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Preface

This research work is the eclosion of the seed I have carried throughout my childhood when I was dreaming about new technologies and videos games, when I was spending hours diving in a virtual world that taught me so much, be it on a cognitive level or on a concrete aspect. This project is an embodiment of my experience that was enhanced by the modest amount of technical knowledge I acquired through my curriculum. I dared to seize the opportunity that was given, as it allowed me to present the utilitarian side of video games that I discovered at an early age. It was a blessing to be able to join together the amount of fun I always had when I was in contact with video games on one side, and the thrill of learning and acquiring new skills in a cherished domain. Above all, this experience could contribute to the improvement of people's well-being and health conditions. More than a project or a blessing, this is the realization of my childhood dream.

All of these was made possible thanks to the cooperation between my college the university of Badji Mokhtar Annaba, and the research lab IRVA of the Centre for Development of Advanced Technologies (CDTA). So, I would like to thank and show my honest gratitude to all the workers there for their warm welcome and their support.

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First of all, I would like to extend my deepest gratitude to my mother for giving me all the moral support through all these years, for battling by my side, for raising us and give us the right tools to face this world and have a purpose in life. To my father for providing a stable environment that allowed us to evolve without shaking, for his financial support which made us lack of nothing on our path.

I must also thank my younger brother for his profound belief in my work and my abilities, for his practical support in the unknown environment I settled in, once I got to Algiers.

My gratitude and thanks should also go to Noor, that encouraged me and brought an invaluable moral support during my weakest times.

Dedication to my close friends Amine, Fares and Sam and all the other people that have been there for me.

Abstract

Strokes are one of the main causes of disability in Algeria. This pathology represents a serious public health problem due to its high mortality rate. In addition to that, many victims are left with a non-functioning upper limb and cannot have an ease access to rehabilitation methods due to their high cost or the long waiting lists of the public hospitals. This research study investigates the application of virtual reality technologies in post stroke rehabilitation techniques using a developed serious game. Evaluations methods were also proposed for the assessment of the users' gestures captured by the Kinect camera. The developed serious game is made by using Unity engine based on game design principles for rehabilitation. Euclidean distance and Cosine similarity algorithms are programmed and integrated to the developed software as objective evaluation metrics. NASA TLX form is also employed to subjectively evaluating the developed virtual reality application. Obtained subjective results showed proper adaptation of the users to the prototyped VR game. Users gestures are accurately measured and evaluated using the carefully chosen combination metrics. Results are portrayed in 3D graphs including Frame number, Cos similarity and Euclidean distance. The designed VR prototype and its proposed evaluation method can be suggested to healthcare professionals to follow their poststroke patient's progression. Collecting more data from an extended number of patients will be mean of building up a machine learning recommendation system for further research.

Keywords :

Rehabilitation, Virtual Reality, Post Stroke, Serious game, Cosine similarity, Euclidean distance.

Résumé

Les accidents cardiovasculaires cérébraux sont l'une des principales causes d'invalidité en Algérie. Cette pathologie est un problème de santé publique à cause de sa mortalité élevée. En outre, de nombreuses victimes sont laissées avec un membre supérieur non fonctionnel et ne peuvent pas avoir accès à des programmes de rééducation en raison de leur cout élevé ou à de longues listes d'attentes dans les hôpitaux publics. Cette étude explore l'application des technologies de réalité virtuelle dans les techniques de rééducation post-accident vasculaire cérébral à l'aide d'un jeu sérieux développé. Des méthodes d'évaluation ont également été proposées pour l'évaluation des gestes des utilisateurs capturés par la caméra Kinect. Le jeu sérieux a été développé en utilisant le moteur graphique Unity et en se basant sur les principes de conception des jeux sérieux pour la réadaptation. Les algorithmes de calculs des distances euclidiennes et des similarités Cosinus ont été intégrés au logiciel développé en tant que mesure d'évaluation objective. Le Formulaire TLX de la Nasa a également été utilisé dans le but d'obtenir une évaluation subjective de l'application développée. Les résultats subjectifs obtenus ont montré une bonne adaptation des utilisateurs du jeu en RV prototypé. Les gestes des utilisateurs sont mesurés et évalués avec précision à l'aide des mesures combinées soigneusement choisies. Les résultats sont représentés dans des graphiques 3D, comprenant le nombre du frame, la similarité Cosinus et la distance euclidienne. Le prototype de RV conçu et la méthode d'évaluation proposée peuvent être suggérés aux professionnels de la santé pour suivre la progression de leurs patients après un accident vasculaire cérébral.

ملخص

تعتبر السكتة الدماغية أحد الأسباب الرئيسية للعجز في الجزائر .يمكن تصنيف هذه الباثولوجيا كمشكلة صحية عامة بسبب ارتفاع مساهمتها في معدلات الوفيات. بالإضافة إلى ذلك، فإن العديد من المتعرضين للسكتة الدماغية تصاب أطرافهم العلوية لتصبح غير وظيفية، ولا يستطيع الكثير منهم الوصول إلى برامج إعادة التأهيل بسبب ارتفاع التكلفة أو طول فترة الانتظار في المستشفيات الحكومية. تبحث هذه الدراسة عن تطبيق تقنيات الواقع الافتراضي في عمليات إعادة التأهيل ما بعد السكتة الدماغية باستخدام لعبة رقمية قمنا بتطويرها . هذه الدراسة تقترح أيضا أساليب لتقييم حركات المستعملين التي تلتقطها كاميرا Kinect. تم تطوير اللعبة باستخدام محرك Unity، مع الاخذ بعين الاعتبار مبادئ تصميم الألعاب لإعادة التأهيل. تم كذلك برمجة خوارزميات لحساب المسافات الإقليدية وتشابهات جيب التمام في البرنامج الذي تم تطويره كإجراء تقييم موضوعي. كما استخدم نموذج استبيان TLX التابع لوكالة NASA للحصول على تقييم ذاتي للتطبيق المقدم. أظهرت نتائج الاستبيان التي تم الحصول عليها تكيّف جيد لمستخدمي اللعبة في الواقع الافتراضي النموذجي .يتم قياس حركات المستخدم وتقييمها بدقة باستخدام قياسات مجمعة مختارة بعناية .تعرض النتائج في مخططات ثلاثية الأبعاد، تحتوي رقم ال الصورة وتشابهات جيب التمام والمسافة الإقليدية .يمكن اقتراح النموذج المطور للواقع الافتراضي الذي وطريقة التقييم المقترحة على أخصائيي الرعاية الصحية لمراقبة مدى تحسن مرضاهم ما بعد السكتة الدماغية. نقترح كخطوة تالية للبحث المقدم، جمع المزيد من البيانات من عدد كبير من المرضى لبناء نظام توصية وتصنيف باستخدام نماذج التعلم الآلي

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List of abbreviations

VR: Virtual Reality

AR: Augmented Reality

XR: Mixed Reality

VE: Virtual Environment

HMD: Head Mounted Display

CAVE: Cave Automatic Virtual Environment

HMD: Head Mounted Display

MSER: Maximally Stable Extremal Regions

AED: Automated External Defibrillation

General Introduction

The recent development of virtual reality technologies and their integration to home systems and video games changed our way to perceive virtual environments and made physical interactions between the user and the system that generates artificial world possible. This evolution has opened a new field of research allowing the emergence of virtual reality in domains like marketing, computer design and data visualization. Medicine was not an exception and many home systems and mainstream game consoles were adopted to offer innovative approaches and go beyond classic rehabilitation methods. . These new forms of therapy offer playful aspect and gives the opportunity to patients to practice from home.

This research study will focus on the application of virtual reality for post-stroke rehabilitation therapies and how we can evaluate the performance of patients' gestures using such technologies.

Virtual therapies are the future of the post-stroke rehabilitation field, they offer the possibility to resolve many problems of the classic methods. They provide advantages like the independency, the consistency, and the participation of the patient. While there has been many research investigating of the use of virtual technologies in post-stroke therapies as the presented work in [1][2][3][4], few of them focus on the methods we can use to evaluate the effectivenness of patient's gestures compared to those used in the classic methods. The evaluation methods are a key concept to the future development of this virtual therapies.

The dissertation' objectives can be summarised in the following points:

- The development of an application based on VR technologies that reproduces gestures of classic post stroke rehabilitation therapies recommended by physicians and physiotherapists. The reproduction of these gestures will be taken over by a 3D avatar which is the virtual representation of the patient in a 3D interactive environment.
- The performance of the VR model will be measured after each experiment using subjective and statistical evaluation.

  Efficiency evaluation of patients' actions by collecting a set of data aimed at estimating the "right" gestures recommended by experts.

This research manuscript is organised as follows:

Chapter 1: Fundamentals of building an AR/VR intelligent system for healthcare application.

In this chapter we will introduce the key concepts and fundamentals of building AR/VR applications for the healthcare domain. We will explain how the VR works and how it can be implemented in a healthcare application.

Chapter 2: An overview study of AR/VR application in healthcare.

In this chapter we will make a state of art of the use of VR/AR technologies in the medical domain and how we can properly design a serious game for this field of application.

Chapter 3: Adopted VR solution for post-stroke rehabilitation.

In this chapter we will present the software and hardware combination of the proposed solution to building our VR application. Evaluation metrics are also pinpointed and presented in this chapter.

Chapter 4: Experimental work and results.

The last chapter reveals insights of the developed application, highlights the evaluation graphs, and discusses the obtained results.

Chapter 1: Fundamentals of building an AR/VR intelligent system for healthcare application.

1.1 Introduction

The virtual reality is a constantly developing technology. In recent years, it has experienced an explosion in its use in various fields. The development of devices and tools like the Oculus Rift and the Kinect Camera made it easier for the general public to use virtual reality

1.2 Definition of VR, AR and XR technologies

as According to [1] Virtual Reality "can be regarded as an enhanced version of Human-Computer Interaction in which human interact with artefacts in a virtual environment and get totally immersed in it. Various devices, such as earphones, Head-Mounted Displays (HMDs) and others are used to support this technology. [1]Whereas augmented reality (AR) is defined as "*real-time direct or indirect view of a physical real-world environment that has been enhanced / augmented by adding virtual computer-generated information to it*" [2].Same as VR, the user can interact with this generated world with specific input and output systems. Finally, cross reality (XR) is described in [3] "*it involves a ubiquitous mixed reality environment that comes from the fusion of a network of sensors and actuators (which collects and sends data related to the real world)with shared virtual worlds, using an augmented reality interface, where the exchange of information is bidirectional between the real and the virtual world.*"

1.3 VR application domains

1.3.1 Video Games

The industry of video games has grown very quickly the last few years. the video games have become more popular and this drives some big companies in the tech industry to create new technologies offering an enriched experience to millions s of gamers around the globe. Companies like Microsoft proposed a VR input system called “The Kinnect”. This camera-based system gives the opportunity to the player’ body to interact with objects in the virtual world.

