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Serious Game Augmented Reality 3D for Physical Rehabilitation

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TECNOLOGIAS
E ARQUITETURA

Department of Information Science and Technology

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Resumo

Esta pesquisa consiste no desenvolvimento de uma solução do projeto FisioAR baseada em dispositivos vestíveis, combinando um conjunto de sensores vestíveis e controlador de headset para uso em interações naturais com um conjunto de serious games terapêuticos VR desenvolvidos na plataforma de games 3D Unity. O sistema permite realizar treinos de reabilitação motora de mãos e dedos, joelhos e pernas tendo em vista que os jogos são para pessoas que sofreram AVC e devem ser tomados cuidados especiais com isso e que os jogos estão devidamente adaptados para serem mais simples. ser jogado.

Este projeto FisioAR tem em todas as implementações, dois aplicativos diferentes projetados, três tipos diferentes de jogos projetados no Oculus Quest.

Dois aplicativos diferentes foram construídos na plataforma Outsystems sendo um destinado a fisioterapeutas e outro a pacientes AVC.

Três tipos diferentes de jogos foram especialmente projetados no Unity Platform Engine e todos os jogos possuem conteúdos específicos para serem jogados.

O primeiro jogo denominado Boxes Game, tem seis cubos apresentados com cores diferentes e seis esferas também com seis cores diferentes. O principal objetivo deste jogo é colocar o número máximo de esferas em uma caixa com a mesma cor e com distância mínima percorrida. Este jogo envolverá o uso de pernas, joelhos e braços e pode ser facilmente adaptado às condições de cada paciente, tornando-o mais ou menos exigente.

O segundo jogo é chamado de jogo de cuidado de jardim. Seu cenário foi feito com pré-fabricados e materiais da loja de ativos da unidade para simular um jardim realista, com regador, cercas e um conjunto de flores. O objetivo principal deste jogo é regar as flores. Esse objetivo simples está relacionado à medição da rotação do punho feita pelo paciente por meio de sensores vestíveis ao regar cada flor. Este jogo é uma pontuação para cada flor regada.

No terceiro jogo, chamado Puzzle Game, há uma tela branca com o mesmo número de divisões que os blocos de imagem existentes no projeto.

Palavras-chave— Unity 3D, Oculus Quest, Realidade Aumentada, Reabilitação Física

Abstract

This research consists in the development of a PhysioAR framework (Augmented Reality Physiotherapy) that consider a set of two wearable sensors (Left Controller and Right Controller and Meta/Oculus Quest headset controller for use in natural interactions with a set of AR therapeutic serious games developed on the Unity 3D.

The system allows to perform training sessions for hands and fingers, knees and legs motor rehabilitation bearing in mind that the games are for people who have suffered from stroke. The training is part of special care that must be taken for this through the serious games that are properly adapted to be a source of motivation and easy to be played.

This FisioAR project includes, two different apps designed, one for calendar and for physiotherapists has a background data with all information needed to do and other to make login in main app and have the possibility to interact with our three types of games specifically designed, developed and implemented for Oculus Quest.

Two different mobile apps were constructed on Outsystems platform, where one is destinated to physiotherapists and other is destinated to AVC patient's.

Three Different types of serious games were developed on Unity Platform Engine and all the games have specific contents to be played according with motor and cognitive rehabilitation objectives.

The first game called Boxes Game, has six cubes displayed with different colors and six spheres also with six different colors. The main goal of this game is to put the maximum number of spheres in a box with the same color. This game will involve the use of legs, knees and arms and can be easily adapted to each patients' conditions, making it more or less demanding.

The Second Game is called Garden Care Game. Its scenario was made with prefabs (assets) and materials from Unity asset store to simulate a realistic garden, with a watering can, fences and a set of flowers. The main goal of this game is to care the flowers with water. This simple goal is related with the measurement of the wrist rotation made by the patient through wearable sensors while watering each flower. This game as a score for each flower watered.

In the Third Game called Puzzle Game, there's a white screen with the same number of divisions as the existing image blocks in project.

Keywords - Unity 3D, Oculus Quest, Augmented Reality, Physical Rehabilitation

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List of abbreviations

SG – Serious Game
AR – Augmented Reality
VR – Virtual Reality
WHO – World Health Organization
BLE – Bluetooth Low Energy
IMU – Inertial Measurement Unit
EMG - Electromyography
ECG – Electrocardiogram
AWS – Amazon Web Services
3G – Third Generation
4G – Fourth Generation
LTE – Long-Term Evolution
GSM - Global System for Mobile Communications
WIFI – Wireless Fidelity
OSS – Office of Strategic Services

Chapter 1 – Introduction

1.1. Topic context

The physical rehabilitation is a long and intensive process and is mostly associated to a person that has been suffered an accident or a stroke attack. Normally, traditional physical rehabilitation is a process that requires repetitive movements and during a considerable period (dependent of the patient's diagnostic). Extended rehabilitation period involves higher costs for SNS and for personal users.

To assure higher motivation of the patients during different type of rehabilitation a framework that may run serious games was considered as solution remote physical rehabilitation.

The proposed solutions avoid the drawbacks of the traditional rehabilitation methods are:

- heavy physiotherapy assessment equipment;
- high costs associated with long therapy periods and the need of fulltime physiotherapists;
- lack of objective evaluation of rehabilitation processes;
- Less or no feedback to the patients, no data record and no data analysis [1].

Most of the people have assisted to some therapy sessions and patient's face normally says that rehabilitation period was very dolorous with less motivation.

The framework that includes different APPs was developed for physical rehabilitation being characterized by more funny and motivational digital physical rehabilitation sessions. The produced data by the hardware component, headset and hand sensors are analyzed to provide information to the physiotherapist about the user outcomes during the physical therapy sessions. Thus, information about improved specific parameters such hand motion angles during exercises are considered.

These systems are personalized according to patient's needs and the specific that will improve or even heal wounds in the future, so in the state of art, I will focus my serious game augmented reality in Unity 3D in persons that has been suffered a stroke attack.

This fundamental words for my state of art mentioned above are explain below:

Serious Games means a computer game with extended propose that exclusively entertaining [2]. Digital games have the ability to engage both children and adults capturing their attention [3].

Augmented Reality systems merge computer generated virtual objects with real world objects scenarios instead of an all virtual world as in Virtual Reality.

This is possible by tracking and positioning virtual objects integrating them in real world [4]. In this system we aimed to use the acquired data from several sensors in an AR Scenario.

Stroke attack is a sudden cerebrovascular disease with a high rate of death and disability and is common cause of death and long-term disability.

Stroke occurs when not enough blood supplies are sent to the brain. Brain cells need oxygen and nutrients to maintain normal brain function.

The lack of blood supply to some parts of the brain results in the death of brain cells.

After stroke, it is difficult to perform daily living activities. Rehabilitation process it has an important role to train the remaining cell to take over their functions [5].

FisioAR framework includes serious game that combine augmented reality to help patients that suffered stroke attacks to progress more during the rehabilitation process.

The user interface was materialized by Oculus Quest (Oculus Meta) that allows to the patient to visualize the game that was developed in Unity 3D.

1.2.Motivation and topic relevance

I chose the theme FisioAR for my thesis because I've already an injury three years in my knee and I need to resort to physical rehabilitation to recover for my operation and I already know the importance of all recovery process and the resilience/persistence during this tough process.

It was an experience that will mark me for my life but that increased my strong personality and certainly that was the best knowledge to learn that life is full of obstacles and full of bad things. But if you have the right thought and the right feelings to overtake with only good vibes, the life will smile to you.

Also it's been proved that serious games is the capacity to increase diversity within training programs, which can aid in creating a fun and engaging "virtual" atmosphere and to engage and motivate the user to perform high repetition of task-oriented exercises that are required in motor rehabilitation existing needs to innovate and develop new solutions based on this excellent impact that serious games have on the entire process of patients.

Based on the joining of my own experience with the knowledge that I have been developed all over the years in course and my own experience in a traditional recovery process, I believe that was the perfect combination to develop this type of system for physical rehabilitation.

1.3.Research Questions

- Develop a serious game with two or three levels that could include exercises involving trunks and limbs.
- Ensure that game is safe for the patient that had suffered a stroke attack.
- Develop serious games characterized by requirements accomplishing for better design and higher acceptance.
- Develop a database to store data and later to be analysed data extracted from the physical therapy exercises carried out by patient.
- Use Oculus Quest as interface for AR experience.

1.4.Research goals

Is the system can be adapted to the person needs a normal physical rehabilitation treatment?

This system can be used by every person with motor impairments?

The FisioAR system can really improve the motivation of the patients for physical therapy sessions?

What kind of parameters can be provided to physiotherapists for objective evaluation of physical therapy sessions?

What kind of problems can be solved with the game experience or patient’s feedback?

How the augmented reality system for physical therapy will well accept as complementary equipment by physiotherapists community?

1.5. Methodologic approach

Design Science Research (DSR) is a research paradigm focusing on the development and validation of prescriptive knowledge in information science. It's mostly used for algorithms, human/computer interfaces, design methodologies (including process models) and languages.

The applied Research method includes:

1: Design as an Artifact should produce a viable artifact in the form of a construct, a model, a method, or an instantiation.

2: Problem relevance - The aim of Design Science Research is to develop solutions based on
in technology for important and relevant problems for companies
and institutions.

3: Design Evaluation - The usefulness, quality, and effectiveness of the artifact should be rigorously
demonstrated through well-executed evaluation methods.

4: Research Inputs Effective - Should provide clear inputs and verifiable in the areas of design artifact, design fundamentals and/or
or design methodologies.

5: Research rigor is based on the application of rigorous methods both in the construction and in the evaluation of the design artifact.

6: Design as a search process is the search for an effective artifact requires the use of available means
to achieve desired goals while satisfying laws in the environment
of the problem.

7: Research communication must be presented effectively to technology-oriented audiences and management-oriented audiences.

1.6. Structure and organization of dissertation

The present work is organized in nine Chapters, that intend to describe the different phases until its conclusion. The first and current Chapter introduces the subject of the investigation and contextualizes the reader about the project developed.

The second Chapter describes the current State of the Art, by presenting other related works and important concepts about this project.

The third Chapter is destinated to the Hardware Description.

The fourth Chapter is dedicated to the Software Description.

The fifth Chapter is related to the AR concepts.

The sixth Chapter demonstrates the 2 OutSystems Mobile Apps developed to a better use of the games by Physiotherapists and the users.

The seventh Chapter writes about the Databases options that was been considered clarifying why to choice was for MySQL workbench database framework.

The eighth Chapter shows all he results and make all analysis about the graphics generated by the presented results.

The ninth Chapter and final is destinated to the Conclusions and all the Future Work that will be made in order to increase this project prototype.

Chapter 2 - State of the Art

2.1.FisioAR - Augmented Reality Serious Game for Physical Rehabilitation

FisioAR platform supports Augmented reality serious game developed in the Unity 3D game engine.

Serious gaming is a novel form of educational strategy in the nursing discipline. There is no clear boundary between serious gaming and other educational technology such as virtual learning environments, digital learning objects and educational games.

In general, it refers to games used for training, simulation or education which can be run on computer devices. For purpose of this review, serious games are described as digital games, virtual environments, simulations and mixed reality and media which engage the player via narrative gameplay, encounters to inform and experiences to convey meaning [6]. The use of serious gaming is gaining popularity in nursing education. This review explores the existing serious games in nursing education in developing nursing competencies.

Augmented reality is an interactive and real-time technology that combines computer-generated images created by a specific software developed for this purpose with the real world and real spaces that human being coexists and lives and this technology allows an addition of virtual data to help people to evaluate and diagnose some important parameters for the research areas in which they are inserted such as tourism, entertainment, surgery, manufacturing, marketing and others [7][8].

Unity 3D game engine is a great platform and mostly used for designed and implementation for video games and some simples simulations. This is possible because Unity 3D offers multiple resources and multiple choices to developer chose the best solution and way to make your idea and have a great experience in visual terms, always trying to imitate as much as possible the reality of the movements that are being created virtually with the introduction of a lot of physics and multiple interactions, programming in CSharp in order to achieve all the components for a game to be fully functional and well designed.

Unity also allows a great experience in multiple and diverse platforms like Windows, Mac, IOS, Android and others and there's an essential plugin called SDK Vuforia created and developed specifically to be used in Augmented Reality serious game development and have multiple resources displayed in your library to easily do a great virtual environment for the game conception such as terrain creation tools, particle system, lighting rendering module and collision detection module [9].

Each of resources have multiple options and methods to change or modify this material for the specific goal that was idealized for developer.

With the Vuforia SDK plugin, developers can have a great and easy work experience in what they want to do with multiple resources and with multiple options displayed to transform, change or create virtual objects in 2D or 3D and also allows the opportunity to acknowledge objects and images or recreate real-world environments [10].

2.2.Stroke attack

In this section, a more detailed description will be made about the main accident that this practical project thesis will focus: Stroke attacks.

Cerebrovascular Accident or Stroke is very common cause of death and a very dangerous disease that could cause a large deficit or multiple disorders dependent of each case or situations [11].

This disease is very unexpected but with severe consequences such as in mobility of the stroke patients or irreparable damage to certain and specific parts of the body with a high chance of people even stop walking or moving upper or lower limbs.

According to WHO, each year over 15 million people suffers stroke with 33%-66% of stroke survivors having upper limbs associated problems, a giant and scary number considering this high percentage of have some disability after a stroke event [12].

Patient's strokes also lost simple and daily routine tasks such as cooking, bathing, dressing, running, eating, using telephone and others because this sudden accident have a real impact in anyone and no one can be safe and aware that a particular event or action cannot have serious effects or consequences with this type of occurrences [13].

Associated with these sudden changes in daily routine can be other problems with a negative and a very prejudicial impact in stroke patient's because after cerebrovascular accident, patient will have to face a lot of recovery process and multiple new things and routines in daily routine and all this changes can cause easily mental problems such as anxiety, marked demotivation, depression or even a cognitive loss [14].

So, I have mentioned above some and important facts that a stroke attack can cause in physical and mental aspects. For that reason, is essential to have a fast and well-oriented control immediately after an attack of this type occurs and speed of the post stroke process is vital for a quick and efficient recovery.

After a stroke event, the patient has to be a quick intervention a has to stay in total rest in a hospital with the supervision of specialized people (doctors, nurses and physiotherapists) [5].

They stayed in a specialized unit with diary specific plans and always well oriented and with the supervision of a medicine professional.

After the doctor have the opinion that patient can return home, a specific recovery plan for the affected parts is started.

These exercises will be followed by physiotherapists and will be performed, preferably, at the patient's home to have the maximum possible comfort during them.

For a great and effective recover therapy there's some fundamental aspects to consider: a constant, proactive and mobilizing patient's motivation, a good intensity in each exercise and a well-oriented training with repetitive movements to improve slowly some specific and affected area of the body [5].

However this traditional conventional physiotherapy has some fundamental drawbacks: time, money and lack of measurements.

And for these reasons, in recent times have been designed and thought multiple solutions like play games during a therapy session to solve this problems and because it's more funny if we related with mental part [13].

A lot of studies have supported this theory that a virtual environment can increase and improve the patient's rehabilitation during the sessions.

In a specific study [15], 312 stroke survivors was evaluated and only 31% of them has realized their recommended rehabilitation plan and with a few people this small percentage in a big scale is easy to conclude that in major part of the cases the traditional physical rehabilitation is not done correctly.

To mitigate and try an efficient solution as I mentioned above, the use of new technologies will represent a complementary solution taking advantage not only of new technologies but also bypassing the lack of professionals, saving time and money.

2.3. Physical Rehabilitation

In this section, it will focus about the main purpose that this FisioAR project will be developed: physical rehabilitation for stroke patients.

Physical rehabilitation is mostly part of times necessary and used to recover patient's that have suffered accidents whether with less or greater severity in order to keep patient's wellness and regenerate all the ailments left by the same accident as best as possible considering the severity and condition of the victims.

Most of the situations, physiotherapists have to use multiple resources to know with the best precision the development and the improvement of each patient according to initial diagnoses, so they use some measurement material and perform some important tests in a defined sequence to have a good evaluation of the recover process and to keep the patient motivated to do different and much more difficult exercises specifically designed for the problems needs to treatment and repairment.

The concepts of physical rehabilitation and functional training which are proposed by [17] as follows:

1) It should be patient-centered and consider the needs of patients for functional rehabilitation;

2) Functional training should be linked to the patient's daily life, focusing only on the training of functional activities;

3) Patients should be encouraged to perform functional activities as often as they can, instead of being limited to 5% of the daytime daily, under the guidance of the therapist; it is best to keep the patient in a skill learning environment.

However, and focusing now on the main accident that will affect the FisioAR project, stroke patient's associated to a neurological deficit, usually have flaccidity or muscle weakness post stroke event and spasticity which stops the use of weakened muscles and leads to poor motor control.

Spasticity and motor control can lead to muscle imbalance and disturbance of the antagonist and agonist muscles.

In addition, prolonged immobility associated with the stroke event may also generate some contractures and more weakened muscles.

To increase this drawbacks most of patient's stroke have to stay in bed to proper recover process and alone in major cases, so to solve this problems there's a novel of solutions using the expansion of the technology as the principal mechanism to innovate and improve patient's stroke physical rehabilitation, being the FisioAR project one of those multiple projects that aims to remove all these revealing and essential problems for a person with special needs that these stroke patient's requires.

Physical therapy is a medical branch that focus on the rehabilitation of motor condition for patients after different types of accidents including stroke events. The physiotherapists also are assuming leadership roles on health maintenance, wellness and fitness of their patients.

Considering in particular the physical rehabilitation process for patients who suffered stroke events, it is characterized by long period of physical training associated with high costs for patients and society.

The rehabilitation is strongly dependent to the frequency and effectiveness of the physical rehabilitation sessions, and in these conditions the remote physiotherapy self-training at home represents a complementary a successful solution, that contribute for reduction of the rehabilitation period.

Self-training based on classical rehabilitation processes always require professional supervision and the usage of equipment that doesn't provide any type of information regarding the rehabilitation process. In the last decade the physiotherapist community and the physiotherapy services users have been increased the interest for novel solution that apply information technologies in physical rehabilitation field.

Physical therapy such as stretching the joint to reduce joint stiffness and spasticity and active motor control training to improve the capacity to recover balance and locomotion are important components of treatment. This, however, is labor intensive and may not be conveniently available to patients post stroke.

2.4. Types of Smart Sensors

In this section I will address several smart sensors that can be added and can be an alternative to the sensors and the hardware used in this practical project in order to enrich the FisioAR project with data that will help to understand the evolution and improvement of a stroke patient.

1- Inertial Measurement Unit (IMU)

In [19] we have an smart sensors called Inertial Measurement Unit (IMU) Flora LSM9DS0 9DoF IMU. This sensor has an accelerometer, a gyroscope and a magnetometer, with 3 axes each one, and it's widely used as a motion detector in GPS navigation correction, virtual reality (VR) and robotics. The IMU presents a I2C communication interface and connected to the Lilypad Simblee providing information about patient's orientation and displacement.

This component, presented in Fig.1., can be a good alternative to our hardware IMU measurement chose because with IMU we can measure X,Y,Z information about the patient in order to treat and to evaluate them during all process rehabilitation recovery.

The main disadvantage of these components is the local to put these hardware's because it probably will limit the patients' recovery and it's a better idea to have all the members and body parts free of any external material that difficult any types of movements because it will also influence the value in the sensors and it's not good to our results, expectations and analysis.

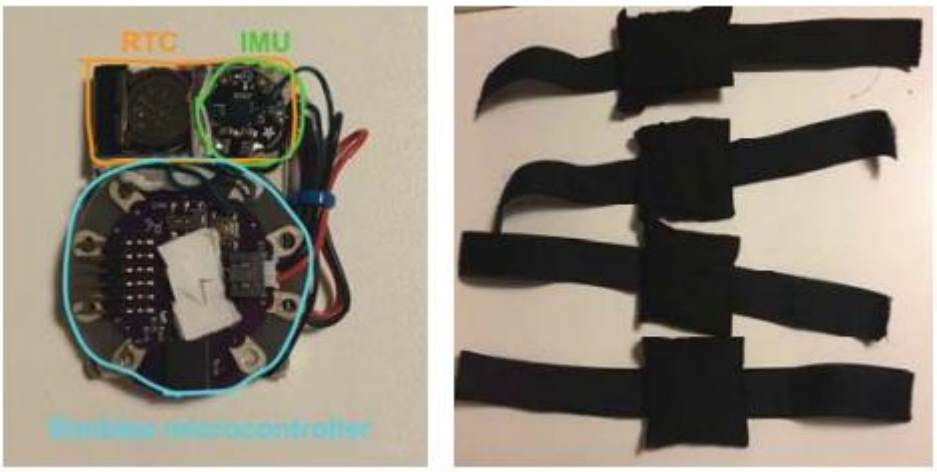

Fig.1. System prototype: a) smart sensor prototypes; b) wearable sensor cases.

