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A remote rehabilitation training system using Virtual Reality

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Abstract*—The *rehabilitation process of sports injuries, movement and balance of the elderly with mobility problems as well people with injuries, is of key importance for the best possible recovery of proper functioning and mobility of the limbs of these individuals. In most cases, rehabilitation is provided in specialized rehabilitation centers, through services and recovery programs that are carried out for a specific period of time. During the patient's stay in the rehabilitation center, professional gait and balance analysis systems are used to assess his condition. These systems are usually too expensive, difficult to use, and can not be easily replaced by lower cost devices that provide the same quality and reliability. Furthermore, due to COVID-19 pandemic, the physical presence of a person during the execution of rehabilitation program has become prohibitive in many cases. Our solution offers an at-home rehabilitation exercises system using Virtual Reality with a human-alike Virtual Coach. The exercises for each patient are defined by doctors providing a personalized record tracking the rehabilitation progress.

Keywords—Virtual Coach, Virtual Reality, Motion Capture, Remote Rehabilitation

I. INTRODUCTION

In the last few years many software solutions were developed for medical and health proposes. Health coaching is now a standard for setting personalized goals and monitoring the everyday progress. Devices that can be warn the patient to keep a schedule for medication or other scheduled instructions from the doctor is the simplest method of such an automated system. With the rapid development of data process and mobile applications more complex solutions were developed. The simple warning system now consists of a virtual agent that the patient not only expects some instructions but he can interact with. Gupta et al [1] presented a data collection process, annotation schemas and agreement results and built an autonomous virtual assistant health coach that learns from expert demonstration to interact with patients via SMS. Ramchandani [2] examined the advantages of using a Virtual Coach (VC) along with the corresponding app for enhance Diabetes care.

Expanding the idea of a virtual coach, avatars were now the substitute of a human health coach. Actually there are two types of virtual coaches: human and Artificial Intelligence (AI) A human that it can be reached through a conference service inside an app can be considered as a virtual coach. [3] on the other hand an AI VC is computer software that has designed to act like a human. [4] Research has established the benefits of a human alike coach. Home based training programs are more convenient for older adults [5] and recently operated on people. COVID-19 made the physical presence of a person during the execution of the rehabilitation exercises more risky for patient's health. Personalized virtual coaching through AI avatars can in one point substitute the whole procedure when is possible. Mocanu Irina et al. [6] described two different type of exergames developed especially for elderly people that aim to motivate users to make exercise at home and does not require medical knowledge with the usage of avatars. Lan Yu-Ju et al. [7] proved that students learned better by watching their own 3D avatars doing motions than by moving their own bodies to produce the motions or doing nothing.

All the above indicates that the usage of humanoid VC can improve the results of rehabilitation sessions and therefore the use of such applications is becoming more frequent by individuals who haved already tried them. Tsakanikas et al. [8] recently presented the results of a virtual coaching system using a sensory platform. Patsantaras [9] showed how the sport exercises of avatars could be a significant theme in sport sociological analysis. Introduction of Virtual and Augmented Reality environments in health sector provided therapeutic solutions. The accelerated developments in computer graphics and advanced computer interfaces made it possible to combine these technologies with AI VC. Kouris et al. [10] presented a virtual balance therapy, supported by Information and Communication Technology devices, to monitor user's activity during the day and provide real time feedback for the correct execution of physiotherapy exercises.

Granqvist et al [11] showed that users prefer medium exaggeration over realistic or grossly exaggerated flexibility, an important result to consider about when develop a new virtual reality application. Escalona et al [12] proposed EVA, an augmented reality platform to engage and supervise rehabilitation sessions at home using low-cost sensors. It also stores the user's statistics and allows therapists to adjust the exercise programs according to their performance. Lastly,

Pérez-Medina et al. [13] presented a usability study between a simple game and a more complex gamified environment to support therapeutic exercises for patients with hip replacement. The first one was developed in JavaScript and the second one in Unity 3D. Improved VC taking advantage of the latest graphics and the latest mobile VR hardware available, presents a fully realistic humanoid avatar inside in an everyday situation, in order to enhance realism, as more likely the majority of the patients never had a similar experience in the past. A set of the most important exercises was recorded through motion capture under the supervision of medical staff and afterwards presented by the VC in a home-based

rehabilitation program.

II. Environment and Avatar

One of the most crucial steps is the environment design that the user will see inside Virtual Reality application. Due to the specific use case is particularly important to provide a realistic and everyday environment. It also may be considered that it is highly possible most of the users never had any experience with a VR application before. Therefore, this experience must be simple and as realistic as it gets fulfilling the users expectations regarding this technology. Beyond the virtual environment some rules of proper operation, i.e., the high fps and smooth movement, were taken into account during the development.