Figure 1 Players interacting with virtual objects using the Kinect Camera [4]

In 2014 Facebook has purchased Oculus Rift company, a startup that developed a headset allowing its user to be entirely emerged in a virtual world and interacting with the game objects using controllers in his hands.

Figure 2 Image of The Oculus Rift Headset. *[5]*

1.3.2 Medicine

VR allows medical students to perform operations in a controlled environment and to learn from this 3D simulation before doing anything in the real world. Furthermore, AR/VR also allow distant surgeons to perform complex surgical operations by controlling a remote robot without being physically present in the surgery room. [6]

Figure 3 A medicine student using the Arch Virtual System to simulate an operation. *[7]*

1.3.3 Military domain

Many national armies are now using the VR technology to train their members. Immersive virtual world using headsets, special military suits and virtual guns are used to simulate different battlefield scenarios. To reduce risks, VR drones, tanks and military vehicles are used on simulations before taking hands to real applications. [8]

Figure 4 New army members training using immersive technologies *[9]*

1.3.4 Computer assisted design and scientific data visualization

More and more design offices are using VR technology to create environments such as homes and infrastructures. This help designers and their clients to visualize the interieur and exterior design and the final result with 3D models. Laboratories and medical staffs are also using the VR to perceive a holistic picture of complex 3D proteins and chemical components in a 3D enhanced environment. [10]

Figure 5 Computer assisted design using VR technology *[11]*

1.3.5 Medical rehabilitation and psychotherapy

Some laboratories and hospitals have proved the effectiveness of therapies and rehabilitation using the VR technology. In case of psychotherapy, patients are immerged in 3D virtual world facing slowly and progressively their biggest fears with the guidance of a psychiatrist.

For medical rehabilitation patients do some exercises in front of cameras or using remote controllers. The connected software evaluates the patient movements and provides new progressive challenges every. [6]

Figure 6 Motor rehabilitation session using VR technology *[12]*

1.4 Computer vision

1.4.1 Definition

When looking to a certain image the human brain can understand what this image represents, understand the relationship between parts of the image and get a correct interpretation of the semantic of that image (understanding a gesture or a word for example).

A computer fails to do that, it can only see blocks of a digital image represented by bits and cannot really understand what this image really mean. This concept is known as a semantic gap [13].

To get the computer interacts with the user in real time and to have the feeling of a “fake” reality, the system has to react to each user’s gesture at the speed of a normal conversation between two humans. That is what computer vision and gesture recognition aim to do. [14]

1.4.2 The mechanisms of computer vision

To detect objects in the space and to understand the semantic of some movements, a lot of algorithms and techniques were developed. A non-exhaustive list of the most common techniques is presented below [14]:

- **Blob Detection**

This technique is used to determine various regions in an image, algorithms like the maximally stable extremal regions (MSER) looks at the number covariant regions in a given image, which means that if there is a green space in an image of a road, the algorithms will detect them due to their colours and their frequency. If another green space is detected, the algorithm understands that these two objects are related and have the same nature.

- **Scale Space**

This technique breaks the image into smaller pieces then reshapes every object in the image to different scales to better understanding the object nature and its proprieties.

- **Template Matching**

This technique is used in applications like Facebook and in airport surveillance system . It consists of matching small parts of an image with a chosen template. We can easily search for a certain person in image if it picture already exists in the profile pictures database.

1.5 Gesture recognition

1.5.1 Definition

Human–computer interaction is an important feature of VR technology. It supplies a variety of mechanisms and tools giving access to different functions and possibilities. Enabling people to obtain immersive feelings in 3D virtual scenes. [15]

1.5.2 Devices

The gesture recognition devices can be split up in three major categories [15], the wearable sensor-based devices, the touch devices and computer-based vision interaction equipment. The wearable sensor-based devices are objects like the VR gloves that collect human hand motion and posture There are also the inertial sensors that use accelerometers to determine the motion of the user and the posture of the device. For example, the same technology is used in our telephones and in controllers like the remote controller of the Wii (Nintendo).

Figure 7 Hand movements simulation using VR gloves *[16]*

The touch devices are essentially composed of technologies like touch screens. They are commonly used in recent mobile phones and stylus pens. Sensors like magnetic or ultrasonic trackers, combined with a touch screen send to the operator system information like handwritings or draws.

Figure 8 Pen Tablet used in drawing *[17]*

Computer-based vision interaction equipments are devices that do not require external inputs, the gesture recognition is calculated by internal algorithms and methods, we can cite as an example the Kinect Camera from Microsoft.

1.6 VR/ AR application in Healthcare field

The recent development of VR/AR technologies had made it in complex structures and systems like the healthcare domain. Specialists started first to use it for educational purposes, offering trainings on complex, life-saving processes in a risk-free environment.

The significant success pushed companies and researchers to develop more complex VR tools made for the healthcare domain. The VR is now used for [6]:

-Diagnostic tool with the 3D imagery.

Figure 9 3D Diagnosis using VR *[18]*

-Mental illness treatment: it offers the possibility to expose patients to their source of anxiety and fears.

Figure 10 Treating fears and phobias using VR *[19]*

-Pain management and physical therapy, patients are doing rehabilitation exercises in a safe and controlled environment.

-VR as a tool in surgery: complex surgery operations are possible now with specialists from all over the world and far away from the patient using elaborated robots controlled by human surgeon.

1.7 Serious games

1.7.1 Definition

Serious games are characterized according to the authors Alvarez Julian and Damien Djaouti in their book "Serious games, an Introduction" [20] by two principal points:

1/ They combine between video games and several utility functions: learning, communication…

2/ They address markets like education and medicine and not only to the entertainment market.

1.7.2 Serious games and healthcare

Many applications of serious games have been developed for the healthcare domain for both medical providers and patients according to Francesco Ricciardi and al [21]. In some health-related professions, education and training must be practiced during the entire working period and not only limited to school years. Continuous training is useful and sometimes necessary, especially in surgery. Serious games provide a controlled environment for new recruits to learn new skills and practice without the fear of making critical mistakes. They are also beneficial for patients to learn procedures about their health habits. [21]

For example, in 2010 Sabri et al [22] created a serious game for knee replacement surgery, which is a risky operation, where one small mistake can have large consequences for the patient for his entire life. The serious game described permits training of orthopaedic surgical techniques to orthopaedic surgical residents outside the operating room with a multiplayer modality.

Another example of serious games used in healthcare is the AED (automated external defibrillation) Challenge [23] which is a web-based serious game for teaching and training AEDs and first aid manoeuvres to emergency medical services professionals.

Finally on the patient side of using serious games in healthcare domain we mention the diabetes patient education platforms Timeout [24] which is a serious game developed for teenagers and adult with type 1 diabetes. The objective of the game is to teach all manoeuvres related to the insulin level measurement and all the good lifestyle and alimentation habits.

1.7.3 VR/AR and serious games

According to Checa David and Bustillo Andres in their study “A review of immersive virtual reality serious games to enhance learning and training” [25] 15 years ago, the emergence of large 3D viewing tools such as the Head Mounted Display (HMD) and the Cave Automatic Virtual Environment (CAVE) created a new field of research and development for the initial educational VR experience. Results of the research [26] made on such systems showed that the players show greater interest in learning through these environments while facilitating the understanding of complex concepts. The military industry has also started investing in this field and created the VR training for their new recruits. [8]

The high cost of the first VR/AR systems hampered its use in mass public applications. The development of relatively low-cost HMDs such as the Oculus Rift and the launch of free versions of powerful motor engines (e.g. Unity) had then a great impact on making VR serious games publicly available on a large scale.

1.8 Conclusion

In this chapter we defined important concepts and technologies for the reader, to understand how every part of our system works and how the virtual reality and its application in serious games can help us reaching the goal of this study.

Chapter 2: An overview study of AR/VR application in healthcare

2.1 Introduction

In this chapter we will discuss the major steps and key findings using VR/ AR technologies in the healthcare domain. This will lead us to make a brief overview of their history, to show up the recent trends in these technologies and to compare between the classic methods for the post-stroke rehabilitation and VR/AR systems. We will also see how we can develop an effective VR/AR application adapted to the patients.

2.2 History of VR/AR application in healthcare domain

The first application of the VR in the healthcare domain goes back to 1990 [27]. The main purpose of the system was to help doctors in visualizing complex medicine data before going ahead for surgery. Researchers from Clark Atlanta University, in 1992, had the idea to use this new technology to treat various mental disorders, especially in phobias therapy . [27] In 2009, the international society for virtual rehabilitation was created to make a gap between engineers, scientists and clinicians. Its main task was the introduction of new technologies like VR and AR systems in motor, psychological, cognitive, and social rehabilitation. [27]

A Meta-analysis was made in 2014 analysing 19 publication and involving 1474 patients, concluded “that the depression therapies using computer games has significantly lowered the severity of depressive symptoms in the studied group” [28]

2.3 Recent trends of VR/AR application in healthcare domain

2.3.1 Application in healthcare practices

The VR technology can now bring pieces of the real environment and expose them to people who suffer from anxiety and fears like claustrophobia and social anxiety [6]. This form of therapy is known as the exposure therapy [29]

Figure 11 Treating acrophobia using a VR headset *[30]*

Also, a company named Limbix gives the hlep patients to be exposed to their fear through VR glasses and other devices, in order to face phobias like Acrophobia (the fear of high buildings) and Arachnophobia (fear of spiders) [31].

The medical school of Stanford University initiated a project named “The Autism Glass Project” [32]. Its main purpose is to help children affected by autism to interpret other’s emotions using AR glasses. This will lead the children to develop a certain degree of social interactions through memory of previous interactions and practice.

The phantom limb is the sensation that an amputated or a missing limb is still here. Patient who still feel that a missing limb can also experience pain coming from that phantom member. The AR technology gives the opportunity to patients to see a virtual member on the screen whenever they try to move the amputated one. This can lead to achieve a therapeutic effect on the patient’s brain [33].

2.3.2 Application in medical education

Medical students and clinicians have now the possibility to visualize detailed structures of each part of the human body using the VR/AR technology. Based on this fact, clinicians and doctors can give more detailed explanations to their patients using these virtual images. [6]

Anatomy 4D (Figure 2) is a great example of such applications. This app can be downloaded on any smart phone and display detailed 3D structures of different human body parts. [34]

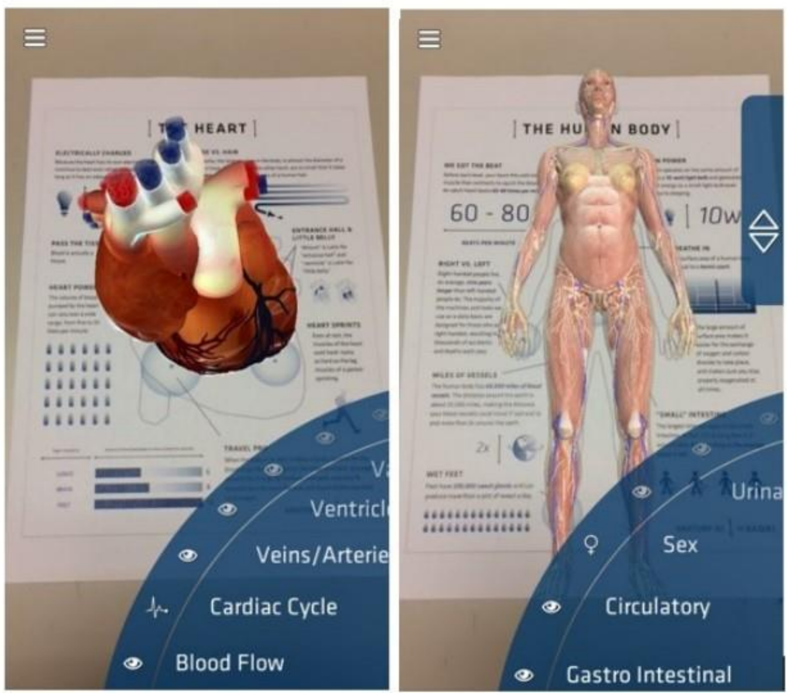

Figure 12 Anatomy 4D App - virtual heart (left) and human anatomy (right) AR display. *[6]*

The VR technology provides a risk-free environment for medical students to train and learn from their mistakes by doing complex surgery operations in a 3D environment.