2- Smart Gloves Interface

In [20], the computing platform of the smart gloves is an Arduino Nano board based on an Atmel AT-mega328P microcontroller that has 10 bits ADC and 8 multiplexed analog inputs. The gloves are equipped with an IMU MPU-9250 with a gyroscope and an accelerometer to capture the rotation and speed of the hands. It also incorporates an AK8963 magnetometer. The IMU is connected to the board's SPI port. Each glove (Fig.2.) contains 5 Flexi Force A201 sensors for extracting force values, and 5 FlexSensors 2.2, for obtaining bending values. Each of these sensors is inserted in each finger of the glove.

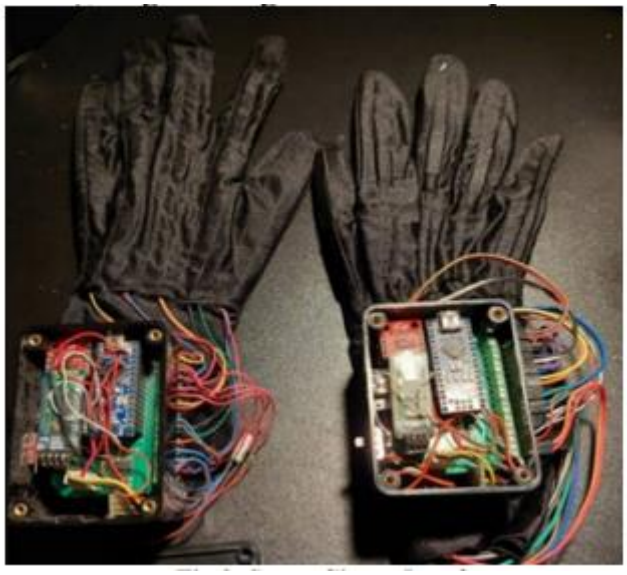

Fig.2. Smart Gloves Interface

This component can also be a good alternative to our hardware wearable sensors controllers chose because with IMU we can measure X,Y,Z information about the patient in order to treat and to evaluate them during all process rehabilitation recovery.

Also, the same disadvantage because will have a strong probability of limit the patients' recovery hands and it's a better idea to have all the members and body parts free of any external material that difficult any types of movements because it will also influence the value in the sensors and it's not good to our results, expectations and analysis.

These hardware components are quite heavy and to play a game of this design and with the Oculus it is necessary that the area be of considerable size so as not to interfere with the patient's movements.

3- Motion Measurement Unit

This type of smart sensor allows to the user measure the velocity and your motion during a specific therapy session, including a smart carpet on the floor to measure and to extract all these parameters.

This smart sensor called SensFloor (Figure 3) it's very useful to use in closed spaces and where the space is well defined so the patient performs his movements within the perimeter of the smart carpet.

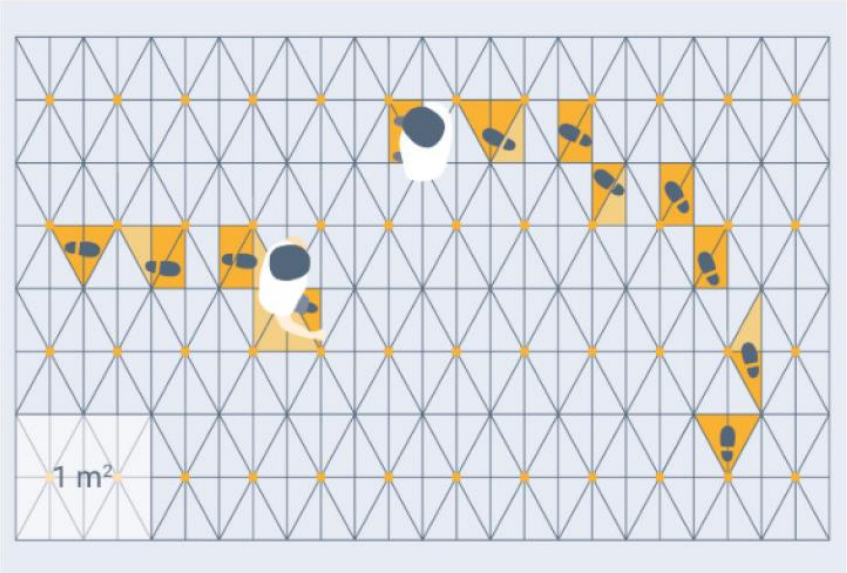

Fig.3. Smart Carpet -Motion Measurement Unit

For our project it's a good idea to measure the distance that patient perform during the game played in the time consider. Not yet implemented this distance measure but in the future we will use this component so it's important to make a reference about that.

4- Actuator

An actuator (Fig.4.) helps and a have precious function in patient's that have suffered a severe and serious injuries in skeletomuscular or neurological part of the body with the necessary power to stimulate and to be able to do the rehabilitation exercises.

This stimulation will help a lot during the therapy and rehabilitation sessions.

To realize this actuator, the micro-fabrication process used is based on double-side etching process. An SOI wafer with a device layer thickness of 50µm is used. The electrodes and the U-shape springs are built in the device layer using photolithography and deep reactive ion etching process (DRIE).

The system is a compromise between a classical capacitor plate actuator and a zipper actuator [21, 22]. Since the system's response is sequential, it can be used as an analog to digital converter (AD). [23]

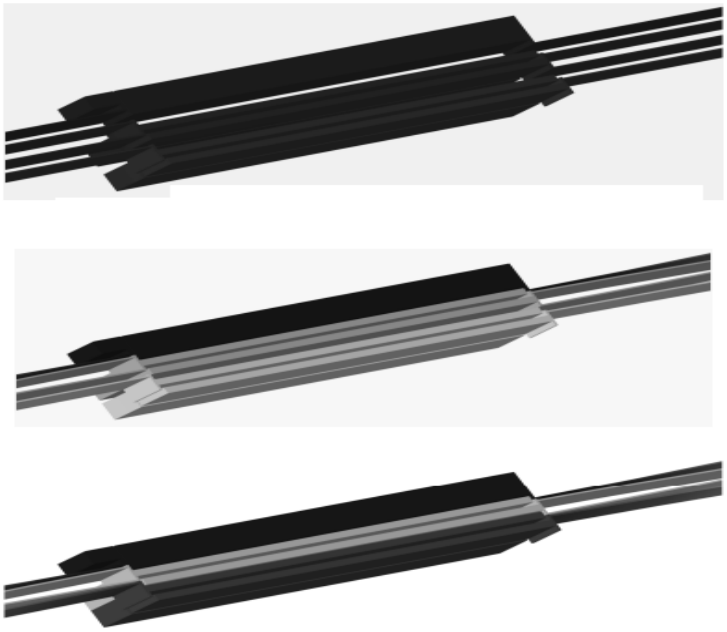

Fig.4. 3 different Actuators Examples

5- Virtual reality head mount

A good example with Virtual head mount has been applied to learning to play the piano as a use case (Fig.5.). A total of 33 piano students participated in a study to compare participants' interpretation outcomes and subjective experience when using a MR application for learning piano with two visualization modes (border lines on all the keys (Wireframe) vs. solid color hiding the real keys (Solid)). The two visualization modes provided a satisfying experience. Even though there were no significant differences in the analyzed variables, the students preferred the Solid mode, indicating that short-distance Passthrough limitations should be minimized in application development.

In this example they also implement Passthrough API that are applied for Mixed Reality experience during the game playing like this FisioAR projects. [24]

Fig.5. Photograph of a user playing the piano with the application and what she is seeing superimposed (blue and green) and the C keys (orange).

6- AWS Cloud Server

Amazon have been developing a very useful and great state of art cloud services suitable for a lot of purposes with a good focus in IoT area.

It also presents communications capabilities such as 4G LTE, 3G, GSM and WIFI that makes an Internet connectivity possible in several conditions making it easier to connect to our Cloud App.

Amazon also provides a great layer of security which is very important IoT systems like this since we have sensible patient health data.

AWS IoT Core Platform (Fig.6.) is a cloud vendor that helps with data management and rich analytics of IoT devices. It is highly secure with multilayer protection and is a free service included with an Amazon AWS account(which is paid). Bi-directional communication between internet connected devices such as sensors, microcontrollers, smart appliances with AWS Cloud is made possible. [25]

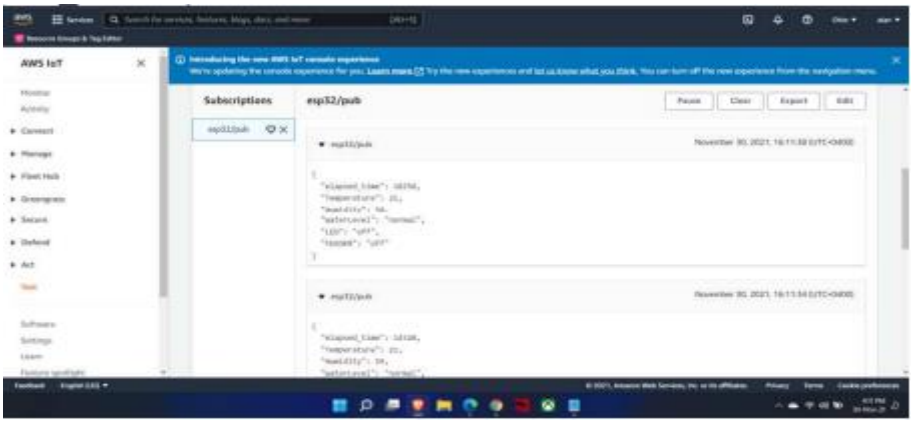

Fig.6. AWS IoT Core platform

2.5.Virtual Reality, Augmented Reality, Mixed Reality

As already noted in the previous sections, traditional physical rehabilitation is a very boring type of training that greatly influences the effects of rehabilitation and the recovery time of the stroke patient.

The physical rehabilitation of suffered an accident or a stroke attack is a long and intensive process in order to upturn to normal condition or at least an acceptable state of physical motion.

This process entails high cost of both time and money for the patient, but this cost is generally increased when the patient feels demotivated which leads to extended rehabilitation periods. [20]

Therefore, Virtual Reality (VR) [26] is a new technology with quick development that can be used in the field of physical rehabilitation.

Using the new and proliferating technology in constant evolution, together with multi-sensors it allows an excellent interaction between the virtual world and the reality of the environment in which we live.

Applying VR to rehabilitation therapy makes rehabilitation training more fun [27] and therefore leads to an increase in patients' enthusiasm and motivation during one or more rehabilitation training sessions.

In the late 1990s, researchers began to apply VR to the field of brain injury therapy and psychotherapy [28-29].

Another approach to mitigate the problem mentioned above about the traditional rehabilitation process is Augmented Reality (AR) technology.
Augmented Reality (AR) technology [30] is derived from VR technology through the tracking and positioning of computationally virtualized objects and for that reason they can be perfectly integrated into the real world.

An example of an augmented reality system is the combination of tracking algorithms and the real-time overlapping of ellipses in the recorded position of the patient's hand.

But there are many other examples, such as the FisioAR project, which as mentioned above, focused on the treatment of stroke patients needing extra care in choosing the different types of games, the different materials to use and the best strategies to use. defined for a good collection and treatment of the data that need to be analyzed.

Regarding mixed reality, it creates a space in which both physics and virtual elements coexist, allowing easy interaction between the two, which can be quite useful in robotics applications, since it creates a platform that allows the development and testing of algorithms of control.

Mixed reality system can be defined as a system that:
• combines physical objects in at least one physical environment and virtual objects in at least one virtual environment;
• works interactively (often called real time);
• spatially maps physical and virtual objects together.

2.6.Related Works

2.6.1. Technological Approaches to Stroke Therapy

In recent times, multiple technologies and technological approaches to stroke have been developed and tested with the primary aim of increasing the fidelity of the use of materials.

Regarding this topic, several systems may be considered:
• constrained-induced movement therapy
• Robotic training system
• Sensor-based system with wearable systems included

In CIMT the stroke patient wears a device on the healthy arm for a long time, thus limiting the movement of the healthy arm and the affected arm is used [31].
Another approach is the robotic training system. Robotic technology was started 15 years ago. At that time, the scientific evidence that supported rehabilitation approaches was inadequate [32].
It should be noted that this technology allows therapists to work with many stroke survivors simultaneously, due to the advanced calculation of robotic technology.

The sensor-based system is another alternative approach that can be attached to the body part or clothing and may include wearable systems in clothing made of fabric, which will open numerous potentials in the field to monitor the patient's progress during the therapy session [33].

The ability of existing commercial games for stroke rehabilitation has been tested by some research in the therapy community. Motion-based input device games, such as the Play-station 2 Eye-Toy [34] and Wii Sports [35], have been used in studies of stroke therapy.

However, these games lack inspiring interactive gaming experiences to engage the patient and are too complex and expensive to use at home [36].

One good example about Technological Approaches to Stroke Therapy is presented [37] in 2005 and consists in a multi-tier telemedicine system and a WBAN network for computed assisted rehabilitation applications and ambulatory monitoring performing real-time analysis of sensor data.

In 2010 an Adaptive Mixed Reality Training System for Stroke Rehabilitation was reported [38] which consisted by a system for helping people who have hemiparesis.

In 2017 a hands rehabilitation system that uses Leap Motion Controller as natural user interface for a serious game was presented [39] the remote detection of the motion being captured with high accuracy but no information about the muscle activity was extracted.

A. Tea pouring game

In this game, the patient holds an object that simulates the representation of a virtual kettle, aiming to move the designated position, maintaining it for a certain period, simulating the tilting of the 'kettle' to pour water into an empty 'cup'.

With the coordinates calculated in real time, the system evaluates whether the ‘kettle’ has reached the designated position.

We describe this Tea Pouring Game (Fig.7.) because your main purpose is very similar to the Garden Care Game developed in this project related to the movements that the player has to do when he put the tea in the cups.

Comparing this game to Garden Care Game we have more Game Objects interactions and more environments features to a better game experience and a good external environment between the player and the game.

Fig.7. Tea Pouring Game

A Kinect-based Augmented Reality Game for Lower Limb Exercise

This is an augmented reality game in which 4 moles are displayed on the stage and each mole appears and disappears moving up and down at random.

Each step on the mole increases a count, and when it is stepped 10 times or more, the speed of the mole's appearance becomes slightly faster when it resumes.

The main objective of the game is to understand how many moles can be stepped on in a total of 60 seconds.

Other Similar Solutions of PhisioAR Project

The mixed reality and IoT technologies are frequently used as part of smart physical rehabilitation. Thus, in [40] is presented a solution for physical rehabilitation of upper limbs using technologies such as mixed reality (MR) and Internet of Things (IoT). In this case a set of serious games were developed using Unity for MR scenario. The Meta Quest 2 was used as MR interface. Additionally smart sensors inserted onto a pair of gloves that are used to perform real-time of force and acceleration during training sessions .[40]

Other reported solutions are referring the solutions based on virtual reality (VR) for physical rehabilitation of upper limbs where therapeutic serious games are considered. The interaction with VR scenario is caried out using smart sensors embedded in a headband and gloves. [41]. Smart equipment for physical rehabilitation assessment is reported in [42].Thus, during gait training a walking aids is used by the patients affected by lower limb impairments. The system can deliver information that can be used on VR or MR scenarios associated with serious games for physical rehabilitation.

The smart physical rehabilitation becomes a new reality and challenge regarding the technology adoption by the users increased costs. In this context in [43] the authors are presenting a smart physical rehabilitation system that combines augmented reality serious games and wearable sensor network to improve the patient engagement during physical rehabilitation.

An interesting solution is reported in [44] that describe a measurement system and methodology for motor rehabilitation of hands and fingers. The interaction with serious games developed in Unity 3D game engine is performed using a natural user interface based on Leap Motion Controller.

What´s brings new in the proposed solution is the functionalities of the patient's APPs has the interaction and the possibility to adapt the game area for you and to have the best place to do all this rehabilitation process and this three different games that have the main objective of patient has different types of recovery such as: cognitive and motor rehabilitation.

Garden Care Game is a game more specific for motor rehabilitation, Box Game is destinated more for cognitive rehabilitation and puzzle game as this two important types presented in your game area.

2.7. Serious games development software technologies

In this Section we have some different platforms that could be use has engine to develop this Project such as Godot, Stride, Unreal Engine 4 and CryEngine and also write some advantages and disadvantages about each alternative platform mentioned and why we chose Unity 3D instead of this ones.

A comparison of capabilities of these technologies was considered.

Why Unity 3D is best alternative for developing Mixed reality games?

Before choosing Unity as my final option for carrying out this practical project, I first considered my experience with this game engine, where I had previously developed other types of games and where I felt more comfortable carrying out a more complex

project. and with different and new challenges to overcome, such as using Oculus Quest and Mixed Reality.

From this starting point, I then went in search of different solutions that could be more useful and easier to use than Unity in the development of this FisioAR project.

After some research I found 2 reference documents that made me consider in order to be able to compare all the tools.

I also saw some comparison videos of each of the Games Engines that will be described here and I will number some of the points considering the criteria used in [45] for the best choice of a Game Engine in the realization of a Serious game.

The general criteria that were defined in order to carry out the comparison method were 3:

- Software
- Development
- Acquisition

For Software we have 4 different aspects of analysis:
Audiovisual display

- Rendering
- Animation
- Sound
- Streaming

Functional display

- Scripting
- Supported AI
- Physics Engine
- Event Handling

Combinability

- Component export/import
- Development tools

Networking

- Client-Server
- Peer-to-Peer
- Heterogenity
- Multi-platform support

For Development, we considered the aspect of Accessibility and the ease of using objects from different sources and making them compatible:

- Documentation
- Support
- Code Access
- Introduction Effort

For Development we considered other aspects regarding Accessibility:

- Licensing
- Cost
- System Requirements

And for distinguishly each one of this aspects we use two different colors to define an advantage or a disadvantage for each engine considered:

Advantage
Disadvantage

After these criteria, we proceeded to compare Unity with the other game engines considered through the research that was carried out:
The first two game engines to be analyzed are called Godot and Stride and have as an important characteristic that they are 2 engines that were developed and published more recently.

Godot

Fig.8. Godot Framework

Software	Development	Acquisition
Audiovisual display - Rendering - Animation - Sound - Streaming	Accessibility - Documentation - Support - Code Access - Introduction Effort	Accessibility - Licensing - Cost - System Requirements
Functional display - Scripting - Supported AI - Physics Engine - Event Handling		
Combinability - Component export/import - Development tools		
Networking - Client-Server - Peer-to-Peer		
Heterogenity - Multi-platform support		

Table 1 – Different components considered for Godot

Stride

Fig.9. Stride Framework

Software	Development	Acquisition
Audiovisual display - Rendering - Animation - Sound - Streaming	Accessibility - Documentation - Support - Code Access - Introduction Effort	Accessibility - Licensing - Cost - System Requirements
Functional display - Scripting - Supported AI - Physics Engine - Event Handling		
Combinability - Component export/import - Development tools		
Networking - Client-Server - Peer-to-Peer		
Heterogenity - Multi-platform support		

Table 2 - Different components considered for Stride

CryEngine

Fig.10. Cry Engine 3D Game Environment Example

Software	Development	Acquisition
Audiovisual display - Rendering - Animation - Sound - Streaming	Accessibility - Documentation - Support - Code Access - Introduction Effort	Accessibility - Licensing - Cost - System Requirements
Functional display - Scripting - Supported AI - Physics Engine - Event Handling		
Combinability - Component export/import - Development tools		
Networking - Client-Server - Peer-to-Peer		
Heterogenity - Multi-platform support		

Table 3 - Different components considered for Cry Engine

Unreal Engine 4

Fig.11. Unreal Engine 4 framework

Software	Development	Acquisition
Audiovisual display - Rendering - Animation - Sound - Streaming	Accessibility - Documentation - Support - Code Access - Introduction Effort	Accessibility - Licensing - Cost - System Requirements
Functional display - Scripting - Supported AI - Physics Engine - Event Handling		
Combinability - Component export/import - Development tools		
Networking - Client-Server - Peer-to-Peer		
Heterogenity		

- Multi-platform support		

Table 4 - Different components considered for Unreal Engine

Unity 3D

Fig.12. Unity Engine Logo

However, I chose Unity 3D as a working tool for the FisioAR project as it is a tool that I have already worked with and in which I consider it easier to accomplish all the intended objectives and it's very easy to integrate the project developed and implemented in Unity 3D with an Android Platform like Oculus Meta Quest.

Also it's very easy to add any new Game Object or testing new features with the existing Game Objects and Unity has a great Asset Store where we can find really good Objects and Materials to make great games and adaptation to our needs and our ideas about the implementation concepts with the Unity Asset Store web page.