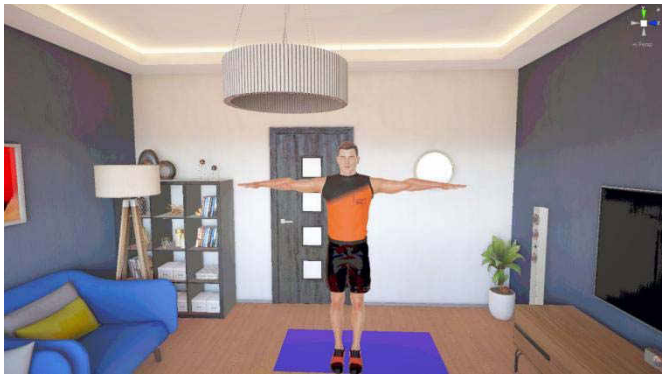

figure 1. Exercise room

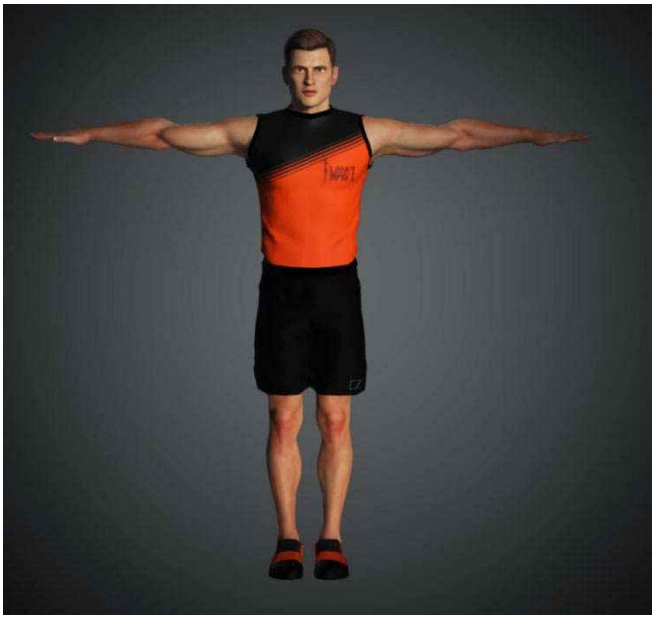

figure 2. High quality humanoid avatar

Considering all the above a living room was designed using everyday staff like a television and a couch. A special effort to the lighting of the environment was given in order to enhance realism. Therefore, all the reflecting surfaces of the objects that surrounding the user, were tested. Free 3D objects were used in that case from different sources combined with the basic features of Unity to build a realistic place.

A human realistic avatar in a VR environment is very important for a user when he has to interact with. Though, the most important in this case is that all the crucial parts and joints of the body used during the exercises to be clearly visible. For the purposes of the project a high realistic rigged avatar with sports outfit was designed. The rig followed the most usual rules and it can be used from all the available designing programs in ease. The picture shows the Virtual Coach (VC) inside the room in Unity Editor.

III. Animation - Motion Capture of the Exercises

A. Rokoko Suit

One of the most important tasks is to have a flawless representation of the movement during the exercises from the VC. For the purposes of this project a set of 15 rehabilitation exercises was recorded. In order to achieve high level of accuracy a motion capture (MoCap) solution was chosen. The full body Rokoko suit was chosen in order to capture the exercises. Rokoko suit can transmit the data through WiFi using its hub controller. Its 19 inertial sensors are placed in the major joints of the human skeleton that are interested in, like knees and elbows. The software that comes along with the suit can define an indicative avatar with basic measurements of the user that wears the suit.

It is of great importance to measure the distance of the main sensors in order to achieve a fully representative from real world to virtual world of the software.Corresponding software offers real time streaming which gives us the ability to check and correct the poses at the same time. All the recordings took place with doctors' presence in order to guide the VC model to have the desirable movement in each step of the exercise and fix possible wrong poses that could be disastrous for the patient's health. At this stage the fingers could not be captured from the suit and there were corrected during the integration.

figure 3. Rokoko's Studio software

As all consumer MoCap systems Rokoko is not an exception regarding a necessary post process of the final result of the recordings. Either some noise from metal pieces which interrupts the clear transmission of data either large continuously recordings that cannot locate the exact position of the user comparing with the initial position, cause some errors to the final result that must be corrected before importing them to the VC. Fortunately, the Rokoko software offers some filters and post-processing tools that can be used to define manually the current position and movement of the user that corresponds the real to the virtually world. i.e., locomotion issues can be corrected by indicating in which timestamp user's feet touch the ground or defining the first and last position of the recording. For the purposes of this objective a video was also captured in order to compare the final result with the actual and desirable movement.

The exporting procedure is the next step that follows the approval of the recordings. Rokoko's software gives the potential to choose from the most popular type of files, like fbx and bvh, that are been used in MoCap solutions.

Considering that the whole recoding must be used inside Unity from a similar (regarding the skeleton architecture) avatar the fbx solution was the chosen one. Furthermore, 4 different skeleton types are provided along with fps configuration in order to achieve the best corresponding options to the chosen solution.