Many hospitals around the world like the Taipei Veterans General hospital are now equipped with this technology offering their students a controlled space to train and to learn quickly [6].

2.3 Case of study: post stroke rehabilitation

2.3.1 Classic methods for post-stroke rehabilitation

2.3.1.1 Definition of a stroke

World Health Organization defined stroke as a "neurological deficit of cerebrovascular cause that persists beyond 24 hours or is interrupted by death within 24 hours" [35]. In other terms it is a medical condition caused by a poor blood flow to the brain which can cause the death of some cells. Strokes can be split up into types [36]: Ischemic due to the lack of blood and Hemorrhagic due to bleeding. The main risk factor for a stroke is the high blood pressure [37]. We can also include other risk factors such as obesity, high blood cholesterol, tobacco, diabetes… etc. A stroke can have a huge impact and can be a life changing event for a person. it will influence a physical, psychologic and social levels [38]. a non-exhaustive list of the stroke repercussions is presented:

- Difficulties to leave the house and having social maintained life.
- Unhappiness and psychological consequences like depression.
- Difficulties to talk or/and walk.
- Struggle with everyday life tasks like washing and bathing.

2.3.1.2 Physiotherapy

Physical therapy is one of the health professions, her primarily role is to help improving a patient's physical functions through various exercises. It applied by a physical therapist. A physical therapy can be divided into 3 major steps [39] :

- Recovery: We can observe a naturel recovery by the patient after few hours or few days after the stroke, the patient can slowly move the affected limb.
- Recovery and rehabilitation: the neural system can create new circuits to offset the affected ones, this can be possible by applying specific exercises along the treatment of the patient. Rehabilitation: The patient identifies his weaknesses with the physical therapist and work on reducing them or on bypassing them to get a perfect symmetrical fully recovered body.

2.3.1.3 Exercises for the upper body

Some examples of the exercises used in the physiotherapy for the upper body by the professionals of the domain are highlighted in the following figures [40] [41]:

Moving a bottle (Figure 13): -Place a bottle next to a standing up box

- Lift the bottle over the box and put it down on the other side

- Repeat the same movement in the opposite direction

Figure 13: Exercises for the upper body (Moving a bottle) *[40]*

Throwing a ball (Figure 14): - Stand opposite a wall holding a ball

- Throw the ball against the wall

- Throw the ball upwards if possible

Figure 14: Exercises for the upper body (Throwing a ball) *[40]*

Using a spoon (Figure 15): - A spoon on the table

-Pick up the spoon on the table

- Lift the spoon to your mouth

Figure 15 : Exercises for the upper body (Using a spoon) *[40]*

2.3.2 VR/AR applications for post stroke rehabilitation

2.3.2.1 The advantages of VR/AR applications over classic post-stroke rehabilitation methods

The major goals of a rehabilitation therapy are to make quantitative and qualitative improvements in daily activities to improve the quality of independent living. Motor recovery is determined by early intervention, task-oriented training and repetition intensity [42]

One of the common problems in the classic therapies is that patient can feel boredom, fatigue, lack of motivation and cooperation [43]. These feelings are considered as problems that restrict the rehabilitation progress . The virtual reality can provide interesting and engaging tasks that are more motivating than the formal repetitive therapies.

Weiss and his colleagues suggested that the virtual reality platforms provide a number of unique advantages over conventional therapy when trying to achieve rehabilitation goals [44].

These advantages can be grouped [45] in the following way:

- Virtual reality systems provide ecologically valid scenarios that elicit naturalistic movement and behaviours in a safe environment. This environment can be designed according to the needs and ability level of the patient engaged in the therapy.

- The realism of the virtual environments offers patients the opportunity to exploring independently and increasing their sense of autonomy in directing their own therapeutic experience.

- The controllability of virtual environments allows for consistency in the way therapeutic protocols are delivered and performance recorded, enabling an accurate comparison of a patient's performance over time

- Virtual reality systems allow the introduction of "gaming" mechanisms into any scenario to enhance motivation and increase user participation.

In addition to all these advantages the use of game elements can be a mechanism to drive the attention of the patient from the resulting pain of movements. Because the patient is focused on achieving goals within the game and forgets that he is doing exercises of a therapy. Davis et al. in [46] describe a state of a flow in which the patient forgets that he is going through a rehabilitation process and totally focuses on achieving the game goals. Furthermore, VR technology can have economic advantages over the classic methods by allowing patients to practice exercises from home and minimising direct and indirect costs [47] .

2.3.2.2 VR/AR efficiency compared to the classic post stroke rehabilitation therapies

The virtual reality offers the capacity to individualize treatment needs while providing increased standardization of assessments and training protocols [48]. In some systems, the interaction may be achieved via a pointer operated by a mouse or joystick button. In other systems, a representation of the user's hand (or other body part) may be generated within the environment where movement of the virtual hand is "slaved" to the user's hand allowing a more natural interaction with objects.

The visual interfaces in the other side are used to create variable degrees of immersion in the virtual environment. As visual interface, we mention the example of the conventional desktop monitors, the head mounted displays or more complex ones like the cave automatic virtual environment (CAVE).

To prove the effectiveness of VR/AR applications many studies have been conducted, Feldman et al. in [49] specifically compared movements made with or to virtual objects in a VE to movements made with or to real objects in real environments. The results showed that there were no differences in movement characteristics between the real and virtual task in participants with hemiparesis.

They also concluded that VR is similar enough to reality to provide an effective training environment for rehabilitation.

Rose et al. in [36] studied the transfer of training of a simple sensorimotor virtual task to performance on the "real world" equivalent and concluded that the final real-world performance benefited as much from real as virtual practice. Research presented in [50] reported preliminary data from healthy adults using a bicycle linked to a virtual visual environment and suggested that this training system would be beneficial for postural balance control.

A report based on two case studies using the Vivid GX video capture technology demonstrates improvements in upper activity function [51].

2.3.2.3 Game design of VR/AR application for post stroke rehabilitation

To build effective exergames we need to take in consideration two fundamental motor learning principles that affect positively the rehabilitation [52]. The first one is the task variability; this principle helps to retain learning for more time [53]. The second principle is progression. It implies that motor learning and rehabilitation programs benefit from a continuous adaptation of task difficulty to increasing skills level and avoid negative emotions like fear or demotivation [54].

Another element to take in consideration when building a 3D game for post-stroke rehabilitation is adapting its use for elderly people [55]. This why we need to integrate familiarity aspects in the developed exergame. Three major aspects have to be adopted [55]:

“-**Symbolic Familiarity**: Objects, scenes, and activities, which frequently appear in elderly's daily life, should be infused into the system.

-**Cultural Familiarity**: Traditions, patterns, concepts, and rituals, which exist in the elderly's culture, should be infused into the system.

-**Actionable Familiarity**: Actions to interact with the system should be consistent with the actions used when interacting with the real world*”*

2.4 Conclusion

In this chapter we have presented a brief state-of-the-art of VR/AR technology applications and its recent trends in the healthcare domain. Major advantages of using VR technology for our case of study (rehabilitation after a stroke) have been described. Concepts on how to build effective exergames adapted to different patients' categories were also presented in this chapter.

Chapter 3: Adopted VR solution for post stroke rehabilitation

3.1Introduction

In this chapter we will present the major principles taken in consideration when developing our exergame for the rehabilitation of post-stroke patients. We will also detail the utilized software and hardware components. In the final part, we will present the major metrics used to evaluating the performance of the proposed VR solution.

3.2 Study Diagram

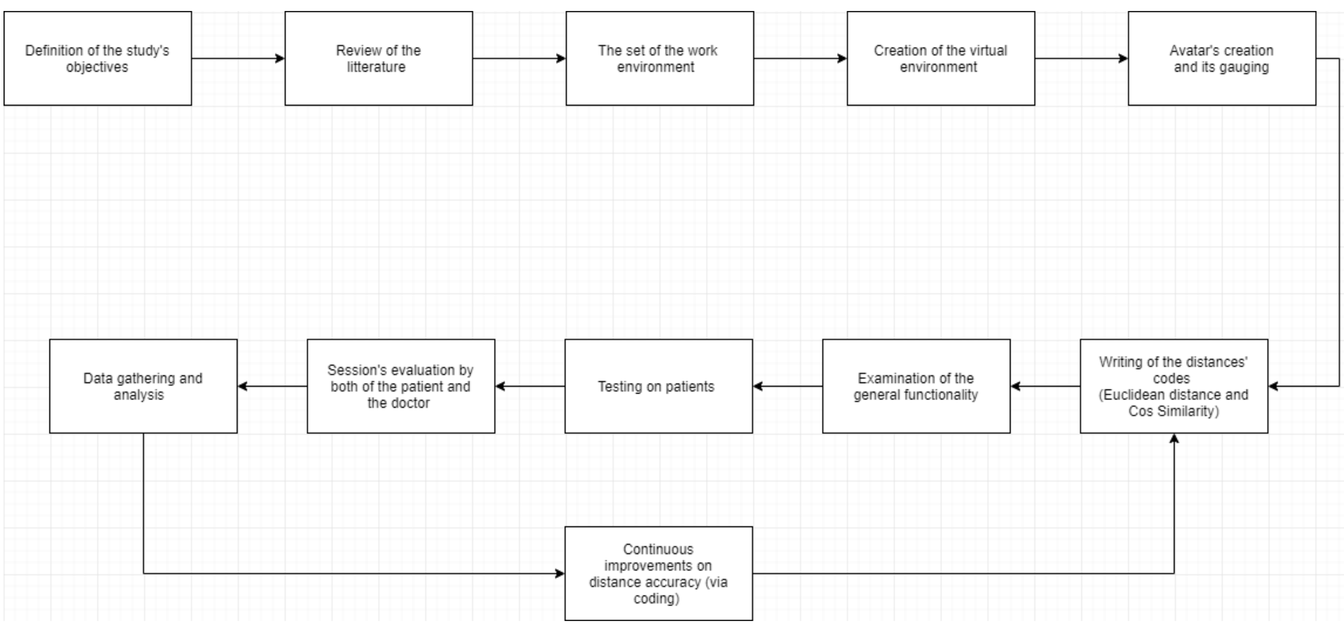

Figure 16 Study Diagram

We started our study by defining objectives that our game has to accomplish and how our study can improve its results when extracting the first data. We then made a literature review on the available in different search engines. This gave us the opportunity to understand different game design aspects and how to use the virtual reality in our project to realize the predefined goals.