Software	Development	Acquisition
Audiovisual display - Rendering - Animation - Sound - Streaming	Accessibility - Documentation - Support - Code Access - Introduction Effort	Accessibility - Licensing - Cost - System Requirements
Functional display - Scripting - Supported AI - Physics Engine - Event Handling		
Combinability - Component export/import - Development tools		
Networking - Client-Server		

- Peer-to-Peer		
Heterogenity - Multi-platform support		

Table 5 - Different components considered for Unity 3D

To learn the basics of how to work in Unity 3D, I switched to Course Preview 3D games with Udemy's Unity + multiplayer mode following my advisor's advice.

Below are some of the topics that I found most relevant to apply them later in the practical FisioAR project.

- Section 1: Introduction, time: 21 min.
- Section 2: Programming in CSharp, time: 4h35min.
- Section3: 3D objects, time: 2h41min.
- Section 4: Light, camera and action, time: 2h23min.
- Section 5: 3D object movement, rotation and scale, time: 30 min.
- Section 6: 3D Physics, time: 4h22min
- Section 8: Bonus Section, Duration: 5m
- Section 9: Export and Import of animated models, Duration: 1h27m
- Section 10: Triggers, Duration: 43m
- Section 11: Creation and destruction of PreFabs, Duration: 40m
- Section 12: Particle System, Duration: 3h9m
- Section 16: Particle System, Length: 35m
- Section 17: Last Adjustments to the Character's Shot
- Section 18: Navigation
- Section 21: Render Pipeline

2.8.Game Planning

Since Oculus Quest, glasses that will be used to make the game play in Augmented Reality 3D with application in physiotherapy, come with wearable sensors with application in hands, this will allow not only greater interaction with the user as it will allow a better and more efficient development of the system, achieving not only a more realistic approach and incorporation of virtualized objects with the whole real environment and all the components that are inserted in the real environment.

The first objective when the FisioAR thesis started to be idealized was to develop a serious game that could cover the 3 parts of the body: head, trunk and limbs.

However, and after a more realistic analysis of how to carry out this project with all the required requirements and also realizing that the movement of the legs would be natural with the course of the game due to natural movements that extended according to each intended movement. We concluded that it would be better to develop 3 types of games that required the movements of the head and upper limbs only.

For 1st, 2nd and 3rd type of game, the main objective will be to move both the upper and lower limbs and then some of the suggestions below will be presented:

• Make a certain type of shapes that is on the screen, joining all the pieces that are distributed in the mapping of a given room (the objects will be grabbed and placed through the wearable sensors).

• Play a game of bowling in Augmented Reality.

• Make a game to pick up the desired objects and try to avoid the unwanted objects.

• Make a game where objects will be placed in a box according to their color and you will have a time limit to place all objects in their boxes.

• Make a game where the balance will be tested using a fictitious rope, whose main objective is to try to pass the whole rope to the other side! (using the accelerometer)

Additional Suggestion:

• Make a game whose main objective is to try to apply a visual memory game to test the patient's memory capabilities!

Here are some suggestions that I devised for the game designed for the FisioAR thesis!

Chapter 3 – System Description: Hardware

3.1. FisioAR Project Hardware Description

In this chapter we will explain all hardware parts that make this rehabilitation system work.

For the development of these three different types of Unity rehabilitation games, essential technology was used to make all these games worked properly in Oculus Quest environment: Android Platform system compatibility allows an easy passage of the game between development mode (Unity 3D) and testing or playing mode (Meta Quest Oculus.

3.1.1. Oculus Quest and two wearable sensors integrated

Oculus Quest is a virtual reality (VR) headset developed by Oculus, a brand of Facebook Technologies, released on May 21, 2019.

Similarly to its predecessor, Oculus Go, it is a standalone device that can run games and software wirelessly under an Android-based operating system. It supports positional tracking with 6 degrees of freedom, using internal sensors and an array of cameras in the front of the headset rather than external sensors. The cameras are also used as part of the safety feature "Passthrough", which shows a view from the cameras when the user exits their designated boundary area. A later software update added "Oculus Link", a feature that allows the Quest to be connected to a computer via USB, enabling use with Oculus Rift-compatible software and games.

The interface Meta Quest was chosen as reliable interface for the user that perform the motor rehabilitation considering the AR scenarios and interactions.

Based on this MR the user act in a virtualized world, being concentrated on the game objectives.

Meta Quest is characterized by built-in wearable sensors that helps to make more usable for the user during the training session.

This technology gives users the opportunity to develop their own application programs that can be customized and installed into oculus devices, in this case Oculus Quest is a standalone virtual reality headset (Stand Alone) without the need for a PC to run the application program, so engine to run the program is integrated in the device which is basically based on android with extension (.apk).

As a developer, users must set the device into development mode through an oculus application that is installed on a smartphone device. The device connection process with the Oculus application is done in the same Wi-fi network, so the application can detect the Oculus Quest device that has been activated then in the

developer option settings it is activated so that Oculus can receive the application program.

For a greater understanding and perception of how these technologies make all the difference in this work, some reasons will be list below:

- 2 wearable sensors to helps patient and other users to a better interaction between real world and the virtual objects specially designed and created for the concept of this practical project: gives to the AVC's patient the best recovery for your problem with maximum motivation, entertainment and security in all this long process.
- Four cameras incorporated helping us to implements AR environment in your game.
- Great AR experience with a great interaction between the virtual and real objects
- Great wearable sensors that allow the patient to make the interaction between your actions and the virtual objects movements.
- An easy interaction between the Unity Game Objects development and implementation and the usage of Oculus Quest
- without any complexity in put the games into the Oculus for testing and playing because of the Android Platform incorporated in the System.

Fig.13 and 14. - Oculus Quest and two sensors hand commands

For this project, we chose to work with the Oculus Quest to offer a reliable interface for the user under rehabilitation considering the AR scenarios interactions.

This AR oculus engine has some sensors incorporated to help the physiotherapist to collect all the information needed to your work or project implementation. In our case, we use this sensors to collect data from patients such as our rotation and position during the game playing, treat that data, save that data into a database and store that data in Physiotherapists App to proceed your analysis, storing this information in a calendar that has the information about each patient that physiotherapists in your list work planning.

Oculus Quest are characterized by the following sensors::

- Inertial Measurement Unit (IMU) (Fig.15. a))

- Four Cameras (Fig.15. b))

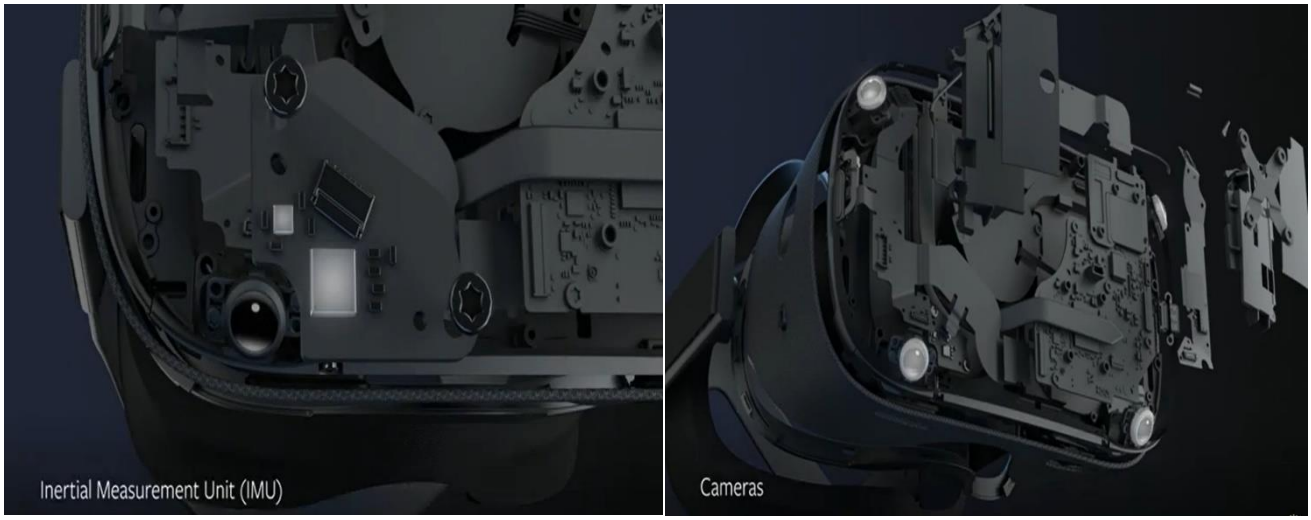

Fig.15. a) Inertial Measurement Unit (IMU) b) Oculus Quest Cameras

- Controller IMU (Fig.16. a))
- Constellation Leds (Fig.16. b))

Fig.16. a) Controller IMU in thesensors hand commands b) Constellation LEDs in two sensors hand commands

This engine places the user in a virtualized world, disconnecting and essentially concentrating on the game itself with all the graphics that Oculus Quest offers us to put all kinds of games in augmented reality to work, it makes the programmer's job much more rewarding and spectacular.

The fact that it also has built-in wearable sensors also helps a lot to make it more accessible on both, the developer and the user side.

On the programmer's side, it makes all the automation of gameplay processes much simpler, such as grabbing objects, throwing objects around, due to the Oculus Integration package already having these functionalities ready to be used.

On the user's side, since with wearable sensors it can have a greater sense of the space in which it is located compared to the virtual objects found in the game made in Unity 3D (Fig.17. a)) and combined with the sensors incorporated with Oculus Quest (Fig.17. b)), the patient can have a great interaction with the virtual reality and with the 3D environment X,Y and Z, the essential 3-axis to create the game Objects for the games and to measure all the data needed and treated for physiotherapists analysis and to verify the evolution of the patient.

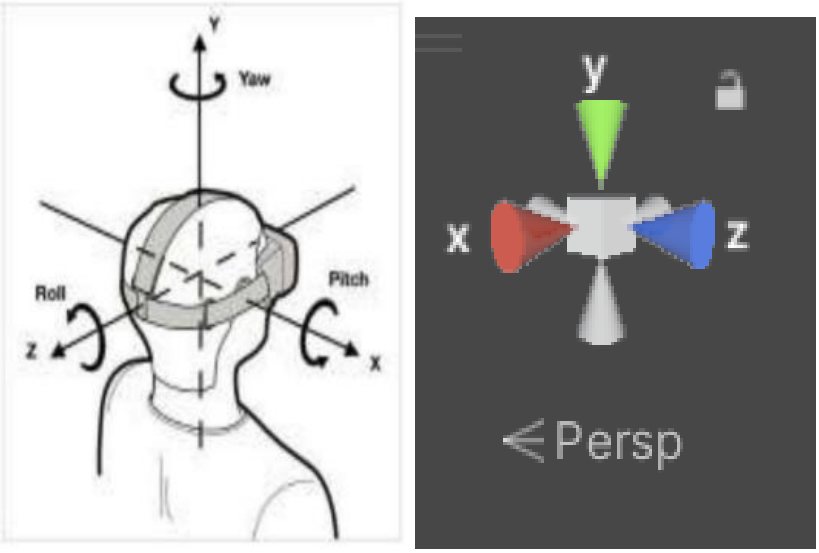

Fig.17. a) 3-Axis Perspetive from Oculus Quest b) 3-Axis Perspetive from Unity 3D

Chapter 4 – System Description: Software

4.1. Introduction

In this chapter we will explain all software parts that make this rehabilitation system work.

Today's advanced information technology, the everchanging types of computer games with the adjustment of quantifiable parameters add more fun and useful degree. A lot of elements are frequently added to these types of games such as Score, Buttons and different materials and textures that all worked in the right way gave to the player a grateful experience and an amazing will to play more and more, the basic concept that made a game a great and sustainable product to put in the market and make good profits with these ideas.

These can be quantified features, coupled with manipulation of interface modification, and could be making the computer game entertainment to enhance the treatment tool [46].

Based on the treatment of the hand rehabilitation and the stimulation of the patient motivation, the AR gaming system should have the following functions:

(1) high performance: the different strength of user hand activities can be received and processed immediately by the app previously installed in Meta Quest.

(2) high interactivity: Meta Quest will give the user meaningful information feedback immediately also with our Android Platform System Implemented.

(3) easy gameplay: easy menus for an easy interaction with all users of this project

(4) maximum security of patients: an AR functionality for a better security for this patients and with all the prevention during the gameplay.

(5) great Support Apps: Two Apps for the 2 Users of this Systems: the users and the physiotherapists and for an adaptation of each patient with the Photos that can be chosen for your free preference.

4.2. FisioAR Project Software Description

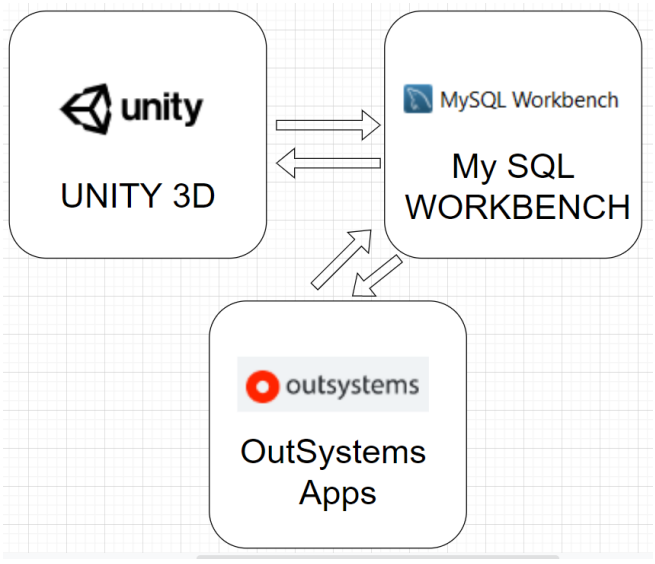

Fig.18. PhysioAR Game System

For the FisioAR framework were developed three different types of serious games (each one with different implemented scripts destined to specific actions during the game), two apps and a database to save all relevant data (Fig.18. schema).

For the development of these three different types of Unity rehabilitation games, essential technology was used to make all these games worked properly in Oculus Quest environment: Unity 3D, OutSystems and mySQL Workbench.

PhysioAR Game System are integrated all these games and apps specifically designed for the necessities of AVC patient's and to make a good performance between the two apps and the 3 unity games was essential to include a Database that will connect all data and all information inserted and collected both for the data collected from the sensors and for the data collected in the app for stroke patients.

In the same database that is designed in MySQL Workbench, there are different tables defined where the data coming from the Unity game for the app, as well as the data that carry out the inverse path, are duly stored.

Unity 3D are specialized game platform that gives to a gamer programmer and to designer easy ways and materials to help to do all maps and all features that games thought will include and all concepts previously defined and well organized and discussed.

Outsystems is a company that designed also easy ways to help programmer to do the same things with less of expensive time and with a lot of "boxes" that include code already realized and well tested help to a person with less acknowledgement or experience time in programming or a specific language the possibly to do really good jobs with your frameworks that are available after install Outsystems App.

But first of all, you have to install some important features in order to make the game functional and for that you have to install Oculus app in your phone, in this app you have some great information about the battery of your wearable sensor and the battery of the headset sensor and some great other things. With this app you can also allow to visualize the game in other tv on other device to play and allows other person to visualize all the contents of the game itself.

Also, you have to install and initialize with the Facebook account, the oculus developer app to create your app (Figure 26) and to create the application ID, very important because you have to put this code in this here (Figure 28) in the Unity Engine and you have to install the Oculus Integration App that can be found in the asset store of the Unity Game Engine.

The software used for the development of all games components such as the Game Objects presented in each game was Unity 3D version 19.4.28 with Oculus Integration package from Asset Store to implements VR and AR in this project, Oculus App and Oculus for Developers Account and Visual Studio and C Sharp Language for all source code implemented.

For a greater understanding and perception of how these technologies make all the difference in this work we will explain all these softwares below.

4.3. Unity 3D version 22.1.23

Unity 3D is an engine platform for Games Development. It is a good environment very easy to put new different Game Objects displayed in 3D space, a lot of options to configure and change the game objects behavior according to the gameplay of the game and what we intend to extract from each object in it.

It also provides the game programmer a diversified asset store where we can find several indispensable products for a faster, more effective and visually attractive job. Android SDK is essential because Oculus Quest is an Android widget facilitating the process of transferring the modification made in Unity to the Oculus Quest device that is connected to our personal computer.

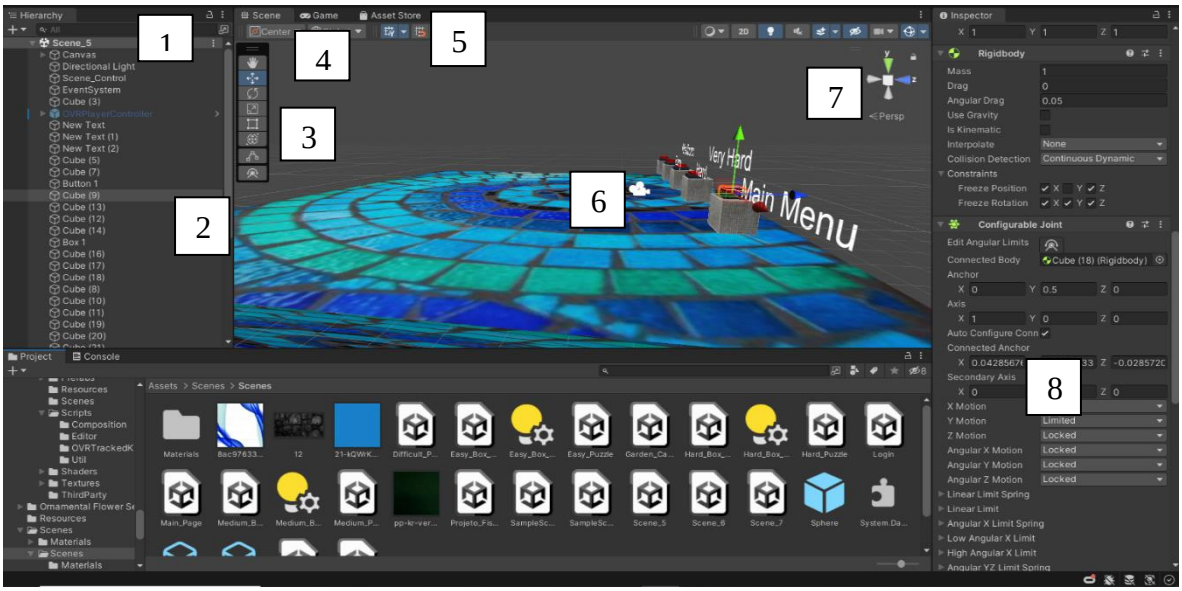

Fig.19. Unity 3D Framework Components Overview

Unity 3D Framework Components:

1- Scene Name
2- Game Object Scene Overview
3- Different Approaches to change Game Objects presented in the scene selected to view and change in 3D environment.
4- Game Scene View with CameraRig in OVRPlayerController with the function of main camera
5- Asset Store where you can choose any new material or other asset to improve your work project in Unity 3D.
6- 3D Environment Implementation
7- 3 Axys(X,Y,Z)
8- Inspector Tab where you can add any Script to some Game Object Interaction or Button Interaction or select any other component such as Collider, RigidBody, ConfigurableJoint or other.

4.4. Visual Studio and C Sharp Language

Visual Studio (Fig.20.) is an integrated development environment from Microsoft and is a program used to implement changes in Unity game objects, defining behaviors to be adopted by each object in the game according to certain actions of the user and the main purpose of the game itself.

These same actions are declared through C Sharp Language, the main programming language that Unity Engine can interpret, read and execute, thus defining their own mechanisms that in the set of all applied scripts will have the expected result for the idealized game.