B. Unity Mecanim

Unity's Mecanim animation system is one of the main reason that Unity was chosen at the first place. Taking advantage of Mecanim's feature an animation retargeting from Rokoko's skeleton to the Virtual Coach's Skeleton can be achieved. As a result, all the recordings during the MoCap procedure are been transferred to the VC. Though, further corrections might be needed due to the different size of character between the joints or the thickness of some of the body parts. In each case all the exercises were checked again only this time with the VC aiming to correct any abnormal poses that would confuse the user and positioning the VC inside the room. Furthermore, 3D objects like a chair and a towel were added to the corresponding exercises were needed in order to reflect 100% the exercise. At this stage, fingers movement was added through Unity's animation system to enhance realism.

C. VR Hardware

The choice of the appropriate VR HUD is important for a user that wants to execute a rehabilitation program wearing a VR component. Due to the type of the exercises all the non-stand alone choices are rejected because the cable that is connected with the PC can potentially pose risks to users. On the other hand, the stand alone solution must provide clear view with high resolution and high number of fps. Furthermore, some of the exercises impose the use of other objects from the environment and therefore a hand tracking feature is necessary instead of holding 2 controllers in each hand. Considering all the above, at the time of the project, the chosen solution was Oculus Quest 2.

IV. IMPROVE VR OPERATIONAL DESCRIPTION

The rehabilitation process begins with the patient's visit to the rehabilitation center, in order to be examined by the medical staff. In addition, the patient is trained in the use of VR glasses to become familiar with them and at the same time, the use of the application is demonstrated to his attendant. Once the scheduled sessions in the rehabilitation center are completed and the necessary instructions for the execution of the exercise program that should be performed daily are explained to the patient and his attendant, they are imported into the patient's record so that they can be viewed using the VR application remotely from his home.

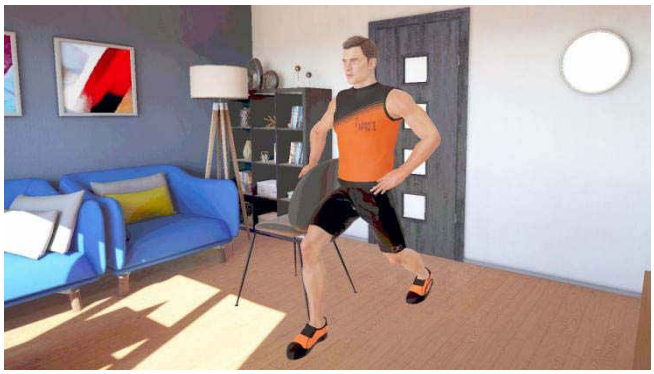

figure 4 Exercises inside VR

Hence, the doctor defines a set of exercises on each patient's file including parameters such as repeats, duration and time period, depending of course on patients' condition and rehabilitation status. In the main scene of the application a menu with the proposed exercises appears. When the user choses an exercise, the VC shows the correct movement along with instructions that makes the whole exercise clearer. At the end of the scene the VC asks for the user to repeat the exercise but in the recommended poses the doctor suggested for its case. VC's role is to show how the exercise must be executed but due to the unique situation of each patient personalized limitations may have, been indicated from the doctor during the visit.

A pop-up window indicates when the user started the exercise and when he ended it. The duration of each exercise is stored as this is an important parameter for improvement evaluation. The doctor, monitoring the patient's progress can modify the rehabilitation program either online or at the patient's next visit.

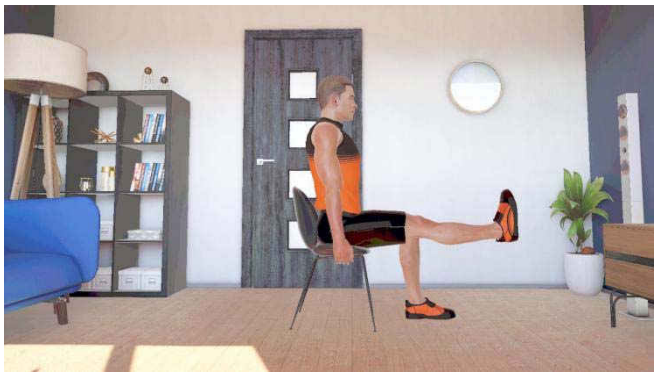

figure 5. Exercises inside VR

V. CONCLUSIONS

This study constitutes a brief presentation of the IMPOVE VR application designed to enable patients with neuromuscular disorders (like stroke, multiple sclerosis, spinal cord injury), musculoskeletal disorders (like knee injuries, hip fractures, tendon injuries) and elderly. to follow remote rehabilitation programs without the need for frequent visits to a rehabilitation center. This approach offers new opportunities to people coming from vulnerable social groups who due to the COVID 19 pandemic were and continue to be more excluded than other people.

In addition, the IMPROVE VR application enables personalized rehabilitation for people living in rural and semi-rural areas who should often move to urban centers where these appropriate infrastructures exist. In the near future, the pilot results of real patients will be used to further improve the proposed system architecture. The proposed rehabilitation platform intends to be used as an alternative, attractive, cost effective and beneficial solution both for therapists and patients as it has been designed to offer an enjoyable experience that will increase patient's motivation along the rehabilitation process.

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