this thesis follows from previous works[10], we did not have to necessarily test every aspect of system. Mainly Before we started testing the system and evaluating it's performance on different devices. The tests that we've executed were split into multiple parts, primarily based on functionality we were testing. These tests could be divided into testing:

- network usage,
- performance.

A. Setups used while testing

Tests were run on multiple devices. Our main focus was testing the system using VR headset Oculus Quest 2, but we've tested the system on desktop computer under different conditions. Our main goal was to test performance and ease of use on other non VR devices. These tests also gave us insight on how patients using VR headset can interact with therapists, who are using desktop client. Hardware specifications of devices used for testing are in table 1.

Platform	***CPU***	***GPU***	***RAM***	***Refresh rate***
Oculus Quest 2	Qualcomm Snapdragon XR2	Qualcomm Snapdragon XR2	6GB	72Hz
Desktop	Ryzen 5 3600	Nvidia GTX1660 (6GB VRAM)	16GB	59.9Hz
Laptop	Intel Core i5-8250	GTX 1050 (4GB VRAM)	8GB	60Hz
Laptop (power saving)	Intel Core i5-8250	Intel UHD 620 (128MB VRAM)	8GB	60Hz

Table 1: Hardware specifications of devices used in testing

B. Network usage

When it comes to collaborative systems in VR, it's important to not forget that in order to achieve satisfactory levels of fluidity, we cannot ignore network usage and performance of the system affected by this. Using suitable network transport protocol, limiting amount of data sent over internet. This can be for example achieved by making more calculations local, rather than calculating everything on server and sharing information with users. This client-side approach causes some unwanted results, such as the need for higher computational power on clients side. During the testing we have not reached values of data sent over network from client of around 10kB/s. On fig. 2 are visualized measurements during testing of data sent from client. Important thing to note is that during normal use, average amount of uploaded data is lower, because during the test we have attempted to achieve highest possible value by artificially increasing user activity, in order to see what the highest value is.

C. Testing performance of system as a whole

During these tests our aim was to test the complete functionality of our program. The setup used was one server, one client (patient) and we tested the functionality on another client using therapist role. We have executed expected normal scenario of rehabilitation of patient. At the same time we have tested limits of the system, such as executing high numbers of requests and forcing high amounts of communication between clients and server. As a primary measurements to evaluate the performance of the system we have used frames per second. The results of tests on all devices can be seen in table 2. The recorded results were then plotted on a graphs, which can be also used as a way to determine if there is a certain issue. Overall the tests had shown good results. Most of the time the performance was stable and we did not experience much fluctuations. The only time we saw lower average frame-rates was when using the software on a laptop without a dedicated GPU.

Platform	***Minimum frames per second***	***Maximum frames per second***	***Average frames per second***
Oculus Quest 2	35	71	70,7764
Desktop	59	60	59,7202
Laptop	0	60	59,6428
Laptop (power saving)	10	60	43,5789

Table 2: Measured values of frames per second

V. Conclusion

Our main objective was to create collaborative system, supporting virtual reality for use in rehabilitation of patients. System was built using Unity game engine, in order to allow for easier expansion of systems functionalities, as well as possibility of gamification in the future. Current implementation supports wide range of commonly used VR headsets, as well as offers option to use system as a Desktop application. The problem when using virtual reality is simulation sickness and overall dissatisfaction, caused by using it. This is one of the main issues, when dealing with patients, that can be even more sensitive to these aspects. We have tested our system on multiple different hardware configurations, which allow us to get a good idea of how the system would run under differing conditions. When designing and implementing the system we have focused on optimizing the system so that it can be extended in the future for more immersive experience. Therefore by creating this collaborative system, we hope to make rehabilitation easier, more enjoyable and we hope it brings better results, which can improve the lives of many people.

References

[1] M. Hudák and B. Sobota, *Kolaboratívna virtuálna realita a rozhrania systémov*, 2021.

[2] B. Sobota, Štefan Korečko, M. Hudák, and M. Sivý, "Mixed reality: A known unknown," in *Mixed Reality and Three-Dimensional Computer Graphics*, B. Sobota and D. Cvetković, Eds. Rijeka: IntechOpen, 2020, ch. 10. [Online]. Available: https://doi.org/10.5772/intechopen.92827

[3] J. Steuer, "Defining virtual reality: Dimensions determining telepresence," *Journal of Communication*, vol. 42, no. 4, pp. 73–93, 1992. [Online]. Available: https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1460-2466.1992.tb00812.x

[4] E. F. Churchill, D. N. Snowdon, and A. J. Munro, *Collaborative virtual environments: digital places and spaces for interaction*. Springer Science & Business Media, 2012.

[5] S. Bialkova and B. Dickhoff, "Encouraging rehabilitation trials: The potential of 360° immersive instruction videos," in *2019 IEEE Conference on Virtual Reality and 3D User Interfaces (VR)*, 2019, pp. 1443–1447.

[6] B. G. Witmer and M. J. Singer, "Measuring Presence in Virtual Environments: A Presence Questionnaire," *Presence: Teleoperators and Virtual Environments*, vol. 7, no. 3, pp. 225–240, 06 1998. [Online]. Available: https://doi.org/10.1162/105474698565686

[7] B. Lange, S. Flynn, and A. Rizzo, "Game-based telerehabilitation," *European Journal of Physical and Rehabilitation Medicine*, vol. 45, no. 1, pp. 143–151, 2009.

[8] I. Oculus VR, "Oculus vr best practices guide," Jan. 2014. [Online]. Available: https://s3.amazonaws.com/arena-attachments/238441/2330603062c2e502c5c2ca40443c2fa4.pdf

[9] S. Benford, J. Bowers, L. E. Fahlén, C. Greenhalgh, and D. Snowdon, "User embodiment in collaborative virtual environments," in *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, ser. CHI '95. USA: ACM Press/Addison-Wesley Publishing Co., 1995, pp. 242–249. [Online]. Available: https://doi.org/10.1145/223904.223935

[10] S. Javorková, "Terapia pomocou technológií virtuálnej reality," 2021. [Online]. Available: https://opac.crzp.sk/?fn=detailBiblioForm&sid=14E8631BC0ED910BF6F4A633AA8B