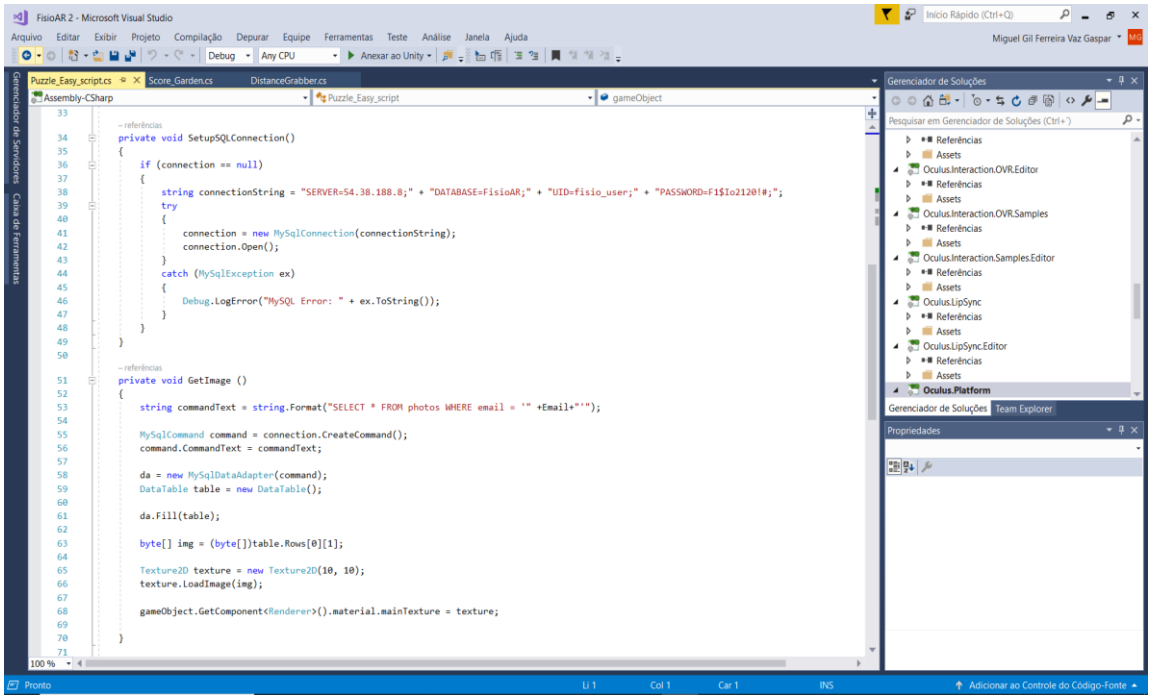

Fig.20. Visual Studio Framework

4.5. MySQL WorkBench

MySQL Workbench (Fig.21.) is an essential tool for storing data associated with a particular company, person or material whose stored data are useful and relevant to enrich and achieve consistent and true information for the purpose that a given project has.

For this specific project, mySQL is mostly used to store information about each patient and all the data that Oculus Quest's wearable sensors and accelerometer can provide us to know more accurately all movements that patient has made during the execution of each training session defined by the accompanying physiotherapist.

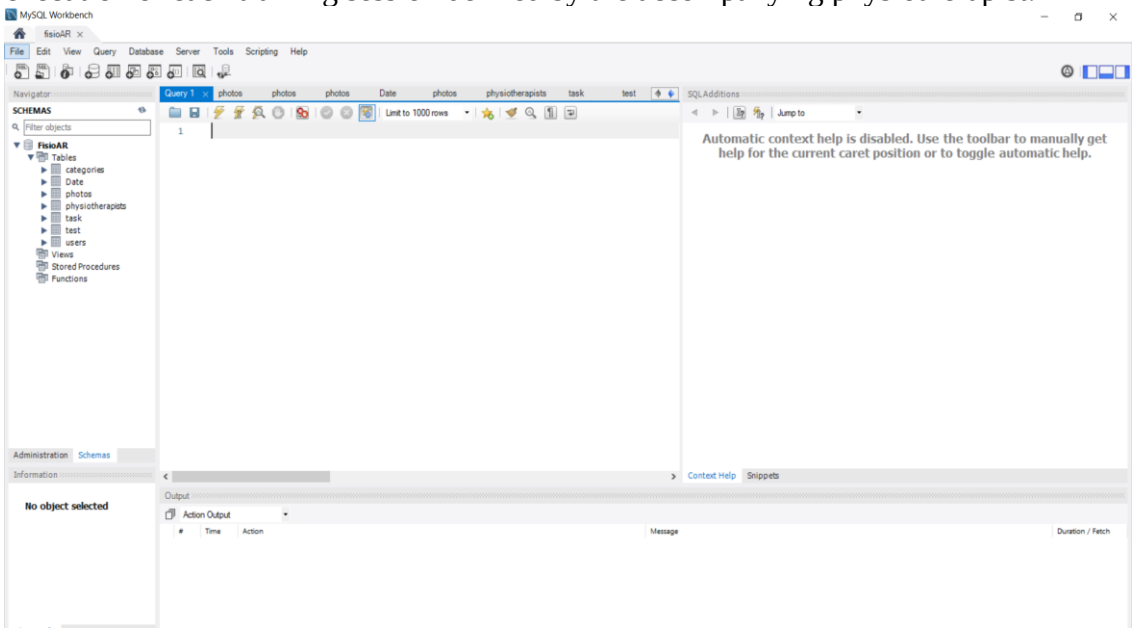

Fig.21. MySQL Workbench Framework

4.6. Oculus Integration package from Asset Store

This Oculus Integration package is essential for the interaction between Oculus Quest headset and Unity 3D, considering all the prefabs and functionalities that this package offers.

For example, to show a game made in Unity we have to use the OVRPlayerController Prefab as our main camera to move that camera according with head movements and to show wearable sensors in a game made in Unity 3D, we have to add OculusTouchForQuestAndRiftS_Left Prefab for a perfect usage of each wearable sensors. These two prefabs are only available due to Oculus Integration Package (Fig.22.) that allows this type of prefabs and scripts to a greatest interaction and an easiest development.

Another practical example that revealed the importance of having this package properly installed in these game development projects in Oculus Quest are the OVR Grabbable and OVR Grabber scripts, fundamental scripts for grabbing the objects that are being used in the game.

These two scripts are also included in Oculus Integration Package.

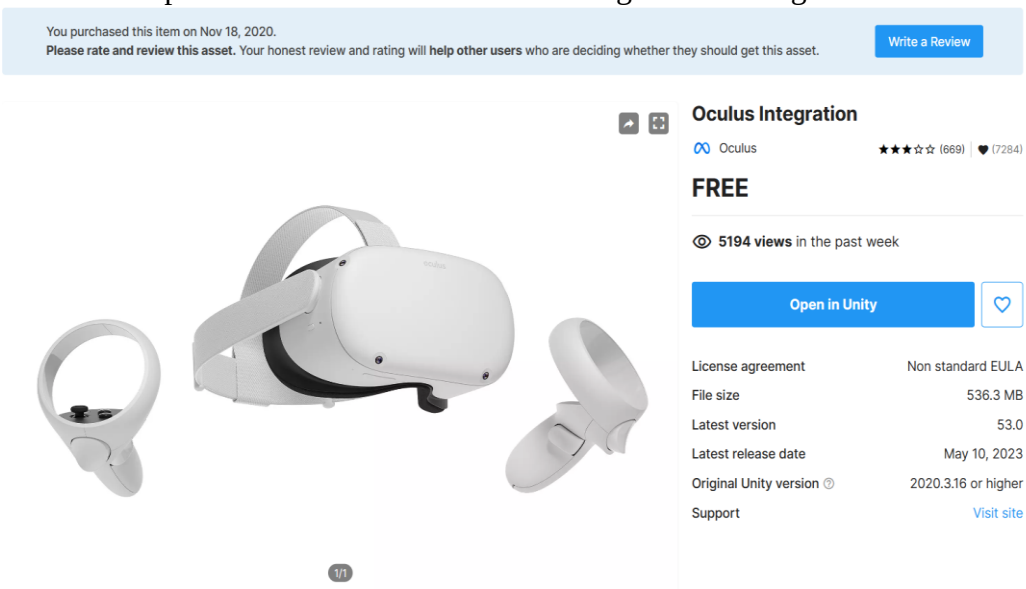

Fig.22. Oculus Integration Asset in Unity Asse Store

4.7. Important Features in Oculus App:

In Fig.24. b) shows as an image of Oculus App before being updated to new features and with different designs that you can view in the image above (Fig.23. b)) that are presenting the App more recent and updated.

In this Oculus App that you can simply install in you mobile phone in App Store, you can maximize the battery life of Left and Right Controllers and also the battery life of Meta Quest Oculus and there's another features like Cast what you're viewing in Meta Quest.

This Cast option can provide to you all images that Oculus Quest can capture with all your application that designed and make in order to testing and to make more easy to the developer can do your changes after testing an update or a new feature previously implemented and have all the information needed from Oculus Meta Quest or Meta Quest 2 and controllers battery percentage.

To develop other games like this project you have to enable developer mode in Meta Quest App and make sure you have Meta Quest correctly on with your Wi-Fi for a great cast with all views from the user Oculus.

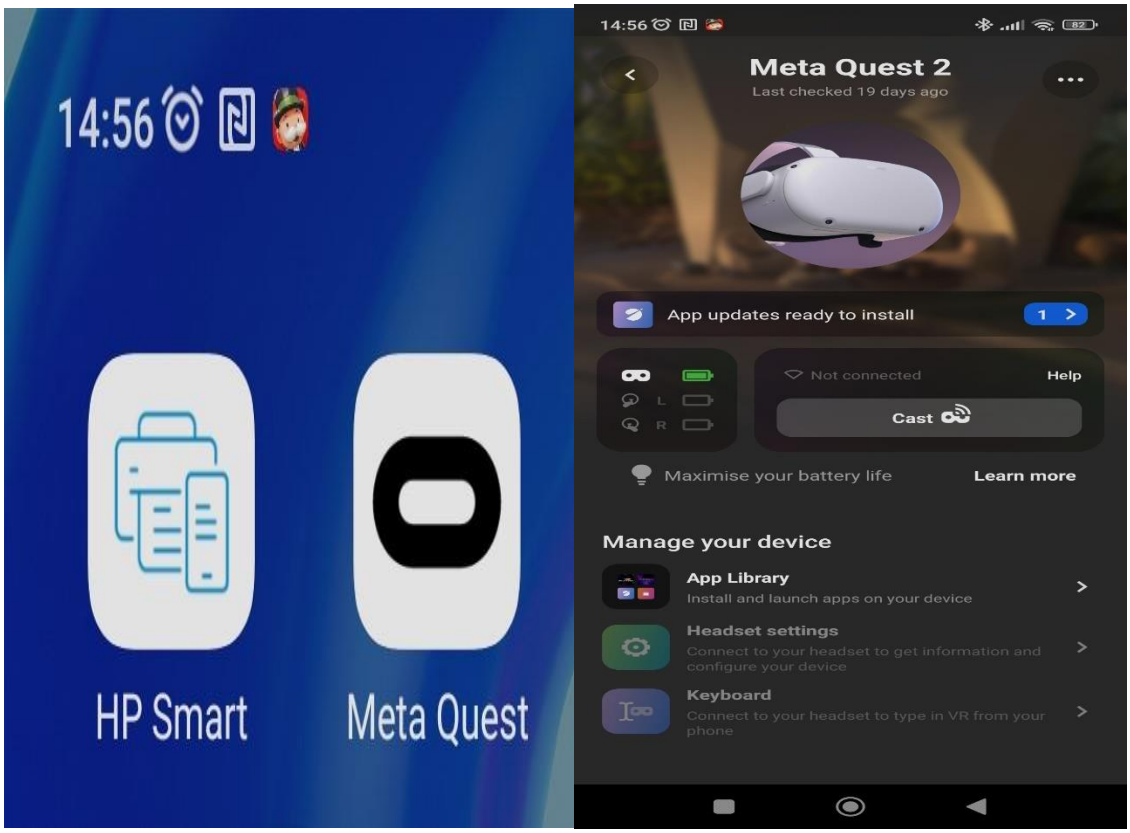

Fig.23. a) Oculus App Logo b) Oculus App Configurations

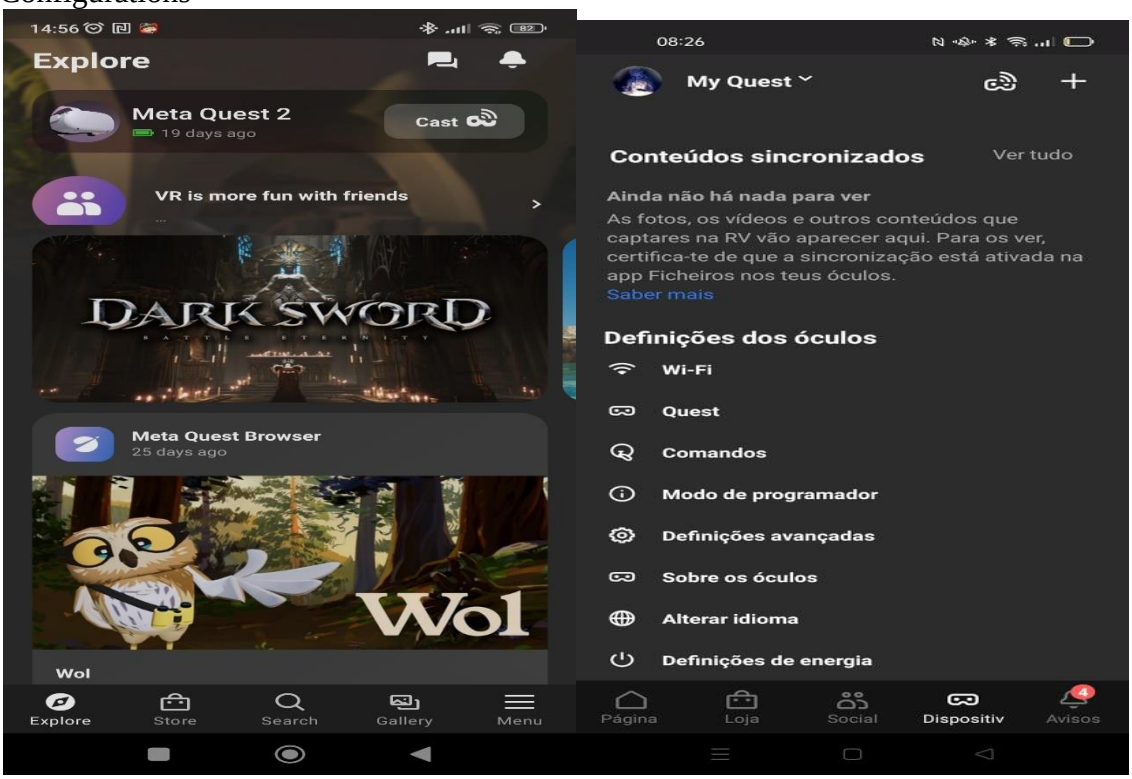

Fig.24. a) Oculus App Overview with Cast Option b) Old Oculus App Framework Configurations

4.7.1. Important Features in Oculus Quest:

In all these images you can there's important steps to make build your app without any problem and with a supplemented suggestion is you have an error on updating SDK version of your Unity Project.

If this problem occurs you have to simply uncheck all this 4 options presented in Edit -> Preferences -> External Tools (Fig.25.) and check again this for options, you can verify that the error disappears if you try to build your app in File -> Build Settings of your Unity Project.

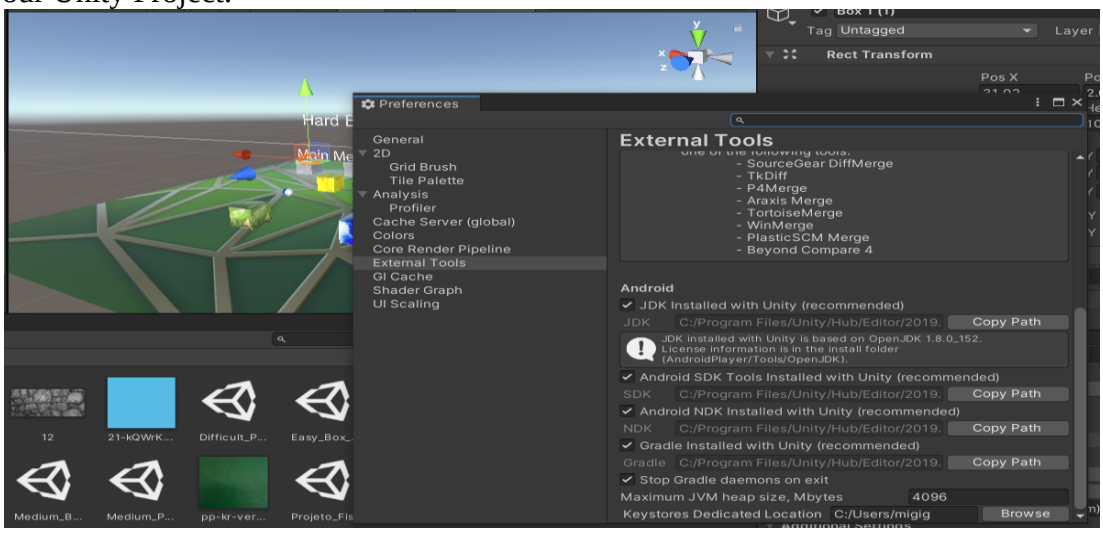

Fig.25. External Tools enable and able on Unity 3D Preferences

Also you have to create an Account in Oculus Developer App and extract after that an Application ID.

This Application ID can be found on the Oculus Developer App, according to Fig.26., and this is very important because it's with that ID you can have a great experience and you can connect with all Oculus Quest capabilities after inserting that specific number in the path presented in Fig.27. After click on the option "Edit Settings" you have to insert the application ID that has been created in Oculus Developer App in the fields similar to the Fig.28. because this Oculus Quest headset follows very specific steps to have a completely and grateful experience of all the project and all of other involving objects.

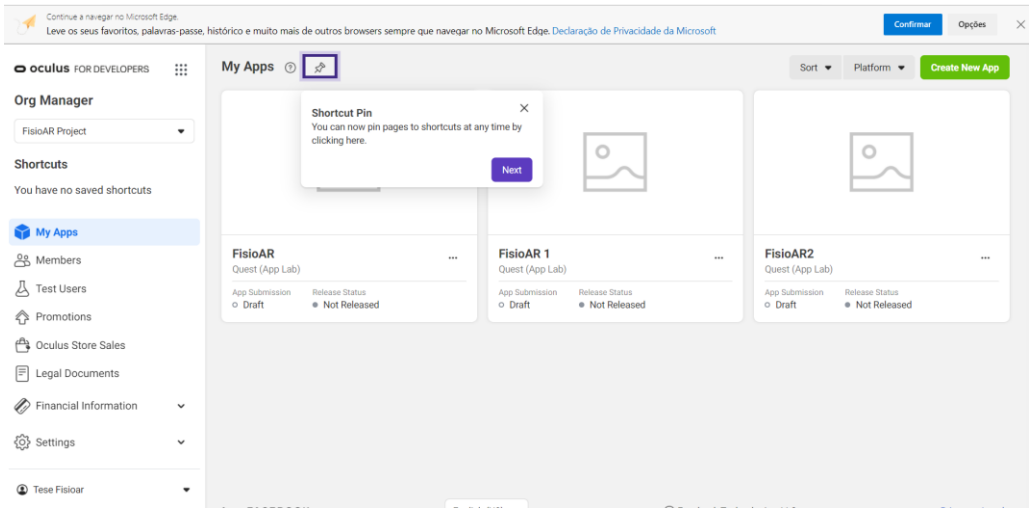

Fig.26. Oculus for Developers app

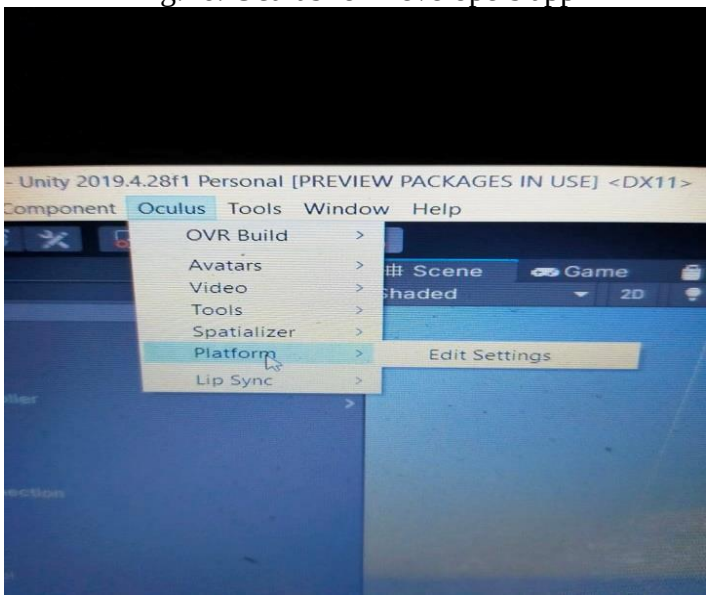

Fig.27.– Oculus Platform Settings on Unity Engine

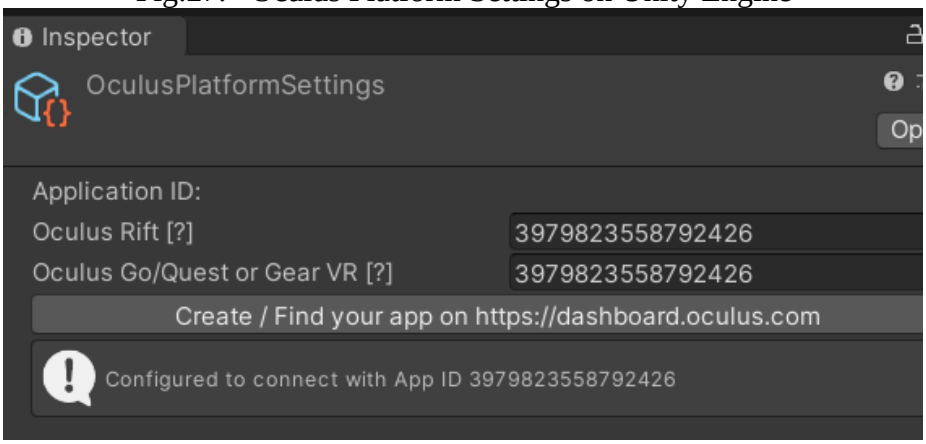

Fig.28.– Oculus Platform Settings

And before start presenting all this 3 games developed we also show to you all the things that are essential to make the things happen and to have a great interaction with all material and Game Objects presented.