The next stage of our study was to create a work environment by installing different software's used in the VR game development and to connect different parts of our system together., This includes the PC, the Kinect Camera, the Unity Software, the Visual Studio IDE and the Kinect SDK. We then created our first avatar and worked to gauging it to work properly with the Kinect camera and to mimic the real-world gestures. We also created a virtual environment where our avatar can interact in and the patient will feel comfortable.

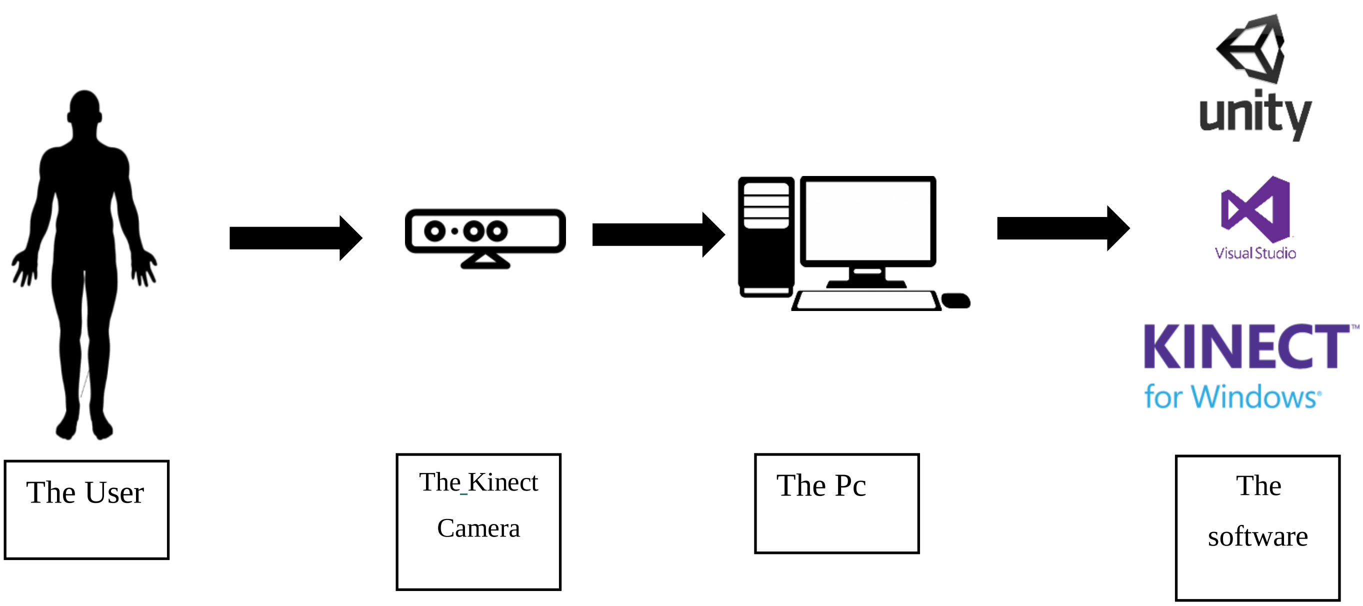

Figure 17 Technical diagram showing all the operating parts of our system

After that, we had to calculate the distance between the hand of the patient and the targeted position of the hand. to do so we used two distances: the Euclidian distance and the Cosine Similarity(We will after explaining why we choose to work particularly with these two norms) .The next step was to check how our game was working and if this particular design and codes were comfortable for the first tests on real users.

We then tested our game on users and recoded the first results by submitting a form at the end of each session and saved the distances generated by our game in a text file to next extract them and plot the results.

The objective of the study was then to collect the more data to improve our codes and VR environment based on patients and doctors' feedback.

3.3 Adopted Hardware and Software

3.3.1 Hardware

- **Kinect Camera**

Kinect (codenamed Project Natal during development) is a line of motion sensing input devices produced by Microsoft and first released in 2010. The technology includes a set of hardware originally developed by PrimeSense, incorporating RGB cameras, infrared projectors and detectors that mapped depth through either structured light or time of flight calculations, and a microphone array, along with software and artificial intelligence from Microsoft to allow the device to perform real-time gesture recognition, speech recognition and body skeletal detection for up to four people. This enables Kinect to be used as a hands-free natural user interface device to interact with a computer system. Kinect is a peripheral that sits atop the user's display similar to a webcam. [56]

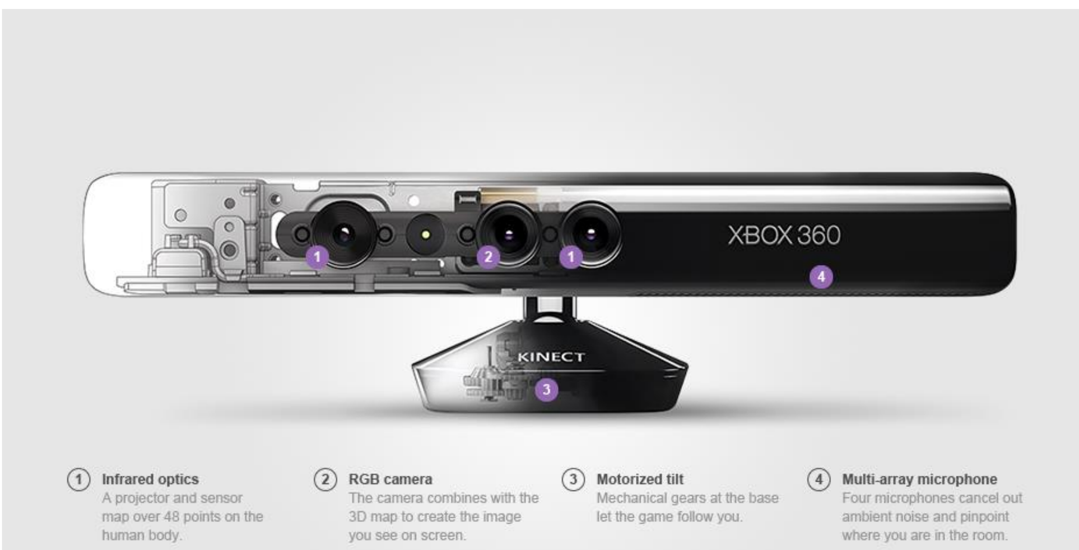

Figure 18 The Kinect Camera *[57]*

Color	**Camera Resolution** **Framerate**	1920 × 1080 pixel 30 frames per seco
Depth	**Camera Resolution** **Framerate**	512 × 424 pixels 30 frames per seco
ield of VIEW (depth)	**Horizontal** **Vertical**	70 degrees 60 degrees
Operative Measuring Range		from 0.5 m to 4.5
Depth Technology		Time-of-flight (To
Tilt Motor		No

Figure 19 Technical specifications of the Kinect v2 *[58]*

- **Personal Computer**

Processor	Intel Core i7-6700HQ 6th Gen
Graphics (GPU)	Nvidia GeForce GTX 950M 4GB dedicated video card
Data storage	256GB SSD/ 1000GB (1TB) HDD
System memory (RAM) size	16GB

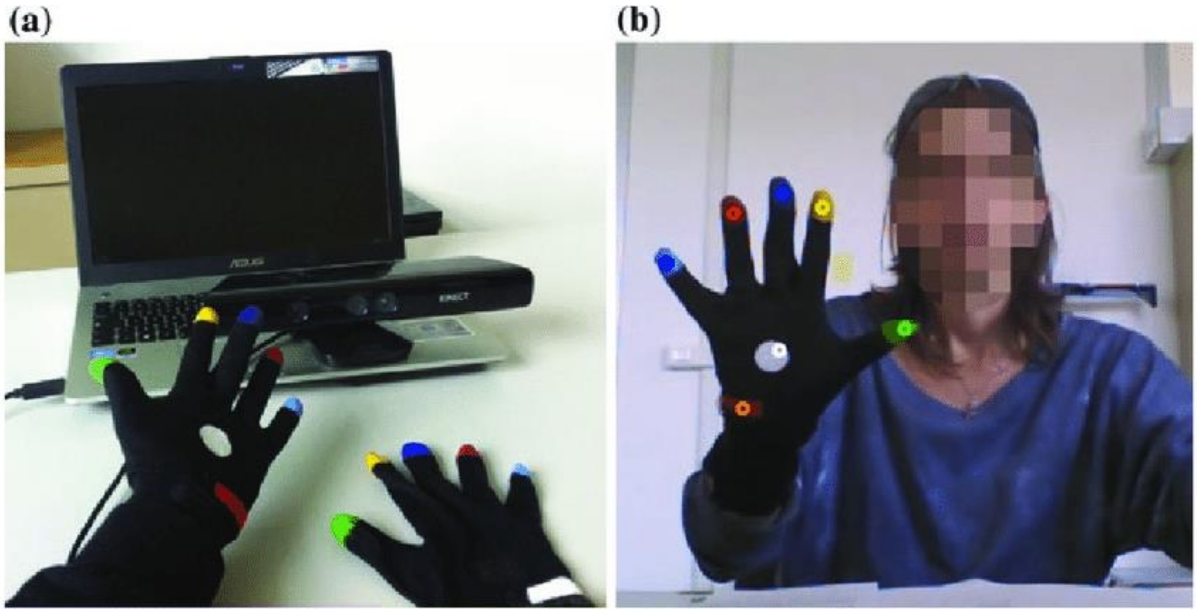

Figure 20 Human computer interface (PC, Kinect and gloves) *[59]*

3.3.2 Software

- **Unity**

Unity is a cross-platform game engine developed by Unity Technologies. The engine can be used to create three-dimensional, two-dimensional, virtual reality, and augmented reality games, as well as simulations and other experiences. [60]

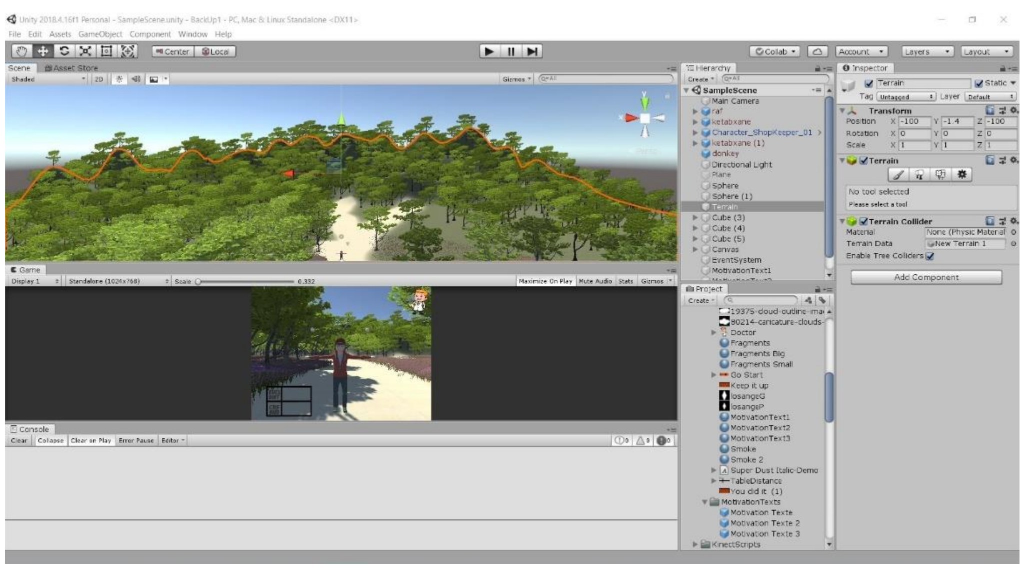

Figure 21 Unity Interface

- **Visual Studio**

Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop computer programs, as well as websites, web apps, web services and mobile apps. Visual Studio uses Microsoft software development platforms such as Windows API, Windows Forms, Windows Presentation Foundation, Windows Store and Microsoft Silverlight. It can produce both native code and managed code.