This word, Game Object are all the objects that will be presented in our game and have to configured in order to work with this Oculus Quest and to interact with game Objects added in your game build project.

To make a quick steps of this configuration, a Game Object has to be these components to can be grabbed by Oculus Controllers in your Unity Environment that can be viewed in the example above:

- Has to be a Rigibody with Gravity to appears a real movement of this object
- Has to be an OVR Grababble script implemented in your environment
- In OVRPlayerController the Game Object that represents the 2 controllers in real world has to be implemented an OVR Grabber Script
- Also in OVR Camera Rig you have select Oculus Quest in Color Gammut option and Eye Level to can view with maximum perspective your game in Oculus Quest.

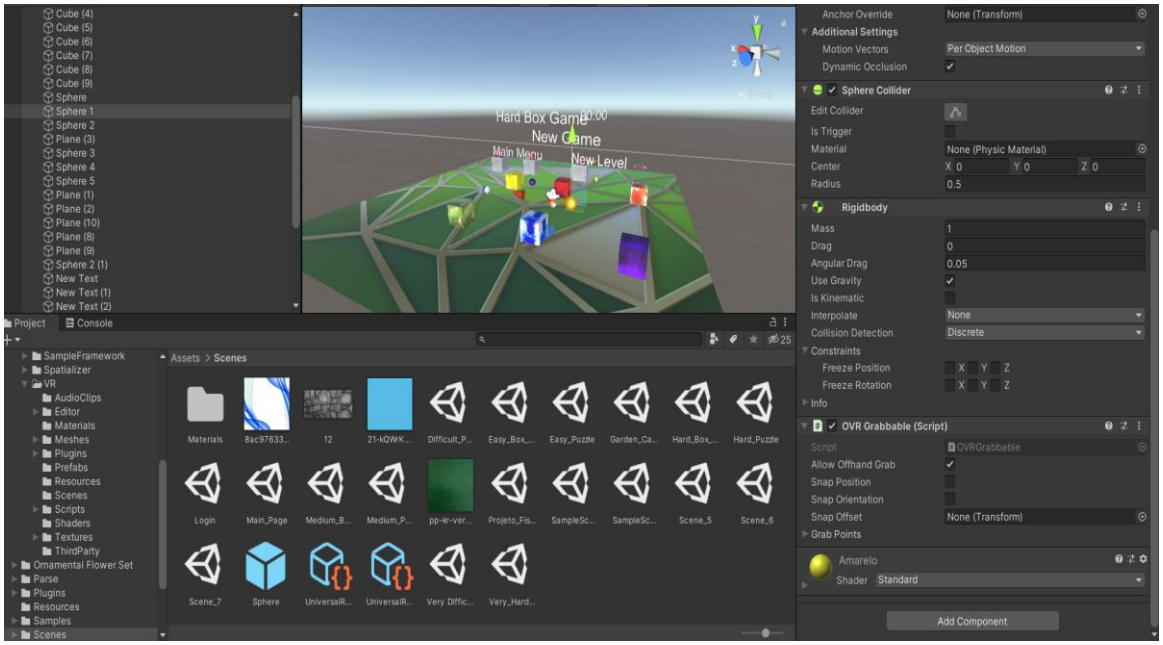

Fig.29. Example of a Scene framework.

And after that initial configuration you can do your changes and implement your scripts in order to make your project works correctly after passing the apk project builder and Android Platform that Oculus Quest supports for build your project, test and to make your final game design and development works really well and with minimum of bugs.

So after this short explanation of all configurations that need to be done in your Unity project we will show to you all this 3 games designed specifically for AVC's rehabilitation.

For that reason all this 3 games are very simple and different levels of difficult according to the level and to diagnostic of each patient.

4.8. FisioAR Games Explained

The first game called Boxes Game, has six cubes displayed with different colors and six spheres also with six different colors. The main goal of this game is to put the maximum number of spheres in a box with the same color and with minimum travelled distance. This game will involve the use of legs, knees and arms and can be easily adapted to each patients' conditions, making it more or less demanding. To make the game more attractive and difficult the boxes change color every few seconds. If you put a sphere in the correct

box (with the same color) another sphere will immediately appear in a random place and with the same color of the sphere that is placed inside the box. In this game, to achieve realistic feedback about the user's performance we added Scores and four limited times to evaluate and have more detailed values in different conditions.

The Second Game is called Garden Care Game. Its scenario was made with prefabs and materials from unity asset store to simulate a realistic garden, with a watering can, fences and a set of flowers. The main goal of this game is to water the flowers. This simple goal is related with the measurement of the wrist rotation made by the patient through wearable sensors while watering each flower. This game as a score for each flower watered.

In the Third Game called Puzzle Game, there's a white screen with the same number of divisions as the existing image blocks in project.

For easy mode we have three pieces, for medium mode we have four pieces, for hard mode we have six pieces and for very hard mode we have nine pieces to complete the puzzles.

The goal is to form an image with all the pieces of photos scattered around the environment. This game will require that the patient moves the knees and arms, managing to adapt the difficulty of the game to the weaknesses and abilities of each person. Also, this game is quite interesting because it will work not only, the physical part, the cognitive part but also the affective and sentimental part of the player since the photos will be chosen by the user through the FisioAR app.

These three types of games were developed with very vulnerable people in mind, so all positive vibes, feedbacks and engaging scenery will be making the games more enjoyable to play.

Below, each game's script is described. An image of the player's perspective is also shown.

4.8.1. Boxes Game

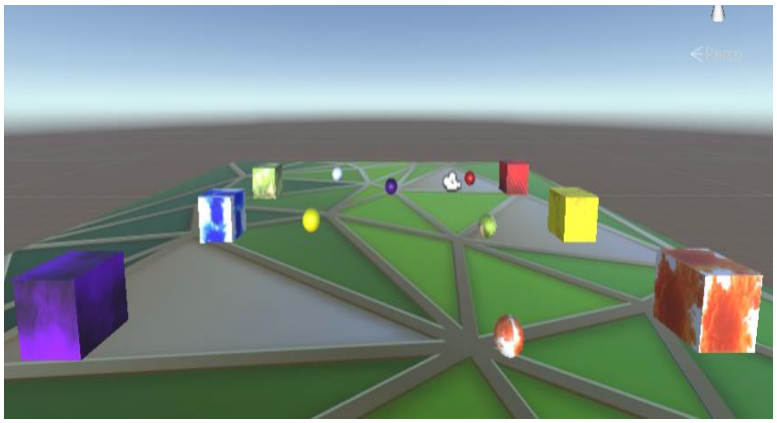

Fig.30. Box Game in Unity 3D

This game (Fig.30.) was designed for physical rehabilitation and this box and balls that composed the virtual scenario has the color interaction to make patient has the ability to put in a predefined time the maximum balls in the correct box according to the color of the box, gives the possibility, with help of Oculus Quest sensors, to measure the agility, the score and all the factors that are directly combined, involved and related to the patient's AVC performance in this game.

The main objective to measure all the moves, steps and all the scores made by patient is to know and have the perception of a significant evolution during the months predefined and predicted by al physiotherapists that are included in these experienced games and that obviously has to be a really good data and results about all these

measurements that will permit physiotherapists to know exactly what point that was improved or even got worse to understand how patient have to focus more and have to practice more during playing the game.

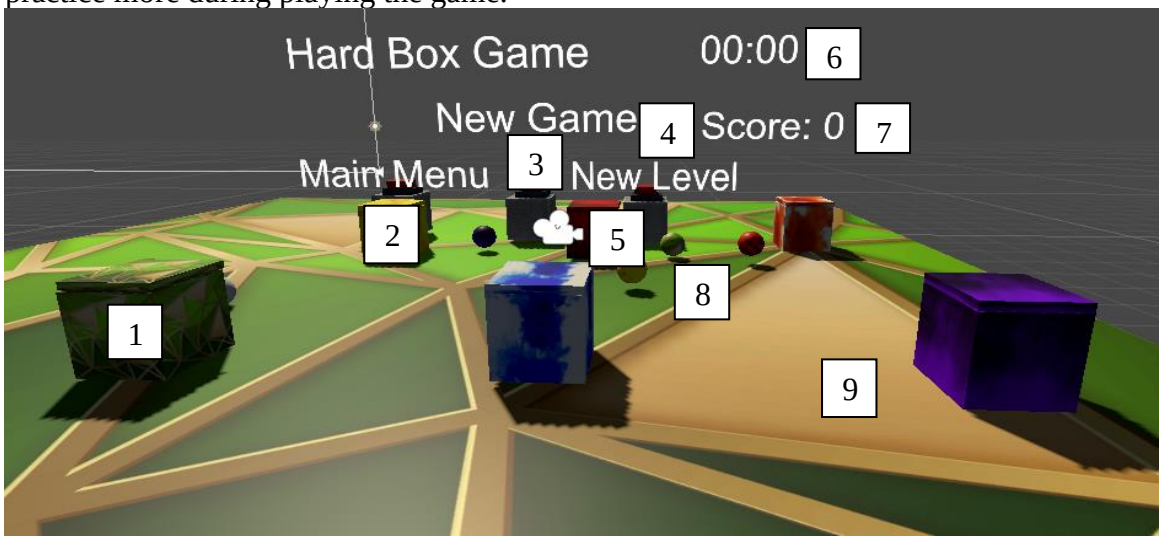

Fig.31. – Other perspective of Hard Box Game Components with buttons in Unity 3D

Box Game Components:

1- Box Game Object
2- Main Menu Button
3- New Game Button
4- New Level Button
5- OVRPlayerController
6- Box Game Chronometer with decrescent Time counting
7- Box Score Game
8- Balls
9- Floor Box Game

This game as also three different levels with the difference of the number of the boxes presented in this game and 3 buttons for the patient have the possibility to switch environments in order to Repeat the Level, change the difficult of the level or even change the game that he wants to play.

Also, we use some scripts to interact and make the game attractive to be played with the desired conditions.

The first script called Change Material is essentially used to change the box's color in a certain period that allows the stroke's patient to recognize and put the correct sphere in the correct box (with a relatively slow color changing period).

The second script it is associated with the moment when the player tries to place the sphere in the correct box, verifying if the material of the sphere that the patient is picking up with the Oculus Quest wearable sensors is the same as the material surrounding the box.

If the material is the same, then the color will also be the same, verifying the necessary condition for the ball to stay inside the box and the patient to be able to score points in the game.

There's another script used by the three games developed and this script is fundamental for this project because it extracts values about the Oculus Quest position

(accelerometer) and wearable sensors position. This data is very useful for the physiotherapist's evaluation of the patient along a considerable number of sessions.

Sphere's game object also has a OVR grabbable script and the two wearable sensors prefabs from Oculus Integration have an OVR Grabber Script, these two scripts are also integrated with the Oculus Integration package which can be downloaded from the Unity App Store.

The combination of these two scripts with some changes in these two game objects allows user to pick up sphere with the wearable sensors during the game.

For a greater player experience to play we have to add this piece of script in because after we grabbed a first object, if we tried to grab any other object included in the game we would never succeed, so this piece of code inside of *OVR GRABBER* script (Located on Source Code – page 85) allows this to be always possible whatever the number of objects already grabbed.

```
if (grabbable == null)
            {
                continue;
            }
```

4.8.1. Garden Care Game

Fig.32. Garden Care Game Components in Unity 3D

Garden Care Game Components:

1- Main Menu Button
2- New Game Button
3- Floor Garden Care Game
4- Regador
5- Plants
6- OVRPlayerController
7- Main Sound of the FisioAR Game
8- Garden Care Chronometer with decrescent time counting
9- Garden Care Score

The main objective of this game (Fig.32.) is to measure the agility of the hands, the score and the movements that a AVC's patient made during the game played in a specific period of time.

In this game, there's three scripts: OVR Grabbable, OVR Grabber and Controllers/Oculus Quest headset tracking values script.

Has we explained in Box Games these 2 scripts (OVR Grabber and OVR Grabbable) are scripts that are included in Oculus Integration Package but to adapt and work properly we have to do some changes for a better interaction between the Game object's material involved in these 3 games.

The OVR Grabbable script *(Located on Source Code – page 83)* is added to the watering can game object settings to allow the patient to pick up this item with wearable sensors. From the wearable sensors side we also added the OVR Grabber script to complete the grabbing interaction. These scripts are included in Oculus Integration Package from Asset Store.

Controllers/Oculus Quest headset tracking is essential for this game to measure all the movements made by game player to physiotherapists knows what was done better or worst compared with previous sessions related by this specific person.

To make physiotherapists job easier also was done an app in calendar format for a consistent and organized information about all interactions between user's game and the values extracted. This app will be more detailed in section 5, it's very simple to use and can give the professional good data to evaluate the performance and the patient's improvements over the months that they proceed with the treatment performing these types of games developed.

The Oculus Quest overview and all the graphics that this visualizer provides to your user offer an awesome game experience and certainly will give to the patient an extra motivation to your recover process.

4.8.2. Puzzle Game

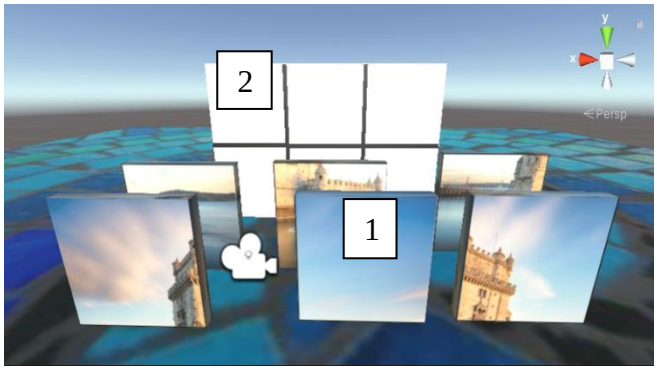

Fig.33. Hard Puzzle Game in Unity3D

In Puzzle Game (Fig.33.), we have 4 types of puzzles with different difficulty levels according to the number of pieces displayed in each game.

For easy mode we have three pieces, for medium mode we have four pieces, for hard mode we have six pieces and for very hard mode we have nine pieces to complete the puzzles.

In this game the patient can choose the photos that they want to appear in each piece of puzzle presented in each mode of the Puzzle Game in our Patient's App.

Before the patient playing the game they have to login or register the App specially destinated for all this interaction or adaptation and after that they just have to put the photos that he wants to appear and the categories that this photos represents in your life and when he starts this games this photos will appear in each piece of the Cube's Game Objects presented in the game.

To win the game the user has to hit all the categories with the photos that are in the game having the function of a memory game.

In developer's side, in this game we have two scripts: Snap Object script and Snap to Location script.

Snap Object script has two attributes in the beginning of class: Game Objects SnapLocation (invisible sphere) and Cube (puzzle piece).

In Snap Object script there's two different conditions: if boolean object are Snapped the attribute isKinematic in Rigidbody Component belong to Plane, is changed to true.

The result of this action allows the Plane (piece of puzzle snapped) to change your positions according to the hand and wearable sensor that snapped the object.

The other condition verifies if boolean objectSnapped and if boolean grabbed have the value false. If this condition is true, the plane object will not change your position.

Boolean grabbed verify if the object was grab by wearable sensor or not.

Snap Object is applied to the Cube Game Object.

In this game we have to implement an invisible sphere (Fig.36.) in each piece of puzzles for give the feeling during the game that the right object with a certain piece of image that belongs to the puzzle was "glued" to the correct part and after that verification this Game Object change the Puzzle Position to the position where the puzzle board is located.

These pieces are compared to the images that they have in your material (in Unity is called Renderer Material) and this that comparation we can know if the right object is trying to get "glued" or not.

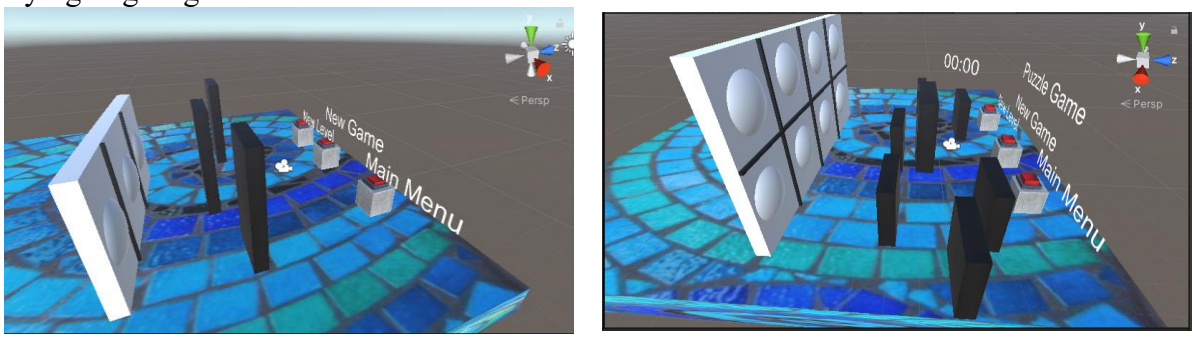

Fig.34 a) Easy Puzzle Game b) Very hard Puzzle

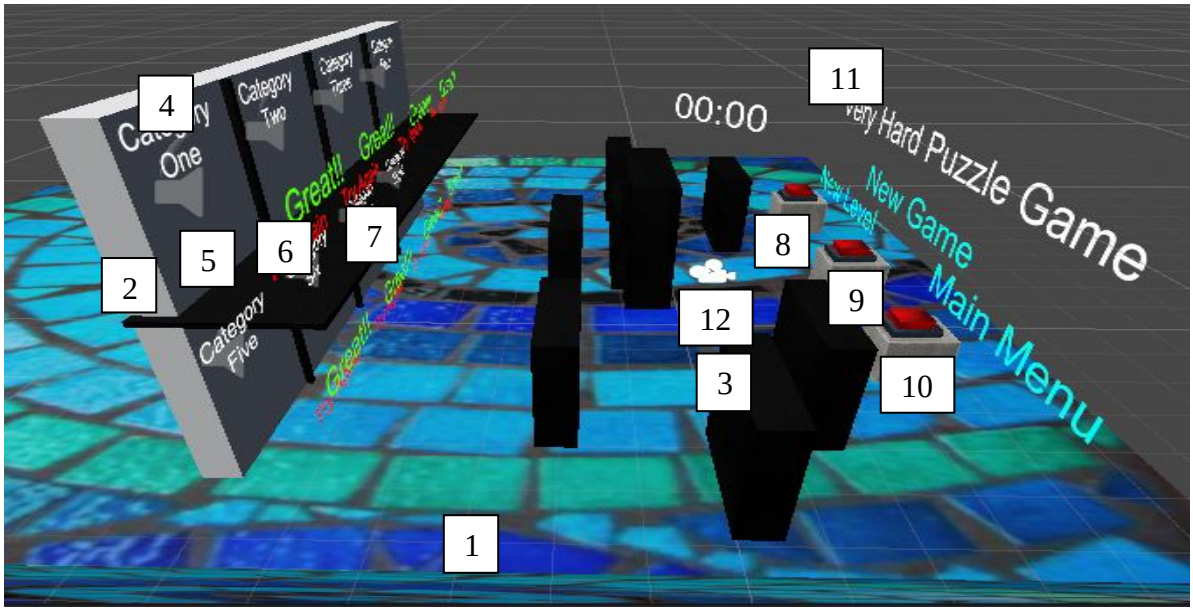

Fig.35. Puzzle Game Components

Puzzle Game Components:

1- Floor Level
2- Panel Photos
3- Pictures Game Object
4- Category
5- Sound Effect
6- Great Text for a correct correspondence between the Category and the Photo
7- Try Again Text for a wrong correspondence between the Category and the Photo
8- New Level Button
9- New Game Button
10- Main Menu Button
11- Game Chonometer in decrescent time
12- OVRPlayerController

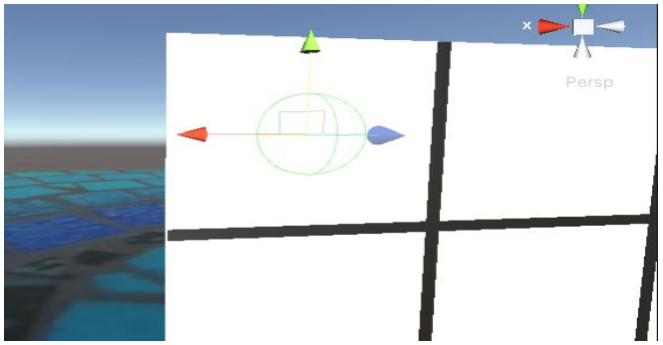

Fig.36. Invisible Sphere in Puzzle Game

In Snap to Location script are three different methods and two attributes in the beginning of class (Game Objects Cube (3 in Game Box Components) and Plane (2 in Game Box Components)).

The first on called OnTriggerEnter changes the boolean variable insideSnapZone to true if there's a collision with the name which is mentioned in the invisible sphere.

In each division created in white board has an invisible sphere, which has the name of cube that is correct and belongs to that position.

The Second method called OnTriggerExit changes the boolean variable insideSnapZone to false if the collision between the cube that collides a certain invisible sphere finish.

The last method, verify if boolean variable insideSnapZone is true and if the patient leaves to grab the cube with wearable sensors (boolean variable grabber are false). If these two variables have with these values, the cube position automatically changes, getting this puzzle piece "glued" to where it belongs in the whiteboard.
SnaptoLocation script is applied to the invisible sphere Game Object.

4.9. Some other important Settings you have to consider:

- You have to add OVRPlayerController (that the prefab that allows you to visualize the games in Oculus Quest Headset).
- Change this Settings in LeftHandAnchor and in RightHandAnchor (Fig.37.) (This component is presented inside the OVRplayerController options).

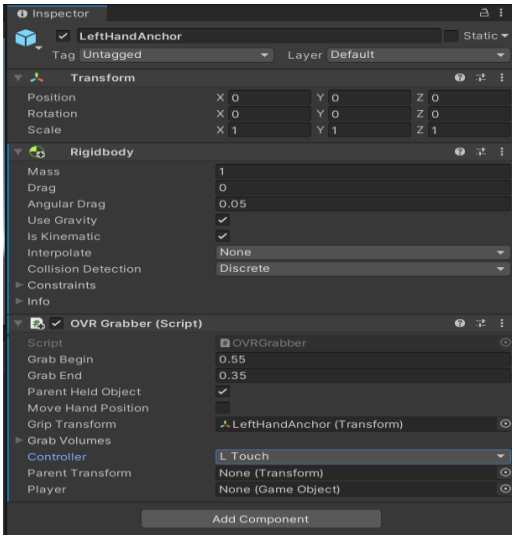

Fig.37. LeftHandAnchor Settings

- Add these components within ovrplayercontroller options (Fig.38. and Fig.39.). You have to add a Sphere because if you haven't this 3D game object if you push the wearable sensors for your body will do a very strange movement that probably will cause a bad experience during the games experiences.

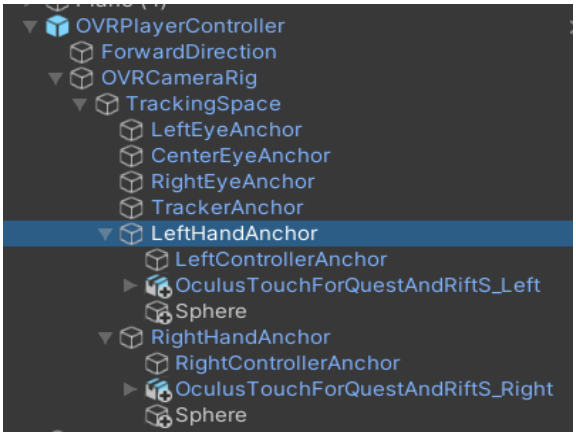

Fig.38. OVRplayercontroller Settings

- Add these settings in Sphere component.

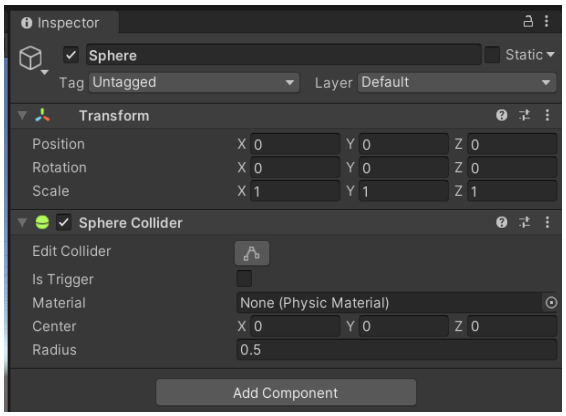

Fig.39. Sphere Settings

- Add OVR Grabbable to the 3D game object that you have to grab.

Chapter 5 – AR

5.1. VR vs AR

In this chapter we will explain how Augmented Reality can improve our work project, a few details about the system that we developed that are essential to be related in an AR environment and how we implemented AR in our system.

In the beginning of our work, we research about other works before starting the FisioAR project and in VR we faced the problem of can't view the real world materials and how this essential aspect would limit our work and our objectives about getting the game experience easy and secure, especially for an user that have suffered an accident and has several injuries associated to that situation.

It's a really disadvantage because put in dangerous the people that are using Oculus because can't has the perception of a real object or even a wall near or around the game play space that choose in Oculus Quest previous definition of room and Scale.

In some games is important have a virtual reality world to a better experience of the environment and to the user has a view of another world in the same real world space but in our game we concluded that is more important the security of patients and a great interaction with real and virtual world than a one hundred percent real world so we decided to implement AR environments in all the three games implemented and described here.

5.2. AR Benefits

Augmented Reality environment has many benefits to our Project and offers great solutions to some problems that we faced during the implementation.

First of all, we have the perception of the virtual and the real world at the same time and the virtual objects can interact with real world offering a fun and a different experience to the patient that can't touch to the virtual object but with the Oculus Quest Engine can have the possibility to move all the objects without making much effort.

In that specific case it's essential to evaluate each patient previously and your conditions before the usage of the technology that we have in our project but we have two advantages: we can quickly adapt any virtual object without any effort and we can assure a great security during the game playing experience.

Another aspect to avoid some risks is reserving an open space division only for the game playing experience and to patient has more confident in order to use the hardware components that we choice for this project: Meta Quest and the corresponding two wearable sensors.

In Meta Quest APP we have the possibility to view any device what we are viewing through the Oculus Quest designed.

5.3. AR Implementation

AR implementation is possible because the four camera incorporated to the Oculus Quest have the capability to integrate the Game Objects that are in a consider Unity Scene with four cameras vision on the background.

Also, we have to implement some features and has to verify if your Unity version is higher than 2020.3.16 and if we have the last version of Oculus Integration Asset, a crucial asset to develop games in Oculus Quest and that has Scripts to help

implements AR in all games. One of this scripts is OVR Passthrough Layer Script that offers all the attributes needed to the Camera Rig in the OVR Player Controller Settings and have to enable Passthrough in Insight Passthrough options.

In the color types in camera we have to put black color options to avoid any disruption in image because the addition of RGB color with the four cameras vision that isn't a good option for a great AR experience, the image will appear with a bad quality with that colors.

During this implementation we face that problem in some experiments so we concluded that if we use black color in camera Backdrop Color option (presented in the image below), the problem would be resolved.

Fig.40. OVR Passthrough API Script and other Settings for Augmented Reality Implementation

5.4. Augmented Reality API Passthrough

The API Passthrough for Oculus/Meta Quest (Fig.40.) provides the user with a perception of the real world in 3D and in real time thanks to the capture of the frontal sensors of the device. It was originally designed for its use by the Guardian application, which is the application that runs at the beginning of the device start-up and that allows a safe area of use to be defined, e.g., to avoid colliding with obstacles in the game area.

Since the interface was not specifically designed to support MR experiences, it has some limitations and artifacts that limit its use in different applications.

Passthrough works as follows: the real-world image is rendered by a special service on a separate layer which is then mixed internally by the device software. The application has no direct access to the image information, the RGB color channels, the depth (Z-buffer), or to any other information captured by the sensors. In other words, the application has very limited control over how to interact with Passthrough, and, in particular, no computer vision techniques such as object detection can be applied.

The current version also does not allow operations that use depth such as Z-buffering (or similar) using Passthrough, so that any virtual element that is drawn on the scene overwrites the real-world image. The API supports some fixed types of compositing with the Passthrough layer, such as automatic edge detection and color keying (which allows drawing the Passthrough in a very limited number of colors) and is always transparent to the application.

Chapter 6 - Mobile

6.1. OutSystems Apps

In this chapter we will explain all the screens used in our FisioAR Project OutSystems APPs and the functionality of each one screens components.

As we mentioned above, we developed two different apps: one for physiotherapists data analyses and designed for create new tasks and other one for AVC patient to register your data in data base project, to add your personal photos that will be displayed in puzzle game and to know every knew task that your physiotherapists added.

6.1.1. Physiotherapists App

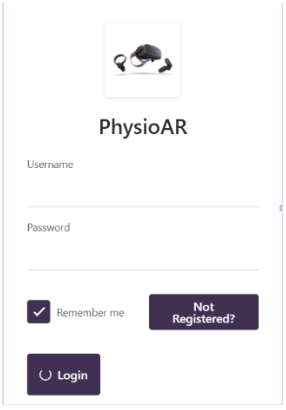

Fig.41. Physiotherapist's Register FisioAR App

In this Screen, Physiotherapists must Register your data to the FisioAR database to have the possibility of try Unity FisioAR rehabilitation games (Fig.41.)

After Confirming your registration data will be able to use all the resources of FisioAR project.

For this specific app and similar to other existing apps we have to put Password 2 times to memorize with more effectiveness the password that you consider in this case and Username and Email has to be unique in the database constructed for this PhysioAR project.

After you click in the below displayed in the screen you can confirm that your registration was well succeed in the screen presented.

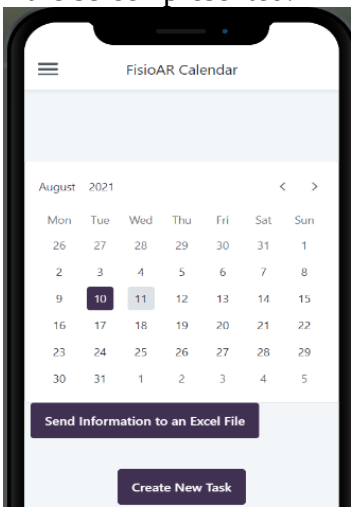

Fig.42. FisioAR Calendar Screen

In this screen, if a physiotherapist click on a specific day, will automatically displayed on screen a list of patients that played the FisioAR games (Fig.42.)

If physiotherapist click on “Send Information to an Excel File” button it will create an Excel File with all sensors data from a specific patient and in this File the professional will can analyze sensors information, comparing with previous data from the same patient and checking if the evolution is happening.

If physiotherapist click on “Create New Task” button, it will appear the AVC Patient’s New Task Screen (Fig.43.), the screen that we will explain next.

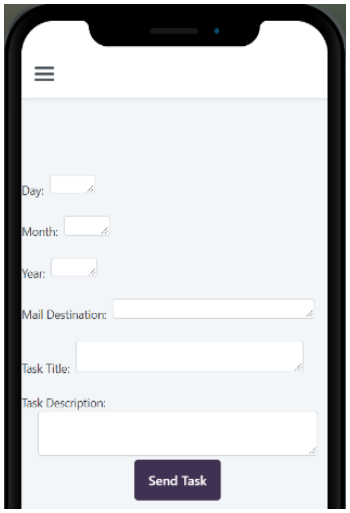

Fig.43. AVC Patient’s New Task Screen

In New Task Screen, Physiotherapist must add the day, month and year that have planned the task and mail destination to send all the task description planning to the patient’s mail destinated to do this training games rehabilitation sessions.

Every time physiotherapists have a new training planned for a specific person or for a significant number of persons you can create any time new tasks here in this section of the application and send all the important and essential information to the AVC patient’s that will receive a notification on your email to notice this new tasks to do and the hour that physiotherapist want to be done give to the person a comfortable way to have exactly perception of wat has to be done in the predefined for this sequence of exercise .

6.1.2. AVC Patient’s App

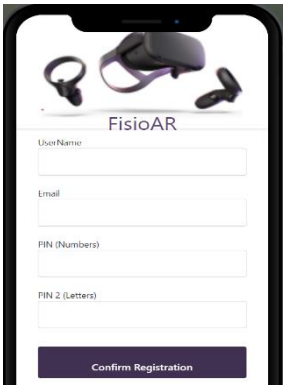

Fig.44. AVC Patient’s Register FisioAR App

This app is specifically destinated to the patient have access and change any time our photos in your game and our Login account and password that access app and unity games.

This registration screen has two different PIN to protect our AVC's patient data for security app and for security of all project, a point very important because in a few months a lot of big company have suffered a considerable number of attacks in our apps and data store bases and installation systems.

In this Screen, Patients must Register your data to the FisioAR database to have the possibility of try Unity FisioAR rehabilitation games (Fig.44.).

After Confirming your registration data will be able to use all the resources of FisioAR project.

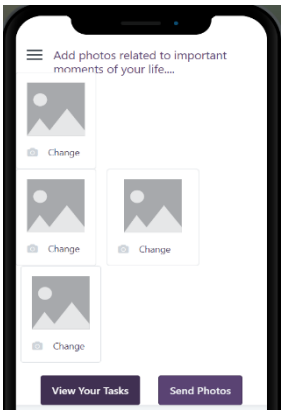

Fig.45. Patient's Photos Screen

In Photos Screen (Fig.45.), Patient's must to choose pictures that automatically remember positive feelings in their lives.

This app is specifically destinated to the patient have access and change any time our photos in your game and our Login account and password that access app and unity games.

After the AVC's patient click on "Send Photos" button, the four pictures chosen by the patient will be saved in FisioAR database and later will be used in the puzzle games, a game described in Section II.

If patient click on "View your Task" it will show all tasks that your personal physiotherapist defined since the beginning of the patient's treatment.

Chapter 7 - Database

7.1. The importance of a Database in all systems

In this chapter we will expose some Database Platforms options and why we chose MySql Workbench Database for our FisioAR Project Implementation.

A database is one of the most important components in any design of a project or system since it encompasses all the data that the system needs and all the interconnections of that same data so that there is a functional logic within it.

It is the main link between the various existing applications in a given project and the data that is passed and which is fundamental to their correct functioning, whether they are:

- Personal data
- User data
- Authentication data
- Data from the application itself (depending on the purpose of the application to be used):
- Videos
- Information Brochures
- General information
- Products
- Prices
- Advertising
-Internal consumption data
-Data generated automatically through some action taken by the application's client

It is in this component of any system that all information is stored, even be it an application, a game or a website, therefore security is an essential factor for its correct functioning because Data Protection is a very sensitive topic, so all user data using a given application must be highly protected and safeguarded.

It’s one of the main concerns for companies and one of the greatest challenges for programmers and data analysts, to be able to store all the information in a safer, more consistent and scalable platform for the largest number of users.

In Industry, various kind of data is generated such as semi structured and unstructured data and expended rapidly. The storage of such a large amount of data is not the only issue but also how to access this amount of data quickly and accurately. From last three decades, such large amount of data is being handled and managed by the traditional databases. The ACID property of SQL database is used to keep the data consistent and efficient to extract meaningful knowledge.

Structured data is manipulated through SQL declarative language of relational databases. The data consistency is the main theme of the SQL databases and can process the data at certain limit [47].

Organizations are required to increase their system capacity such as RAM, Disk; optimized method of accessing data etc. manage large datasets through relational databases. The systems have also limited capacity. In Relational databases, tables are used to store the data. This way of storage to read and understand the data is not the suitable method [48]. Data inconsistency cannot be eliminated to index cross reference data.

Hence, tables are used to store data in the relational databases because these tables are easy to understand and readable.

7.2. Some Database Platform Options

7.2.1. Mongo DB

Fig.46. Mongo DB logo

MongoDB (Fig.46.) is an open-source NoSQL database. MongoDB stores data in JSON-like documents that can vary in structure. Because MongoDB uses dynamic schemas, users can create records without defining the data structure first.

MongoDB stores related information together, which enables queries to process more quickly. To retrieve information, users leverage the MongoDB query language. [49]

7.2.2. Microsoft SQL Server

Fig.47. Microsoft SQL Server

Microsoft SQL Server (Fig.47.) is a relational database management system (RDBMS) developed by Microsoft. As a database server, it is a software product with the primary function of storing and retrieving data as requested by other software applications—which may run either on the same computer or on another computer across a network (including the Internet). [49]

7.2.3. MySQL

Fig.48. MySQL Log

MySQL (Fig.48.) is a widely used, open-source relational database management system (RDBMS). MySQL is free and open-source software under the terms of the

GNU (General Public License) and is also available under a variety of proprietary licenses. [49]

7.2.4. PostgreSQL

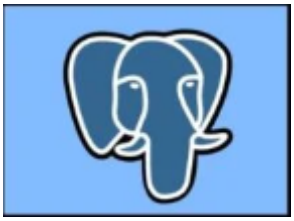

Fig.49. Postgre SQL

PostgreSQL (Fig.49.), often simply Postgres, is an object-relational database management system (ORDBMS) with an emphasis on extensibility and standards compliance. It is free and open-source software released under the PostgreSQL License. [49]

7.2.5. SQLite

Fig.50. SQLite Log

SQLite (Fig.50.) is a relational database management system contained in a C programming library. In contrast to many other database management systems, SQLite is not a client–server database engine. Rather, it is embedded into the end program. SQLite is ACID-compliant and implements most of the SQL standard, using a dynamically and weakly typed SQL syntax that does not guarantee the domain integrity.

SQLite is one of the most widely deployed database engines, as it is used today by several widespread browsers, operating systems, and embedded systems, among others. Heavily used in iPhone applications, it features full-text search and geospatial query support. [49]

7.2.6. Oracle Database

Fig.51. Oracle Database Log

Oracle Corporation's Oracle database (Fig.51.) is a relational database management system (RDBMS) that runs on major platforms like Linux, UNIX, and Windows. It is very popular relational database and is known for its scalability, reliability, and performance. [49]

7.2.7. MariaDB

Fig.52. Maria DB Logo

MariaDB (Fig.52.) is an open-source relational database management system (RDBMS) that's compatible with the popular MySQL database. MariaDB is used by organizations of all sizes, from small businesses to some of the largest companies in the world.

7.2.8. Firebase

Fig.53. Firebase Logo

Firebase (Fig.53.) is a set of backend cloud computing services and application development platforms provided by Google. It hosts databases, services, authentication, and int

egration for a variety of applications, including Android, iOS, JavaScript, Node.js, Java, Unity, PHP, and C++.

7.2.9. My SQLWorkbench

Fig.54. MySql Workbench Logo

MySQL Workbench (Fig.55.) is a unified visual tool for database architects, developers, and DBAs. MySQL Workbench provides data modeling, SQL development, and comprehensive administration tools for server configuration, user administration, backup, and much more. MySQL Workbench is available on Windows, Linux and Mac OS X.

7.2.9.1. Design

MySQL Workbench enables a DBA, developer, or data architect to visually design, model, generate, and manage databases. It includes everything a data modeler needs for creating complex ER models, forward and reverse engineering, and also delivers key features for performing difficult change management and documentation tasks that normally require much time and effort.

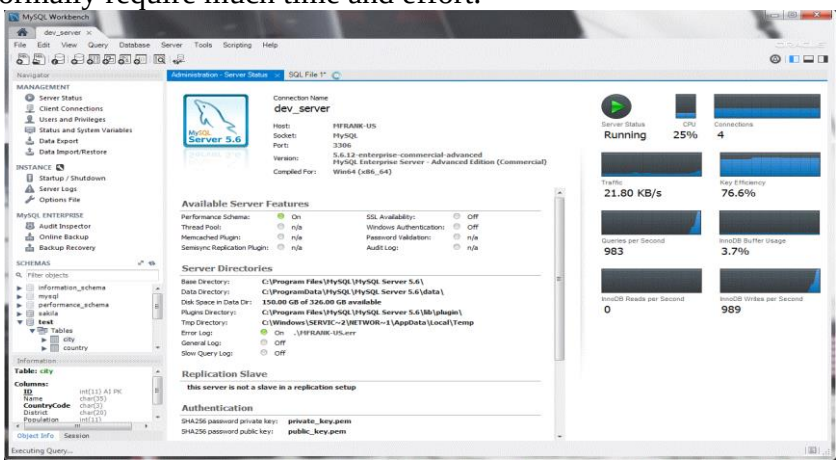

Fig.55. MySQL Workbench Home

7.2.9.2. Visual SQL Editor

The visual SQL Editor lets developers build, edit and run queries, create and edit data, and view and export results.

SQL Editor provides:

Table Editor - easily edit data and commit changes using a simple grid format.