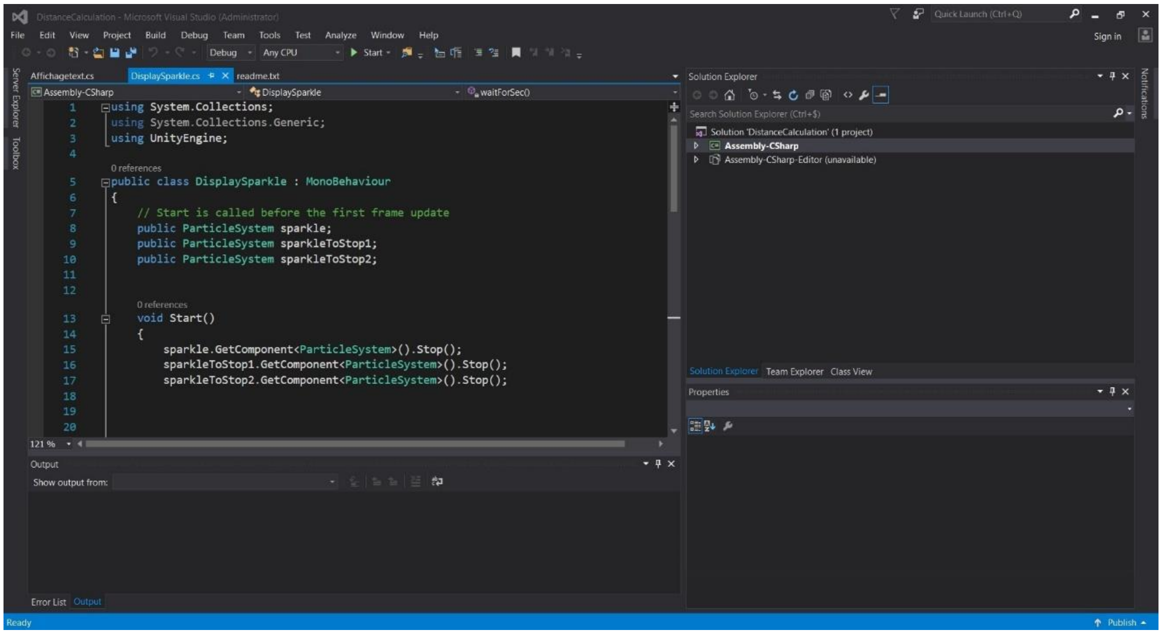

Figure 22 Visual Studio Interface

- **Kinect SKD for Windows**

The Kinect for Windows Software Development Kit (SDK) 2.0 enables developers to create applications that support gesture and voice recognition, using Kinect sensor technology on computers running Windows 8, Windows 8.1,Windows Embedded Standard 8 and Windows 10. [61]

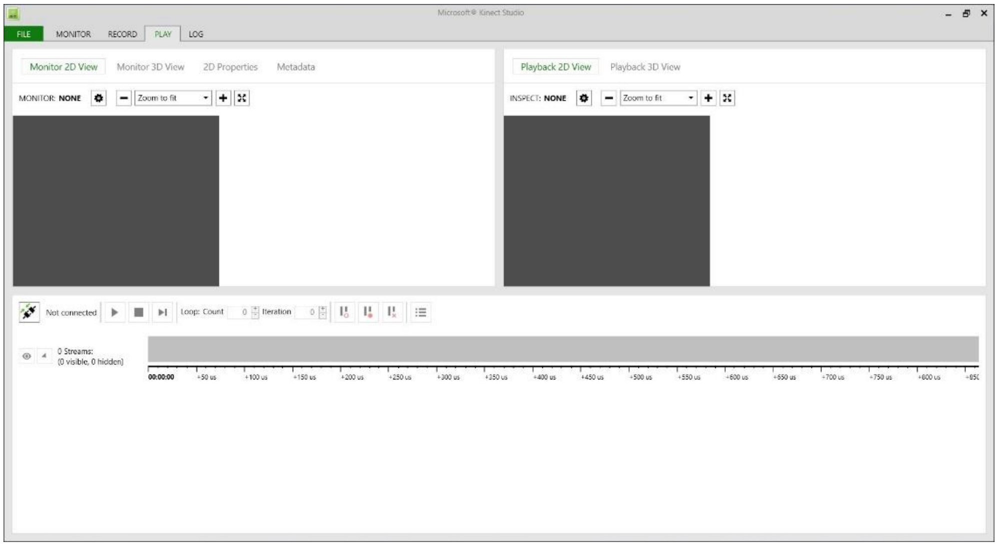

Figure 23 Kinect SDK Interface

3.4 Game design

Our game had to be built on solid foundations in order to fulfil the predefined objectives and the game aspects described in the previous chapter. we choose to focus on these specific points:

- Our game must mimic real world gestures used in post-stroke rehabilitation therapies and formulate a set of specific requirements in physiotherapy.

- Our game must include different stages of difficulties to avoid any negative feeling during the sessions.

- Our game has to motivate the patient through messages on the screen every time the patient crosses a new level of the targeted gesture.

- Our game has to incorporate some aspects of familiarity, so that the patient will not feel lost in this virtual world.

3.5 Objective and subjective evaluation metrics

Both objective and subjective metrics are used to evaluate the proposed VR solution.

Objective metrics are programmed, calculated, and generated by the computer on a text list. They are also displayed on the screen for patient and the doctor if he is attending the session. Subjective metrics are forms given to VR game users after session to collect their feedbacks about the game and its environment.

3.5.1 Objective metrics

3.5.1.1 Euclidian distance:

In mathematics, the Euclidean distance or Euclidean metric is the "ordinary" straight-line distance between two points in Euclidean space. With this distance, Euclidean space becomes a metric space. The associated norm is called the Euclidean norm. Older literature refers to the metric as the Pythagorean metric. A generalized term for the Euclidean norm is the L2 norm or L2 distance. [62]

We choose to work with this distance because Unity 3D and C# assemblies already integrates a lot of functions and methods to directly use into our exergame. Also, many studies we have mentioned before obtained good results when using this metric.

3.5.1.2 Cosine Similarity:

Cosine Similarity measures the cosine of the angle between two non-zero vectors of an inner product space. This similarity measurement is particularly concerned with orientation, rather than magnitude. In short, two cosine vectors that are aligned in the same orientation will have a similarity measurement of 1, whereas two vectors aligned perpendicularly will have a similarity of 0. If two vectors are diametrically opposed, meaning they are oriented in exactly opposite directions (i.e. back-to-back), then the similarity measurement is -1. Often, however, Cosine Similarity is used in positive space, between the bounds 0 and 1. Cosine Similarity is not concerned, and does not measure, differences is magnitude (length), and is only a representation of similarities in orientation [63]. After the first tests using the Euclidian distance, we faced a problem which is that distance between the hand of the patient and the sphere that represents the targeted gesture never reach the constant zero. This problem is first due to the difference of nature between the two game objects, one is representing the hand of the patient and the other is a sphere.

Secondly the Kinect camera always takes in consideration the measure of the depth between the two game objects. To overcome this problem, we choose to work with the measure of the orientation between the two gestures (the patient's movement and the targeted position). An example of the code we used in our study can be found in the annex of this document.

3.5.2 Subjective metrics

NASA TLX:

To assessing the patient feelings during the session and how he was perceiving the tasks required to complete the therapy, we choose to work with the NASA TLX which is a subjective workload assessment tool allowing users to perform subjective workload assessments on operator(s) working with various human-machine interface systems. Originally developed as a paper and pencil questionnaire by NASA Ames Research Center's (ARC) Sandra Hart in the 1980s. [64]

By incorporating a multi-dimensional rating procedure, NASA TLX derives an overall workload score based on a weighted average of ratings on six subscales:

- Mental Demand
- Physical Demand
- Temporal Demand
- Performance
- Effort
- Frustration

An example of the used form can be find in the annex section.

3.6 Conclusion

In this chapter we described the principle aspects we took into consideration when building up our proposed solution, and how they can affect the user experience. We also presented how to effectively measure distances in our solution and how to prevent any negative emotion like frustration or lack of motivation during the therapy by interviewing every patient after the session.

Chapter 4: Experimental work and results

4.1Introduction

In this chapter we will present the game we developed to realize the objectives we set at the beginning of our study. To do so we discuss the diagram of the developed VR solution for post-stroke rehabilitation, present some screenshots from our game to explain how the patients are interacting. Also, we will present the obtained results of the calculated distances and show how users perceived the propped VR game by using the NASA TLX form.