Results Window - execute multiple queries simultaneously and view text results, image and spatial views, and query performance statistics on individual tabs.

SQL Snippet Panel - save and easily reuse common Selects, DML and DDL code.

History Panel - view complete session history of queries and statements showing what queries were run and when. Easily retrieve, review, re-run, append or modify previously executed SQL statements.

Table Data Search Panel - find data across an entire database by proving text search on any number of tables and schemas, showing rows matching a given pattern.

Export Results - export results data to common formats including CSV, HTML, and XML.

7.3. Wy we chose MySQLWorkbench for this project?

We chose mySQLWorkbench for development in our FisioAR project because it has an application on the PC that greatly facilitates its integration with the other components of the project, which in this case are Unity 3D and the two applications developed in OutSystems, being an important link connection between these 2 types of Engines developed in the project.

It also has a working framework that is very easy to use and change, acquiring a very flexible component for a database, since it is a very sensitive topic and that always causes discussion about how the data will be arranged and what they are. the tables and columns to be added considering the layout of the existing data in the project.

7.3.1. MySql Workbench Database

For this FisioAR project we created one database with seven tables to make all the games part well oriented with the data from Unity 3D and the data from the 2 Outsystems App (Physiotherapists App and Patients App).

The seven tables implemented in a the MySQL Workbench Database was: Categories, Date, Photos, Physiotherapists, Users, Tasks and SensorValues.

Categories Table has 9 columns (Fig.56. and Fig.57.): email, category_photo1, category_photo2, category_photo3, category_photo4, category_photo5, category_photo6, category_photo7, category_photo8 (categories that the patient chose in the Outsystems Patient's app).

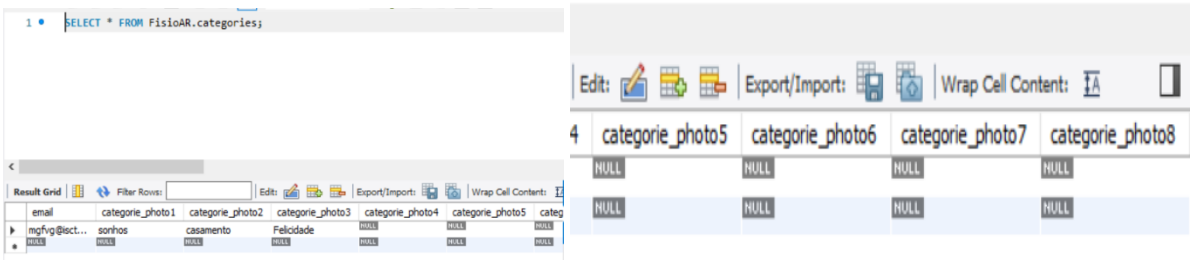

Fig.56 and 57. Categories added by Patients in our App Destinated

Date Table has 2 columns (Fig.58.): Email and Start Date to knows which date was selected.

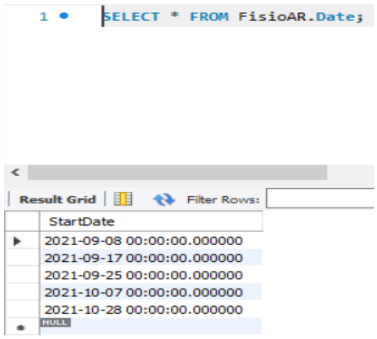

Fig.58. Start Date Search for Physiotherapists in the Calendar

Photos Table has 9 columns (Fig.59.): email, photo1, photo2, photo3, photo4, photo5, photo6, photo7, photo8 (photos that the patient chose in the Outsystems Patient's app).

Fig.59. Photos database table

Physiotherapists Table has 3 columns (Fig.60.): email, username and password (encrypted) (Data for physiotherapists regists in the OutSystems Physiotherpists App).

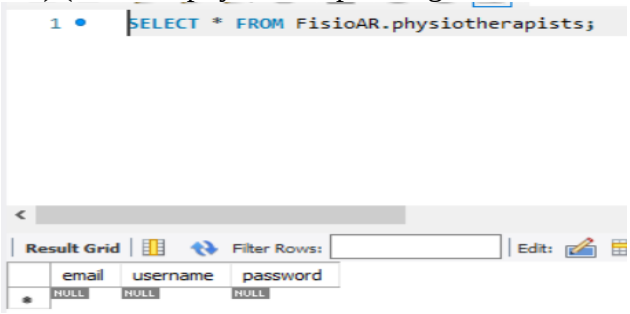

Fig.60. Physiotherapists registers database table

Users Table has 4 columns (Fig.61.): email. Username, PIN and PIN2 (Data for physiotherapists regists in the OutSystems Patients App).

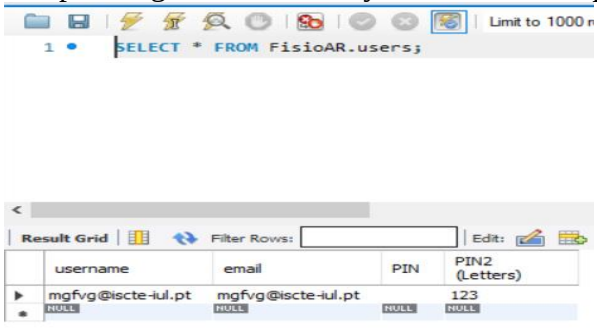

Fig.61. Users registers database table

Tasks Table has 6 columns (Fig.62.): day, month, year, email destination, task title and task description (Data created for physiotherapists in the Outsystems Physiotherapists App).

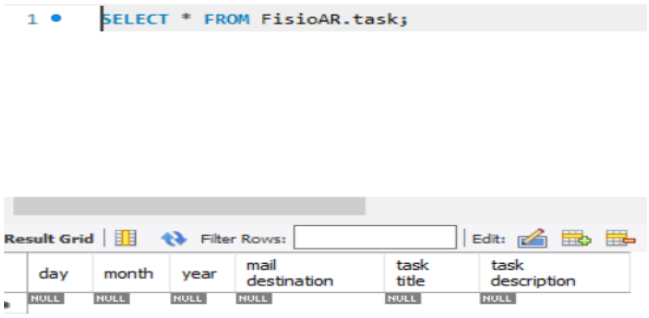

Fig.62. Tasks created by the physiotherapists database table

SensorValues Table has 8 columns (Fig.63.): IdData, Mean deviation, Standard Deviation, Variance, Average Velocity, Average Acceleration, Date and Hour (Sensor Values put by Csharp script after the patient had realized a game with all the information about this game played).

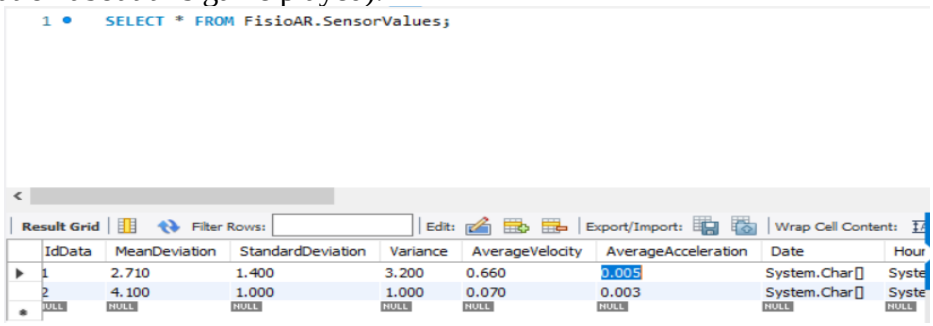

Fig.63. – sensors data (wearable sensors and headset controller) database table

7.3.2. MySQL Workbench Database Connection with:

A. Unity

MySql Workbench connection with Unity is made by three simple methods applied in c sharp language: SetupSQLConnection(), CloseSQLConnection() and TestDB().
In SetupSQLConnection we have to try to connect with our specific MySQL Workbench credential (Server name, Database name, UID and password) and we create a new MySQLConnection with the String that contents these datas.
In CloseSQLConnection() we just close the connection socket created in SetupSQLConnection() to finish all the changes maded between the unity platform engine and the mySql Workbench.
In TestDB() we apply all data that we needed in order to do some important task that involves database component and to make our FisioAR project more secure and safety for the people that will use all this work to try and for your own experience.

```
   private void SetupSQLConnection()
   {
         if (connection == null)
         {
             string connectionString = "SERVER=54.38.188.8;" + "DATABASE=FisioAR;"
+ "UID=fisio_user;" + "PASSWORD=F1$Io2120!#;";
             try
             {
                 connection = new MySqlConnection(connectionString);
```

```
                connection.Open();
            }
            catch (MySqlException ex)
            {
                Debug.LogError("MySQL Error: " + ex.ToString());
            }
        }
    }
    private void CloseSQLConnection()
    {
        if (connection != null)
        {
            connection.Close();
        }
    }
    public void TestDB()
    {
        Email = i.text;

        string commandText = string.Format("SELECT * FROM users WHERE username =
'" + i.GetComponent<Text>() + "' AND PIN = '" + f.GetComponent<Text>() + "' ");
        string commandText1 = string.Format("SELECT * FROM physiotherapists WHERE
username = '" + i.GetComponent<Text>() + "' AND password = '" +
f.GetComponent<Text>() + "' ");

        if (connection != null)
        {
            MySqlCommand command = connection.CreateCommand();
            command.CommandText = commandText;

            MySqlCommand command1 = connection.CreateCommand();
            command1.CommandText = commandText1;

            Console.WriteLine(commandText);
            Console.WriteLine(commandText1+"ESTOU AQUI");
            try
            {
                command.ExecuteNonQuery();
            }
            catch (System.Exception ex)
            {
                Debug.LogError("MySQL error: " + ex.ToString());
            }
        }
```

B. Outsystems

In OutSystems we use a different way to put this data in our outsystems app which is implementing a database extension that will connect with mysql Workbench with your specific credentials and will extract all the entities that are included in the database that will point.

1º - We have to create the extension (Fig.64.)

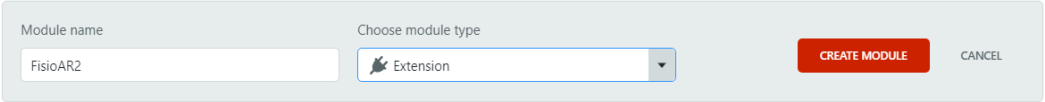

Fig.64. Extension

2º - Connect to your own environment (Fig.65.)

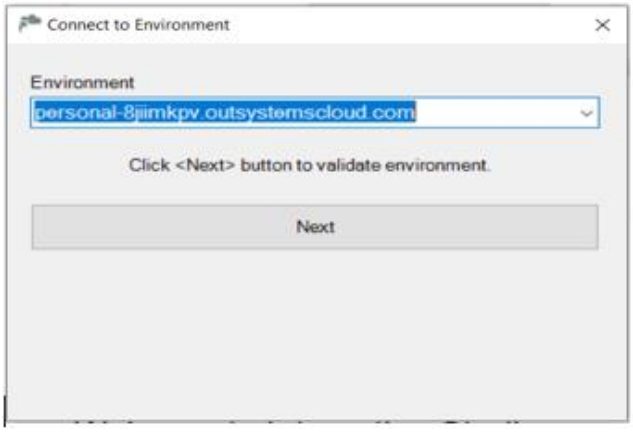

Fig.65. Own Environment

3º - Enter your own username and password (Fig.66.)

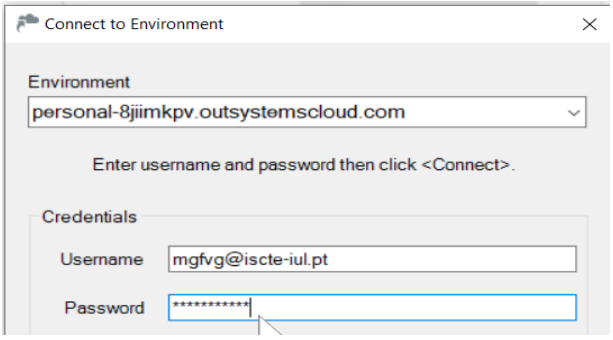

Fig.66. Credentials

4º Click in Entities folder and connect with external table and view

5º Select the Database Connection you want to synchronize with mySQL Workbench database (Fig.67.)

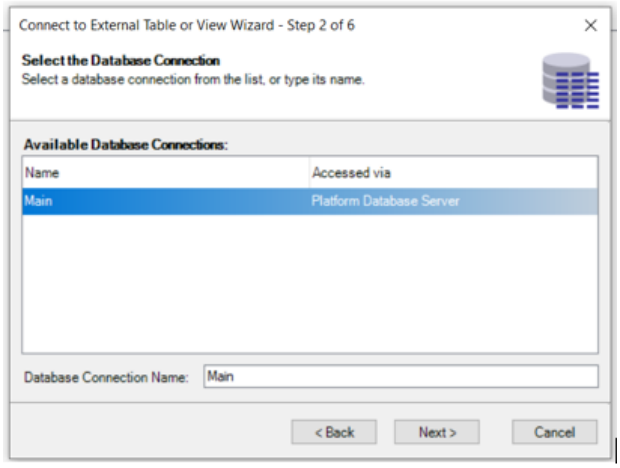

Fig.67. Database Connection

6º Select the Tables yo want to apply in your OutSystems App (Fig.68.)

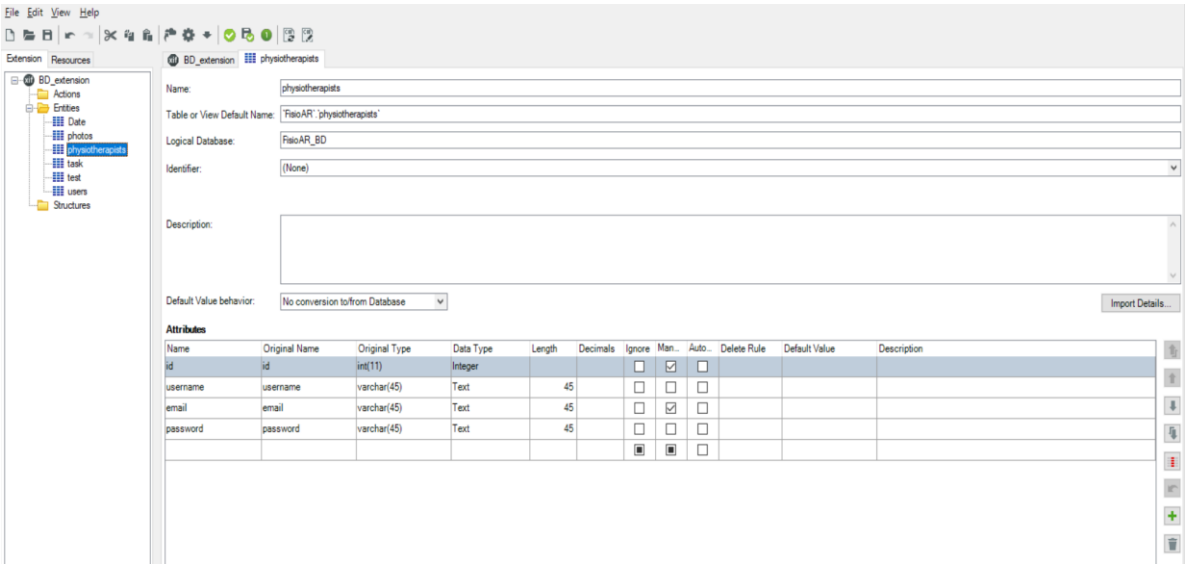

Fig.68. All tables presented in database and added in Database

Extension in order to use this data in PhysioAR app specifically.
7º Click Publish to apply all the changes made in Integration Studio (the tables will appear inside the entities folder)
8º Go to Manage Dependencies in your personal environment Outsystems app in order to update all the changes made and after that will appear the mySQLworkbench with all the tables that are added in it.

Chapter 8 – Results and Discussions

8.1.Results

In this Chapter, we will expose all the results that this system given to us in order to help physiotherapists evaluate all the progress made by your patient's during all the recover process.

These data have this structure because it's that are extracted from the wearable and headset sensors in order to know these five important parameters for physiotherapists: mean deviation, standard deviation, acceleration, trajectory, and rotation of the movement of the patient.

All these data are values from this segments, sequences and these values are displayed and treated in this order and with this aspect during the transfer of data from the serious Unity 3D games made to the database specifically built for storage and for the needs of the games designed.

Data format presented in Source Code of the project are:

- id
- rightController.transform.localRotation
- rightController.transform.localPosition
- leftController.transform.localRotation
- leftController.transform.localPosition
- headsetPos

These values are treated in mean deviation, standard deviation, variance, average velocity and average acceleration before going to the project's database and belongs to four different persons that who volunteered to contribute in order enrich the results of my PhysioAR thesis and whose experience was about to understand how the results could help the physiotherapists in your analysis during the process of rehabilitation and if there would be any evolution even if these people are only a simulation of how a person with reduced mobility would be simulating the games played by a AVC patient with the same condition in a certain period of time.

In these tests, the game as a period of two minutes and thirty seconds controlled by a chronometer presented in the project made so the person has the same conditions of the space and time to compare all the results with maximum precision possible.

This data has been collected with a Database Connection Script presented in attachments of this thesis and this script capture the Right Controllers , the Left Controllers and the Oculus Quest headset sensors that are inside these game Objects and put them in Database that are designed and created specifically for this project and these games to save all data needed both in the game and in the applications created for the concept.

After that we treat this data with specific calculus with the main objective of understand if any difference between these 4 persons is and if the results of this treatment are very interesting results.

Also, I'd like to refer that these persons not actually the target audience of this project because we can understand first of all, if the persons would like to play this type of games in VR and it's necessary to make an upgrade in games environment to experiment these games in persons that as an AVC problems and for this people can play these games with the maximum security.

Before showing these results we will introduce these experiences and what these persons done in order to collect this data for a complete research and investigation of this PhysioAR project thesis.

8.2.Data Analysis of PhysioAR Thesis Project

With all these values that this FisioAR Game System give to us, we can calculate important parameters that can give some physiotherapists a better idea for the evolution of the AVC's patient such as mean deviation, standard deviation, acceleration and trajectory.

For example, with the data displayed and retired from 1ª Person Experiment, we can calculate all these 5 parameters like this:

- Mean Deviation

The mean deviation is defined as a statistical measure that is used to calculate the average deviation from the mean value of the given data set.

Mean Deviation = $1/N \sum n_{i=1} (x_i - m(X))$

M(X)= average value of the data set

N = number of data values

X_i= data values in the set

- Standard Deviation

A standard deviation (or σ) is a measure of how dispersed the data is in relation to the mean. Low standard deviation means data are clustered around the mean, and high standard deviation indicates data are more spread out. A standard deviation close to zero indicates that data points are close to the mean, whereas a high or low standard deviation indicates data points are respectively above or below the mean.

Standard Deviation = $\sqrt{(\sum(x_i - \mu)^2)} /N$

N= the size of population

X_i = each value from the population

μ=the population mean

- Variance

The term variance refers to a statistical measurement of the spread between numbers in a data set. More specifically, variance measures how far each number in the set is from the mean (average), and thus from every other number in the set.

$V = (\sqrt{(\sum(x_i - \mu)^2)} /N)^2$

N= the size of population

X_i = each value from the population

μ=the population mean

- Average Acceleration

Average acceleration refers to the rate at which the velocity changes. We divide the change in velocity by an elapsed time to find out the average acceleration of anything. For instance, if the velocity of a crazy ball increases from 0 to 60 cm/s in 3 seconds, the average acceleration of the ball would be 20 cm/s/s.

$A = \sum n_{i=1} ((v – v0)/t)/N = \sum n_{i=1}$ (delta v/ delta t)/N

A= Average Acceleration

V= final velocity

V_0=Starting velocity

T = elapsed time

N= the size of population

- Average Velocity

Average velocity is defined as the change in position or displacement (Δx) divided by the time intervals (Δt) in which the displacement occurs. The average velocity can be positive or negative depending upon the sign of the displacement.

$V = \sum n_{i=1} ((x – x0)/t)N = \sum n_{i=1}$ (delta x/ delta t)/N

V= Average Velocity

x= final position

x_0=Starting position

T = elapsed time

N= the size of population

8.3.Organization of the Results obtained in the tests realized:

After all Volunteers realized all the three games composed by FisioAR thesis, the results are displayed in the sections below in order to treat all these results and all these movements and positions made by the person who was in the game experience with this order for a better organization and treatment of the results:

- Puzzle Game
- Boxes Game
- Garden Care Game

Puzzle Game

In the first game we have a scenario with four different difficult puzzles:

- Easy Puzzle
- Medium Puzzle
- Hard Puzzle
- Very Hard Puzzle

These 4 different levels has, between each of one, the difference related to the number of the pieces presented in the game scenario:

- 3 pieces for Easy Puzzle

- 4 pieces for Medium Puzzle
- 6 pieces for Hard Puzzle
- 9 pieces for Very Hard Puzzle

The number of the pieces are chosen with the real perspective that the game was made for people with disability and for people that don't have all you capability during the process of recovery/rehabilitation.