4.2 Game Diagram

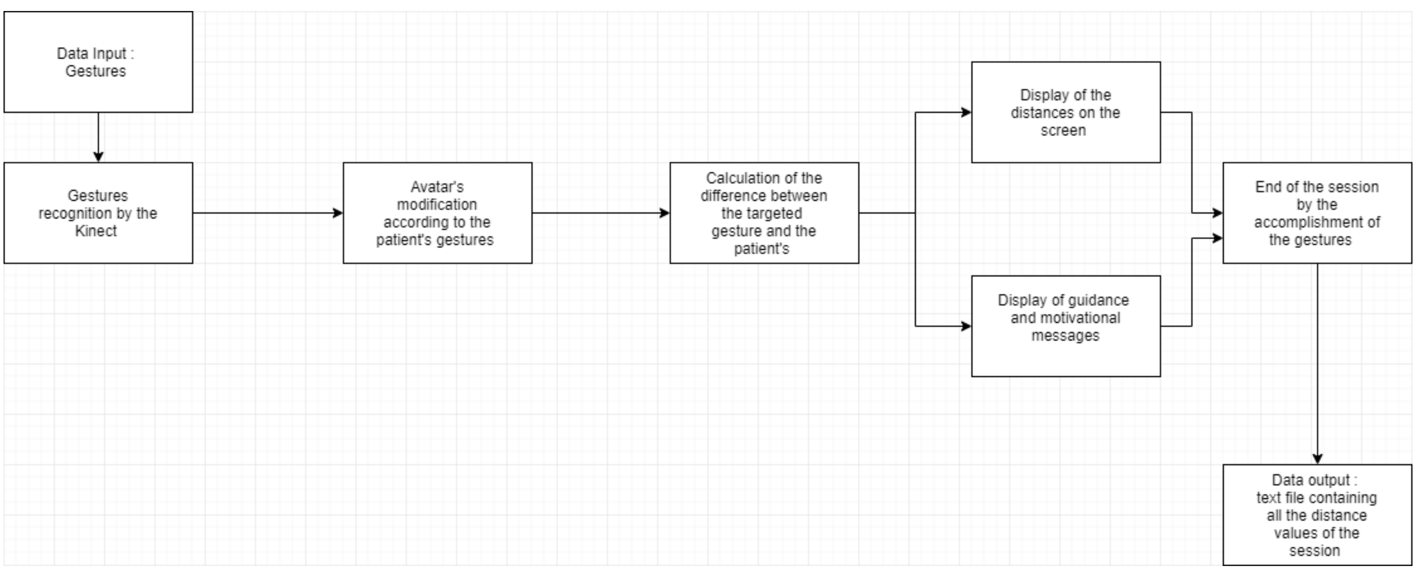

Figure 24 The Diagram we used when building our game

Our game works on this way: First the Kinect Camera has as an input the gestures produced by the patient. It detects his movements and modify the position and the state of the avatar on the screen according to these gestures.

The avatar is the perfect representation of the patient in the virtual environment and does everything the patient is doing. We calculate the distance between the hand of the avatar and the sphere present on the screen which represent the position where the hand of the patient has to evolve to. To calculate the distance, we use codes that implement the Euclidian distance and the Cos Similarity into our game and according to these distances and the position of the patient's hand we display some motivational and guidance messages to help the patient reach the goal of the session. When the patient reaches the objective of the session, the game stops and all the distances generated by the game during the session are saved into a text file to be analysed after.

4.3 Game Interface

4.3.1 The developed VR environment:

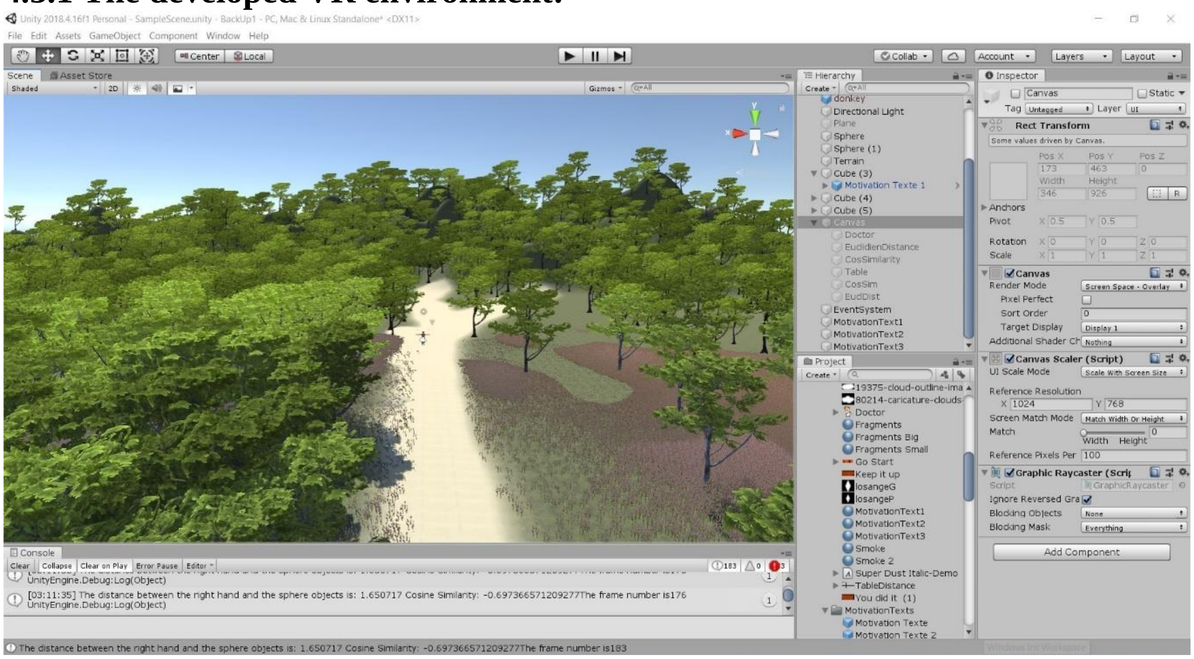

Figure 25 Game Interface: The environment

To make sure that our patient will not feel completely lost in our virtual environment we decided to create a nature territory where the user will feel safe to evolve in, and where he will find some similarities with the real-world environment.

4.3.2 The avatar:

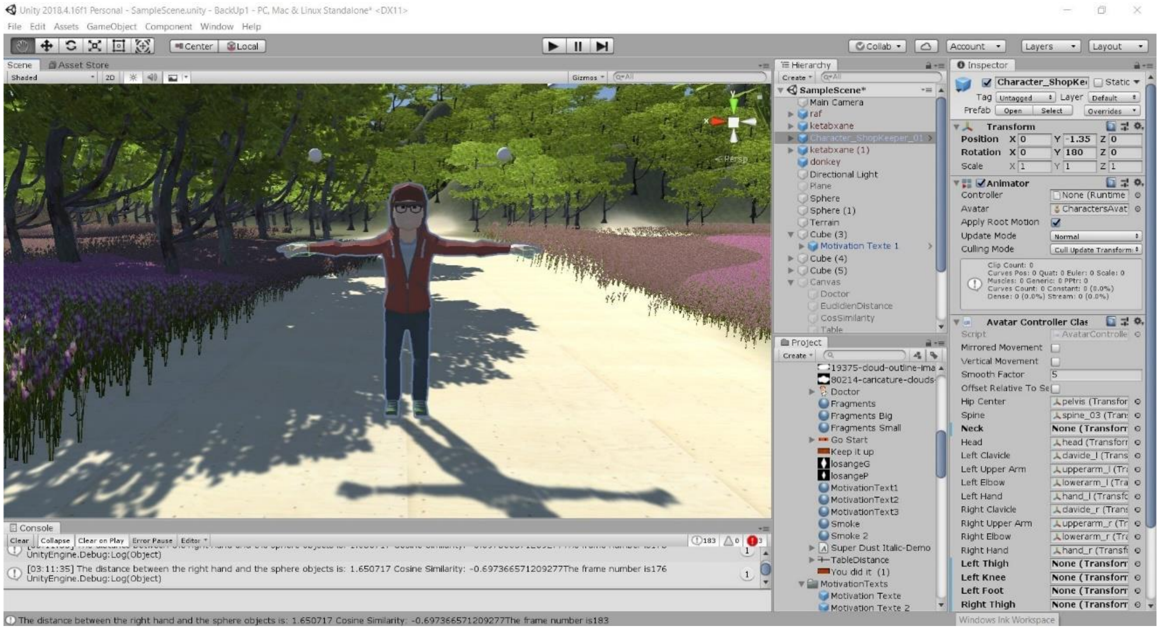

Figure 26 Game Interface: The avatar

The patient can choose an avatar from a large set of avatars, he can select one based of his esthetic preferences, gender, age… etc.

4.3.3 Levels and position:

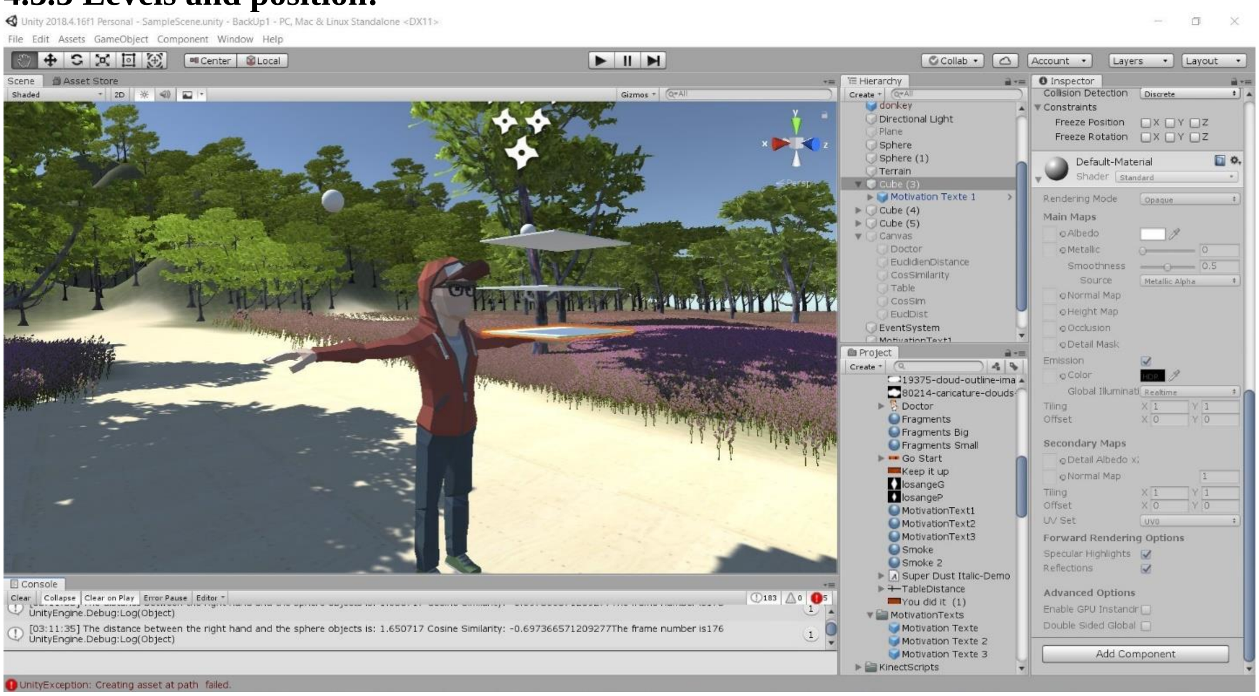

Figure 27 Game Interface: Levels and position

The doctor can modify the position of the spheres, they represent the targeted gesture and also modify the levels or stages according to the need of every session.

4.3.4 Table of distances:

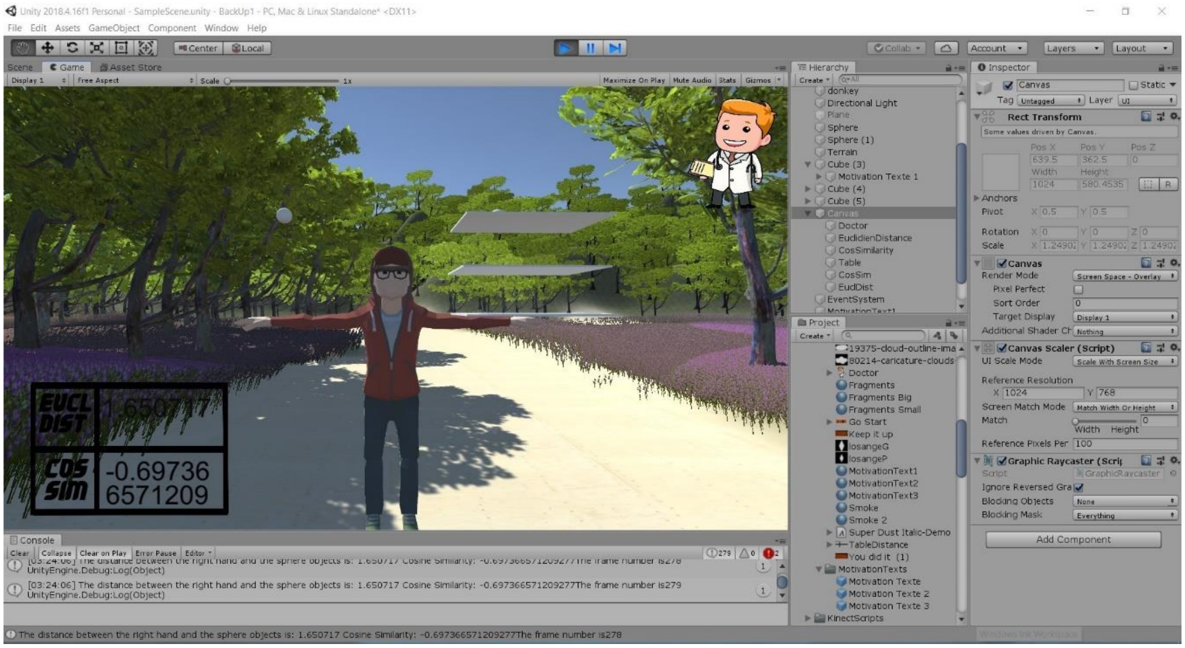

Figure 28 game Interface: Table of distances

Every time the patient moves his hand, we have an upload of the distances. They are then displayed in a table on the bottom right of the screen.

4.3.5 Motivation and guidance messages:

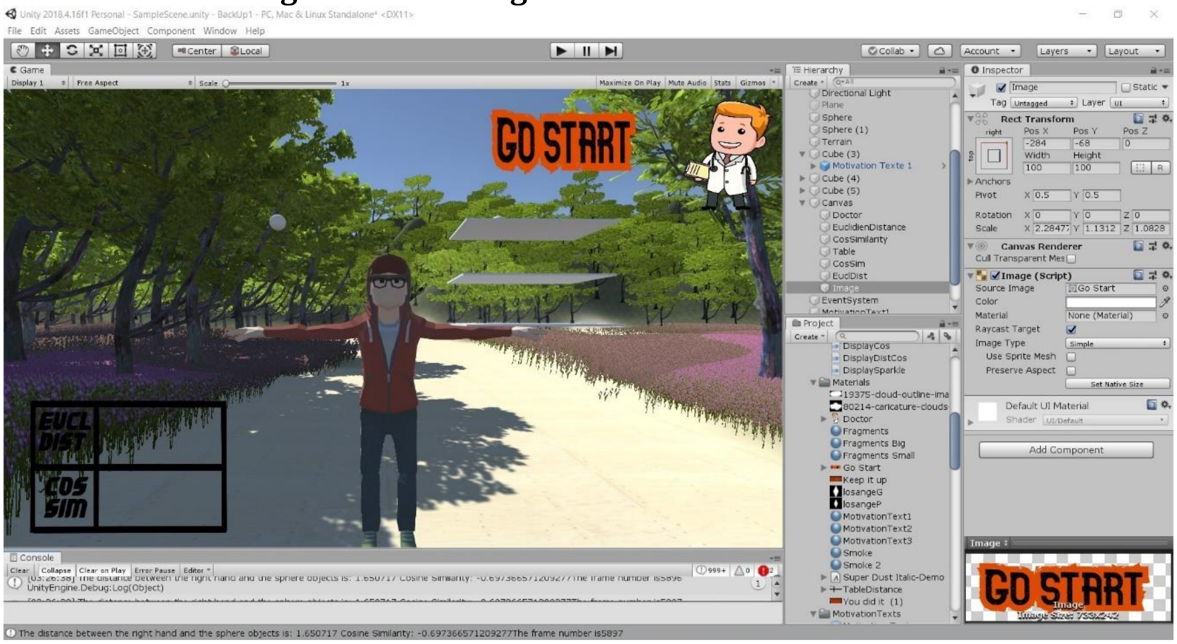

Figure 29 Game Interface: Motivation and guidance messages

Depending on the position the doctor chooses and the levels he set, guidance and motivational messages will be displayed on the top right of the screen to help the patient reach the asked position. These messages help the patient once the session starts so that he will not feel lost if he does the session alone without the instructions of a doctor.

A video demo of our VR serious game can be found in the following link:

https://drive.google.com/drive/folders/1TAqzs9uxx-_SMY71QF0kT2epy4arZuyc?usp=sharing

4.4 Results and discussion

Due to the COVID-19 situation we could not test our game on real patients, because we hadn't the access to hospitals. Although, to measure the effectiveness of our game we tested it on a panel composed of 5 persons: 3 men and 2 women, with an age range going from 20 years old to 75 years old. We explained the principle of our VR game to every person at the beginning of the session. We set different levels of difficulties according to the age of each patient and at the end of every session we gave them the form to get their impression of the game and how they felt during the exercise.

We will display the result of the distance's calculation in form of 3Dgraphs including the number of the frames on the X axis, the Cos Similarity on the Y axis and the Euclidian distance on the Z axis. Answers to the form are then revealed in a table.

4.3.1 Results:

On these graphs we represent how the Euclidian distance and Cos similarity evolve with the number of frames during the sessions

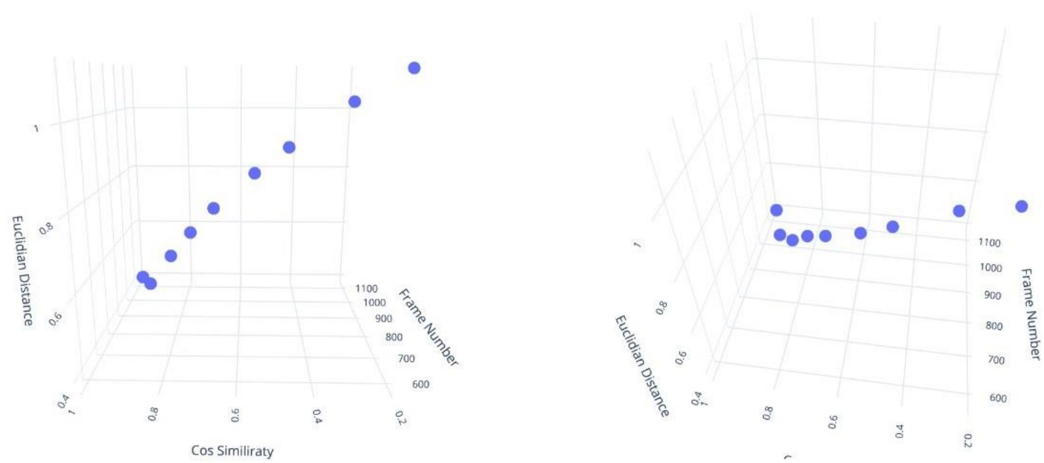

Figure 30 Graph of the session's evaluation: user's age 20 Front & Top views

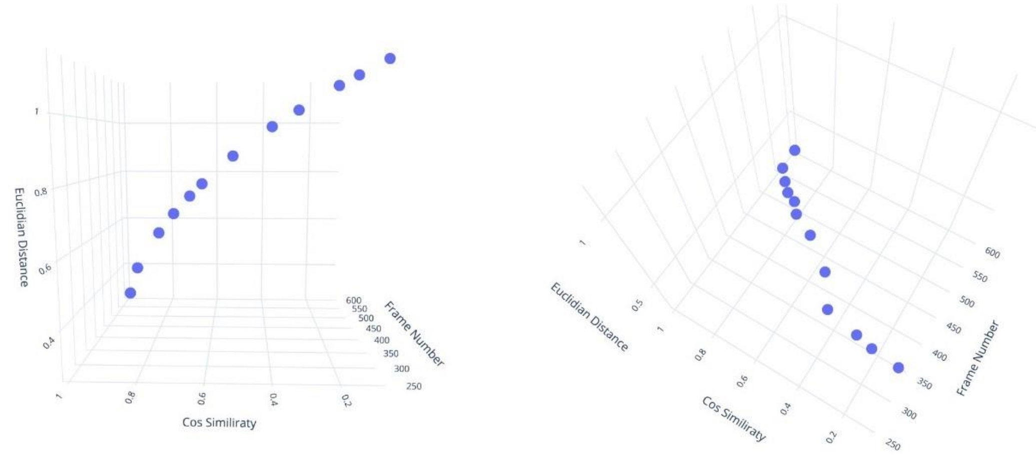

Figure 31 Graph of the session's evaluation: user's age 27 Front & Top views

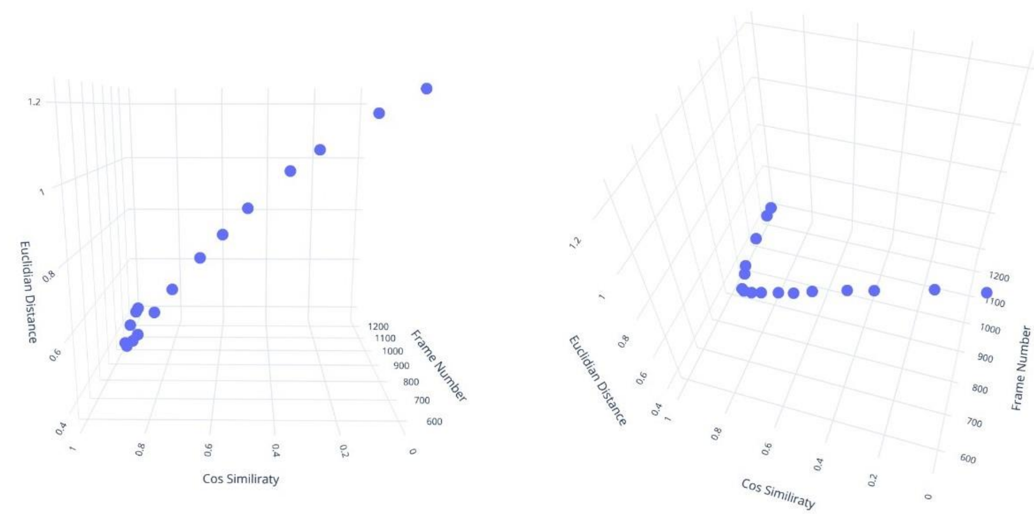

Figure 32 Graph of the session's evaluation: user's age 52 Front & Top views

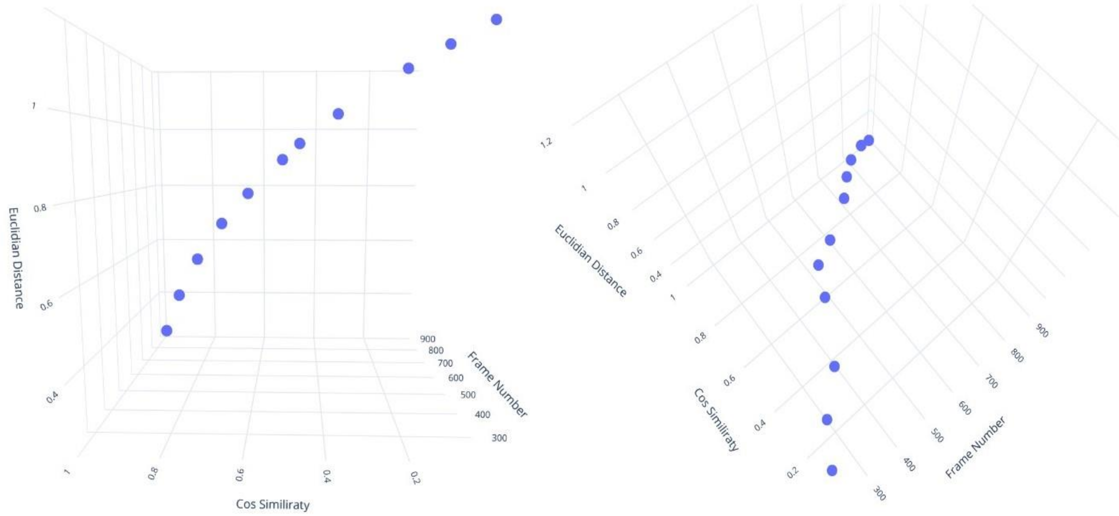

Figure 33 Graph of the session's evaluation: user’s age 54 Front & Top views

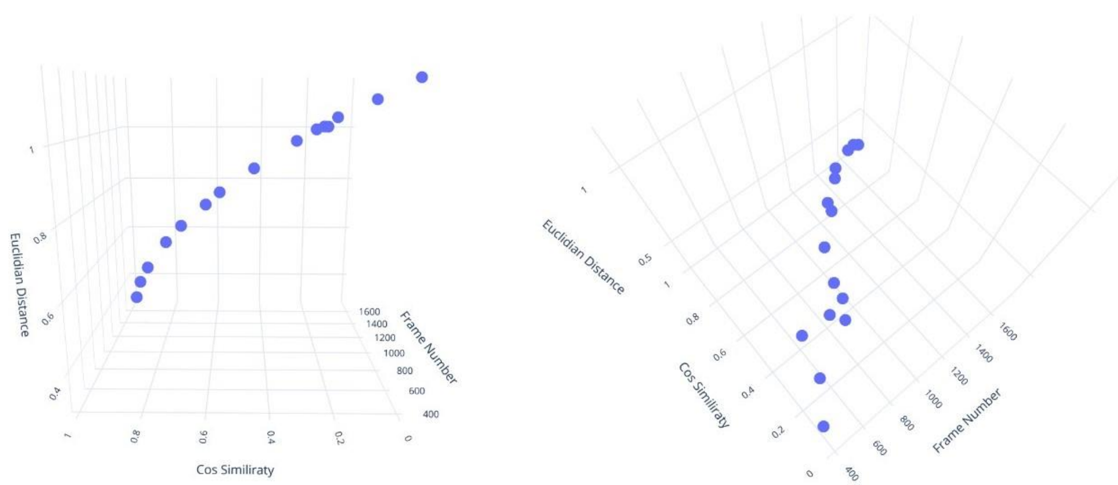

Figure 34 Graph of the session's evaluation: user’s age 75 Front & Top views

Table 1 Results of the Nasa TLX form

Age	Gender	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration
20	Male	4	2	2	16	2	2
27	Male	2	3	2	13	3	1
52	Female	7	9	3	11	9	5
54	Male	5	6	2	14	6	3
75	Female	12	11	4	10	14	7
	Average	6	6.2	2.6	12.8	6.8	3.6

4.3.2 Discussion:

The results about the distances are like we expected them, the first 300 frames are the initiation of the game and can't be took in consideration (we did project only some frames on the 3D graphs because each session represents a massive amount of data, for some of them we had more than 2000 frames), as the sessions goes on and the patient is reaching the goal the Euclidian distance tends to zero (no distance between the two game objects) and the Cos Similarity tends to 1 (same angle). We had smooth graphs from all the sessions we did, expect for our oldest patient (75 years old) who had some complications to keep her hands up.

For the NASA TLX form, all our users had a good experience using our game, the session was not very mentally because all of them had some familiarity with video games and new technologies expect for the oldest one. For this user we had to explain every part of our system and how she can interact and realise objectives within the game using the Kinect Camera, that would explain the high mental demand value. For the physical demand, the objectives of our game are not that difficult to reach for people without physical disabilities, this is why we obtained low physical demand values expect for the 52-year-old patient who declared that she had an accident during her childhood on her shoulders and that she still feels some pain there. The 75-year-old patient also stated that she has some difficulties to keep her hand up. Our game was not time limited and we didn't set any chronometer on the screen during our sessions, that's why all our patients didn't feel any temporal pressing. The effort values can be explained by the same factors we had for the physical and the mental demand parts. All of our users didn't feel a real frustration during the sessions because they were feeling gratified by the messages on the screen and the feeling of reaching their goal on every level without the pressing of a timer on the screen.

4.4 Conclusion

The results we had are positives and seem to validate our study, the codes evaluate the distances correctly and users of our game did not report any real problem and stated that they are ready to work with it for a post stroke rehabilitation. Although, these results cannot be considered as decisive and effective, because we need to get more data from a larger panel of users and to test our game on real patients with a non-functioning upper limb . We also want to get a feedback of doctors on our game and to confirm our study and its effectiveness.

Finally, we would like to incorporate some aspects of artificial intelligence in our game, so that the application would be able to detect any problem or complication during the session when performing some complex gestures used in therapies.

General Conclusion and Future Perspectives

In this dissertation, we had to develop an application based on virtual reality to introduce it into a rehabilitation program for post-stroke patients. A simulation of rehabilitation gestures was introduced to evaluate the proposed simulation, mainly these gestures were recommended in the state of the art by physiotherapists and experts, in order to support post-stroke patients throughout their therapy / treatment sessions. It should be pointed out that these exercises were recommended by professionals to treat physical disabilities due to stroke accidents. The evaluation phase of our simulation was done in terms of two evaluation protocols; a subjective evaluation and an objective evaluation in order to demonstrate the effectiveness of this experimental and inexpensive approach through different metrics. It should be noted that the in vivo evaluation on real persons, who are supposed to represent patients but in good health, was carried out. Unfortunately, due to the health crisis, mainly related to the Coronavirus pandemic (COVID-19), ethical issues and lack of time, our approach had not been tested on real patients with post-stroke disabilities. Moreover, carrying out such experiments can be quite a sensitive process, as the discomfort feeling must be avoided for patients, and also the non-invasiveness condition of the test procedure is important to be fulfilled upstream before running any tests with real patients, in order to not, in any way, disturb patients. In addition, rehabilitation sessions must be conducted in the presence of psychologists and medical officers/ experts. It has recently been reported in the state-of-the-art that reactions of patients during treatment sessions are different and sometimes unpredictable (e.g., patients may categorically refuse to use such an approach, due to problems associated with the acceptance and acceptability of this type of rehabilitation method. However, this is out of topic of this study.), such behaviour is well known as an interindividual difference phenomenon. In this study, an inexpensive approach has been proposed as a novel post-stroke rehabilitation technique. It requires a simple Microsoft Kinect type depth camera and 3D game development software, namely Unity3D. Those tools are a real asset of creativity and were greatly helpful during the implementation / testing stages. The proposal works in real time with a capacity for tracking the user's movements with an acceptable, however, we believe that the latest version of the Kinect camera (Kinect-V3) provides an accurate tracking results thanks to recent built-in algorithms implemented into the Kinect-V3 camera's framework and compared to those implemented in the first version of the Kinect (Kinect-V1) that has been used in our work.

This is a real challenge because despite this handicap on image capturing and movement tracking algorithms in the Kinect-V1, our approach carried out promising results proving the effectiveness of VR-based technique for post-stroke rehabilitation purposes. Further extended future works are cited below:

• Extend our approach in Augmented Reality approaches, and wearable head devices in order to provide an immersive experience for patients, that will be helpful for their acceptance of this novel rehabilitation techniques. • Machine learning and deep learning-based methods will be used as a recommendation system, which will be introduced as an assistive AI-based agent to assist patients reproduce different rehabilitation movements and exercises.

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Annex

The developed code used for calculating Euclidean distance and Cosine similarity:

```
void Update()
    {
        distance = Vector3.Distance(this.transform.position, hand.transform.position);
        int frameNumber = Time.frameCount;
        var firstVector = Vector.Create(new double[] { this.transform.position.x,
this.transform.position.y}); // // we create a vector using the name space Extreme
        var secondVector = Vector.Create(new double[] { hand.transform.position.x,
hand.transform.position.y}); // we create a vector using the name space Extreme
        double dotProduct = Vector.DotProduct(firstVector, secondVector);
        CosSimilarity = dotProduct / (firstVector.Norm() * secondVector.Norm());


        Debug.Log(string.Format("The distance between the right hand and the sphere
objects is: " + distance + " Cosine Similarity: " + CosSimilarity + "The frame number is"
+ frameNumber));

        string path = "C:/Users/Bouznad Fahd
eddine/Desktop/Distances/Distancesrighthand.txt"; //the path to the file where we want
the distances to be saved

        string message = frameNumber+"," + distance+"," + CosSimilarity+"," + "\r\n";




        if (!File.Exists(path))
        {
            File.WriteAllText(path, "\r\n");
        }


        File.AppendAllText(path, message);

       }
```

Annex

The NASA TLX form:

Mental Demand (Low – High)	How much mental and perceptual activity was required (e.g. thinking, deciding, calculating, remembering, looking, searching, etc)? Was the task easy or demanding, simple or complex, exacting or forgiving?
Physical Demand (Low – High)	How much physical activity was required (e.g. pushing, pulling, turning, controlling, activating, etc)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
Temporal Demand (Low – High)	How much time pressure did you feel due to the rate of pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
Performance (Good – Poor)	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
Effort (Low – High)	How hard did you have to work (mentally and physically) to accomplish your level of performance?
Frustration (Low – High)	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?