So for the results we have this section different of the other games because of the number of level and scenarios created by the game:

- Easy Puzzle: 1º Experiment: - Data 2º Experiment: - Data
- Medium Puzzle: 1º Experiment: - Data Table
- Hard Puzzle: 1º Experiment: - Data
- Very Hard Puzzle: 1º Experiment: - Data

Box Game

For Box Game we measure 5 different parameters with the main goal of treat this data after the patient played this game two times.

In the first game we have a scenario with four different difficult puzzles:

- Easy Boxes
- Medium Boxes
- Hard Boxes

These 3 different levels have between each of one the difference related to the number of the pieces presented in the game scenario:

- 3 pieces for Easy Boxes
- 4 pieces for Medium Boxes
- 6 pieces for Hard Boxes

So for the results we have this section different of the other games because of the number of level and scenarios created by the game:

- Easy Box: 1º Experiment: - Data
- Medium Box: 1º Experiment: - Data
- Hard Box: 1º Experiment: - Data

8.4.VR Data Treatment Results

In these sections these Data Treatment Analysis will be an explanation of the results above calculated in each game played and comparing the values with each different persons that made these experiments.

#001 Volunteer Results

In order to treat and make an analysis about the number that has been a result of these 4 experiments and all tests that has been recorded, saved the important values presented in controllers and headsets sensors in Oculus Quest, now it's time to make an interpretation about all these values and what actually they say to us and if exists any difference or any point that influenced unexpected results in PhysioAR games 1º Person experiment: Puzzle Game that has 4 different levels according to number of phots, Box Games that has 3 different levels according to number of balls and boxes and Garden Care Game.

Puzzle Game

For the 4 levels played by the 1º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Puzzle game with different levels with main objective to collect and treat our data extracted from oculus Quest and controllers sensors.

Data:

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*8,811E-15*	*12,656*	*-3,41061E-15 m*	*4,12115E-15 m*	*1,84741E-15 m*
Standard Deviation	*7,8703962*	*6,437744*	*3,629214791 m*	*3,352620468 m*	*3,529410149 m*
Variance	*61,943136*	*41,44454*	*13,1712 m*	*11,240064 m*	*12,456736 m*
Average Velocity	*-*	*-*	*-0,069333333 m/s*	*-0,08133333 m/s*	*-0,07933333 m/s*
Average Acceleration	*-*	*-*	*0,003333333* m/s^2	*-0,00022222* m/s^2	*-0,00088889* m/s^2

Table 6 - Data for 1º Person Puzzle Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*0,48*	*12,112*	*1,312 m*	*0,824 m*	*1,124 m*
Standard Deviation	*5,6708603*	*5,242399*	*3,90693742 m*	*3,248807781 m*	*3,169191695 m*
Variance	*32,158656*	*27,48275*	*15,26416 m*	*10,554752 m*	*10,043776 m*
Average Velocity	*-*	*-*	*-0,078 m/s*	*-0,09666667 m/s*	*-0,10466667 m/s*
Average Acceleration	*-*	*-*	*0,006444444* m/s^2	*-0,00222222* m/s^2	*-0,00088889* m/s^2

Table 7 - Data for 1º Person Puzzle Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*0,116*	*14,612*	*0,484 m*	*-0,32 m*	*-0,24 m*
Standard Deviation	*6,079546*	*7,215813*	*2,924776915 m*	*1,9052097 m*	*2,186086915 m*
Variance	*36,96088*	*52,06795*	*8,55432 m*	*3,629824 m*	*4,778976 m*
Average Velocity	*-*	*-*	*-0,095333333 m/s*	*-0,10466667 m/s*	*-0,09933333 m/s*

Average Acceleration	***-***	***-***	***0,002333333 m/s^2***	***-0,00077778 m/s^2***	***-0,002 m/s^2***

Table 8 - Data for 1º Person Puzzle Game 1º Experiment on Hard Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***1,4***	***14,496***	***2,688 m***	***2,08 m***	***2,272 m***
Standard Deviation	***9,536495***	***6,480128***	***4,632476659 m***	***4,305464435 m***	***3,821727358 m***
Variance	***90,944736***	***41,99206***	***21,45984 m***	***18,537024 m***	***14,6056 m***
Average Velocity	***-***	***-***	***-0,118666667 m/s***	***-0,118 m/s***	***-0,11666667 m/s***
Average Acceleration	***-***	***-***	***0,000666667 m/s^2***	***0,002333333 m/s^2***	***0,000888889 m/s^2***

Table 9 - Data for 1º Person Puzzle Game 1º Experiment on Very Hard Level

Box Game

For the 3 levels played by the 1º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Box game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***1,708***	***15,252***	***2,076 m***	***1,704 m***	***1,732 m***
Standard Deviation	***8,7731527***	***6,956628***	***4,549206524 m***	***3,990452606 m***	***4,180908992 m***
Variance	***76,968208***	***48,39467***	***20,69528 m***	***15,923712 m***	***-0,00133333 m***
Average Velocity	***-***	***-***	***-0,112666667 m/s***	***-0,11866667 m/s***	***-0,11666667 m/s***
Average Acceleration	***-***	***-***	***0,002555556 m/s^2***	***-0,00077778 m/s^2***	***-0,00133333 m/s^2***

Table 10 - Data for 1º Person Box Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,372***	***15,136***	***1,944 m***	***1,728 m***	***1,452 m***
Standard Deviation	***8,8471003***	***7,209798***	***4,164939375 m***	***4,12591808 m***	***3,559887639 m***

Variance	***78,271184***	***51,98118***	***17,34672 m***	***17,0232 m***	***12,6728 m***
Average Velocity	***-***	***-***	***-0,116 m/s***	***-0,11466667 m/s***	***-0,11733333 m/s***
Average Acceleration	***-***	***-***	***0,001111111 m/s^2***	***-0,00133333 m/s^2***	***0 m/s^2***

Table 11 - Data for 1º Person Box Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,204***	***15,108***	***1,472 m***	***1,352 m***	***1,308 m***
Standard Deviation	***7,6453039***	***7,757788***	***4,192870139 m***	***4,056635059 m***	***3,882028336 m***
Variance	***58,450672***	***60,18328***	***17,58016 m***	***16,456288 m***	***15,070144 m***
Average Velocity	***-***	***-***	***-0,125333333 m/s***	***-0,12266667 m/s***	***-0,12533333 m/s***
Average Acceleration	***-***	***-***	***-0,00244444 m/s^2***	***0,002333333 m/s^2***	***0,002111111 m/s^2***

Table 12 - Data for 1º Person Box Game 1º Experiment on Hard Level

Garden Care Game

For the 1 level played by the 1º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Garden Care game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,352***	***14,4332***	***2,252 m***	***2,252 m***	***1,932 m***
Standard Deviation	***9,9491861***	***6,028216***	***2,252 m***	***2,252 m***	***2,523489647 m***
Variance	***98,986304***	***36,33939***	***11,35496***	***11,35496***	***6,368 m***
Average Velocity	***-***	***-***	***-0,131333333 m/s***	***-0,131333333 m/s***	***-0,12733333 m/s***
Average Acceleration	***-***	***-***	***-0,00211111 m/s^2***	***-0,00211111 m/s^2***	***0,001666667 m/s^2***

Table 13 - Data for 1º Person Garden Care Game 1º Experiment on Easy Level

#002 Volunteer Results

Now it's time to make an interpretation about all these values and what they say to us and if exists any difference or any point that influenced unexpected results in PhysioAR games 2º Person experiment: Puzzle Game that has 4 different levels according to number

of phots, Box Games that has 3 different levels according to number of balls and boxes and Garden Care Game.

Puzzle Game

For the 4 levels played by the 2º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Puzzle game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*-0,364*	*18,252*	*4,02 m*	*3,612 m*	*4,212 m*
Standard Deviation	*6,0513602*	*9,169748*	*5,406255636 m*	*5,216455502 m*	*2,988377486 m*
Variance	*36,61896*	*84,08427*	*29,2276 m*	*27,211408 m*	*8,9304 m*
Average Velocity	*-*	*-*	*-0,102666667 m/s*	*-0,09466667 m/s*	*-0,136 m/s*
Average Acceleration	*-*	*-*	*-0,00222222* m/s^2	*0,002* m/s^2	*-0,00133333* m/s^2

Table 14 - Data for 2º Person Puzzle Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*2,456*	*14,684*	*1,984 m*	*1,82 m*	*1,792 m*
Standard Deviation	*10,895203*	*6,787757*	*3,663047911 m*	*3,554982982 m*	*3,01157766 m*
Variance	*118,70544*	*46,07365*	*13,41792 m*	*12,637904 m*	*9,0696 m*
Average Velocity	*-*	*-*	*-0,098 m/s*	*-0,094 m/s*	*-0,096 m/s*
Average Acceleration	*-*	*-*	*0,000888889* m/s^2	*-0,00066667* m/s^2	*-0,00022222* m/s^2

Table 15 - Data for 2º Person Puzzle Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*2,5*	*14,92*	*2,456 m*	*1,976 m*	*2,516 m*
Standard Deviation	*9,615297*	*6,796712*	*4,188899617 m*	*3,910981462 m*	*3,898385307 m*
Variance	*92,453936*	*46,1953*	*17,54688 m*	*15,295776 m*	*15,197408 m*
Average Velocity	*-*	*-*	*-0,123333333 m/s*	*-0,11733333 m/s*	*-0,118 m/s*

Average Acceleration	***-***	***-***	***0,000222222 m/s^2***	***-0,00133333 m/s^2***	***-0,001 m/s^2***

Table 16 - Data for 2º Person Puzzle Game 1º Experiment on Hard Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,616***	***15,32***	***2,568 m***	***1,944 m***	***2,176 m***
Standard Deviation	***9,618923***	***6,568234***	***4,139062696 m***	***3,817144482 m***	***3,332729812 m***
Variance	***92,52368***	***43,1417***	***17,13184 m***	***14,570592 m***	***11,107088 m***
Average Velocity	***-***	***-***	***-0,117333333 m/s***	***-0,118 m/s***	***-0,11666667 m/s***
Average Acceleration	***-***	***-***	***0,000222222 m/s^2***	***0,001111111 m/s^2***	***-0,00011111 m/s^2***

Table 17 - Table 23 - Data for 2º Person Puzzle Game 1º Experiment on Very Hard Level

Box Game

For the 3 levels played by the 1º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Puzzle game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,076***	***13,904***	***2,548 m***	***2,068 m***	***2,136 m***
Standard Deviation	***9,3842805***	***6,480849***	***4,536368592 m***	***4,262496921 m***	***3,836150153 m***
Variance	***88,06472***	***42,00141***	***20,57864 m***	***18,16888 m***	***14,716048 m***
Average Velocity	***-***	***-***	***-0,110666667 m/s***	***-0,10466667 m/s***	***-0,108 m/s***
Average Acceleration	***-***	***-***	***0,000222222 m/s^2***	***-0,00044444 m/s^2***	***-0,00055556 m/s^2***

Table 18 - Data for 2º Person Box Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***1,736***	***15,108***	***1,824 m***	***1,292 m***	***1,816 m***
Standard Deviation	***9,4999453***	***6,596065***	***4,321610811 m***	***3,937050673 m***	***3,874208048 m***
Variance	***90,24896***	***43,50808***	***18,67632 m***	***15,500368 m***	***15,009488 m***
Average Velocity	***-***	***-***	***-0,097333333 m/s***	***-0,10333333 m/s***	***-0,11066667 m/s***

Average Acceleration	***-***	***-***	***0,002111111 m/s^2***	***-0,001 m/s^2***	***0,001 m/s^2***

Table 19 - Data for 2º Person Box Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,124***	***14,372***	***1,988 m***	***1,508 m***	***1,668 m***
Standard Deviation	***9,3152752***	***6,279143***	***4,174714361 m***	***3,985042032 m***	***3,705161805 m***
Variance	***86,774352***	***39,42763***	***17,42824 m***	***15,88056 m***	***13,728224 m***
Average Velocity	***-***	***-***	***-0,11 m/s***	***-0,11733333 m/s***	***-0,11733333 m/s***
Average Acceleration	***-***	***-***	***0,000111111 m/s^2***	***0,001666667 m/s^2***	***0,001222222 m/s^2***

Table 20 - Data for 2º Person Box Game 1º Experiment on Hard Level

Garden Care Game

For the level played by the 1º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Garden Care game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,616***	***15,232***	***0,888 m***	***0,364 m***	***0,388 m***
Standard Deviation	***8,727593***	***7,307346***	***3,029825077 m***	***2,77640631 m***	***3,029650805 m***
Variance	***76,17088***	***53,39731***	***9,17984 m***	***-0,10466667 m***	***9,178784 m***
Average Velocity	***-***	***-***	***-0,110666667 m/s***	***-0,10466667 m/s***	***-0,108 m/s***
Average Acceleration	***-***	***-***	***-0,00122222 m/s^2***	***0,001222222 m/s^2***	***0,001111111 m/s^2***

Table 21 - Data for 2º Person Garden Care Game 1º Experiment on Easy Level

#003 Volunteer Results

Now it's time to make an interpretation about all these values and what they say to us and if exists any difference or any point that influenced unexpected results in PhysioAR games 3º Person experiment: Puzzle Game that has 4 different levels according to number of phots, Box Games that has 3 different levels according to number of balls and boxes and Garden Care Game.

Puzzle Game

For the 4 levels played by the 3º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Puzzle game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*8,81E-15*	*12,656*	*0,204 m*	*-0,384 m*	*-0,212 m*
Standard Deviation	*7,870396*	*6,437744*	*3,123831 m*	*3,149898 m*	*3,297976 m*
Variance	*61,94314*	*41,44454*	*9,75832 m*	*9,921856 m*	*10,87665 m*
Average Velocity	*-*	*-*	*-0,08933 m/s*	*-0,08133 m/s*	*-0,086 m/s*
Average Acceleration	*-*	*-*	*-0,00011* m/s^2	*-0,00022* m/s^2	*0,000222* m/s^2

Table 22 - Data for 3º Person Puzzle Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*2,284*	*14,412*	*1,684 m*	*1,236 m*	*1,304 m*
Standard Deviation	*9,6501084*	*6,68646*	*4,14457718 m*	*4,180776961 m*	*3,69338219 m*
Variance	*93,124592*	*44,70875*	*17,17752 m*	*17,478896 m*	*13,641072 m*
Average Velocity	*-*	*-*	*-0,104 m/s*	*-0,096 m/s*	*-0,10533333 m/s*
Average Acceleration	*-*	*-*	*-0,00233333* m/s^2	*0,002111111* m/s^2	*0,002111111* m/s^2

Table 23 - Data for 3º Person Puzzle Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*1,652*	*14,28*	*2,152 m*	*1,872 m*	*8,288 m*
Standard Deviation	*9,6280166*	*6,242097*	*4,4561149 m*	*4,29885194 m*	*3,879032869 m*
Variance	*92,698704*	*38,96378*	*19,85696 m*	*18,480128 m*	*15,046896 m*
Average Velocity	*-*	*-*	*-0,110666667 m/s*	*-0,10266667 m/s*	*-0,10266667 m/s*
Average Acceleration	*-*	*-*	*-0,00122222* m/s^2	*-0,00122222* m/s^2	*-0,00133333* m/s^2

Table 24 - Data for 3º Person Puzzle Game 1º Experiment on Hard Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*1,852*	*14,632*	*2,364 m*	*1,94 m*	*1,984 m*

Standard Deviation	***8,5564189***	***6,925064***	***4,513260462 m***	***4,336005535 m***	***3,809770597 m***
Variance	***73,212304***	***47,95651***	***20,36952 m***	***18,800944 m***	***14,514352 m***
Average Velocity	*-*	*-*	***-0,116666667 m/s***	***-0,118 m/s***	***-0,11733333 m/s***
Average Acceleration	*-*	*-*	***-0,00088889 m/s^2***	***0,002444444 m/s^2***	***0,001555556 m/s^2***

Table 25 - Data for 3º Person Puzzle Game 1º Experiment on Very Hard Level

Box Game

For the 3 levels played by the 3º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Box game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,144***	***13,628***	***1,448 m***	***1,056 m***	***1,548 m***
Standard Deviation	***6,663635***	***6,023906***	***3,689205877 m***	***3,429276308 m***	***3,892565221 m***
Variance	***44,404032***	***36,28744***	***13,61024 m***	***11,759936 m***	***15,152064 m***
Average Velocity	*-*	*-*	***-0,116666667 m/s***	***-0,118 m/s***	***-0,11733333 m/s***
Average Acceleration	*-*	*-*	***-0,00233333 m/s^2***	***0,002444444 m/s^2***	***0,005444444 m/s^2***

Table 26 - Data for 3º Person Box Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***1,7108***	***14,064***	***2,776 m***	***2,36 m***	***2,512 m***
Standard Deviation	***8,4542178***	***6,725912***	***4,685176624 m***	***4,601954367 m***	***4,124775873 m***
Variance	***71,473799***	***45,23789***	***21,95088 m***	***21,177984 m***	***17,013776 m***
Average Velocity	*-*	*-*	***-0,111333333 m/s***	***-0,11 m/s***	***-0,11066667 m/s***
Average Acceleration	*-*	*-*	***-0,001 m/s^2***	***0,001222222 m/s^2***	***0,001 m/s^2***

Table 27 - Data for 3º Person Box Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***3,74***	***14,836***	***1,912 m***	***1,484 m***	***1,704 m***

Standard Deviation	***9,2554684***	***6,156101***	***4,492500417 m***	***4,485919304 m***	***4,290654029 m***
Variance	***85,663696***	***37,89758***	***20,18256 m***	***20,123472 m***	***18,409712 m***
Average Velocity	*-*	*-*	***-0,102666667 m/s***	***-0,10333333 m/s***	***-0,10266667 m/s***
Average Acceleration	*-*	*-*	***0,001333333 m/s^2***	***-0,00011111 m/s^2***	***-0,001 m/s^2***

Table 28 - Data for 3º Person Box Game 1º Experiment on Hard Level

Garden Care Game

For the level played by the 3º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Garden Care game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***1,108***	***14,9664***	***2,052 m***	***1,2 m***	***0,54064 m***
Standard Deviation	***8,3870023***	***6,259415***	***4,304388458 m***	***3,251963099 m***	***2,373372015 m***
Variance	***70,341808***	***39,18028***	***18,52776 m***	***10,575264 m***	***5,63289472 m***
Average Velocity	*-*	*-*	***-0,117333333 m/s***	***-0,11533333 m/s***	***0,044666667 m/s***
Average Acceleration	*-*	*-*	***-0,00055556 m/s^2***	***0,000555556 m/s^2***	***0,002555556 m/s^2***

Table 29 - Data for 3º Person Garden Care Game 1º Experiment on Easy Level

#004 Volunteer Results

Now it's time to make an interpretation about all these values and what they want to say to us and if exists any difference or any point that influenced unexpected results in PhysioAR games 4º Person experiment: Puzzle Game that has 4 different levels according to number of phots, Box Games that has 3 different levels according to number of balls and boxes and Garden Care Game.

Puzzle Game

For the 3 levels played by the 4º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments

and played the Puzzle game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation	*Left Controller Rotation*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*1,828*	*14*	*1,912 m*	*1,484 m*	*1,704 m*
Standard Deviation	*9,143822*	*6,549987*	*4,4925 m*	*4,485919 m*	*4,290654 m*
Variance	*83,60949*	*42,90234*	*20,18256 m*	*20,12347 m*	*18,40971 m*
Average Velocity	*-*	*-*	*-0,10867 m/s*	*-0,10267 m/s*	*-0,112 m/s*
Average Acceleration	*-*	*-*	*-0,00089* m/s^2	*0,000778* m/s^2	*0,001889* m/s^2

Table 30 - Data for 4º Person Puzzle Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*-0,236*	*15,08*	*2,052 m*	*1,2 m*	*1,216 m*
Standard Deviation	*12,264066*	*6,612517*	*4,304388458 m*	*3,251963099 m*	*3,107830111 m*
Variance	*150,40731*	*43,72538*	*18,52776 m*	*10,575264 m*	*9,658608 m*
Average Velocity	*-*	*-*	*-0,104 m/s*	*-0,102 m/s*	*-0,102 m/s*
Average Acceleration	*-*	*-*	*0* m/s^2	*0,001* m/s^2	*0,000444444* m/s^2

Table 31 - Data for 4º Person Puzzle Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*2,448*	*14,028*	*0,004 m*	*-0,776 m*	*-0,448 m*
Standard Deviation	*9,4571438*	*6,333738*	*2,818212199 m*	*2,896265181 m*	*3,318869687 m*
Variance	*89,437568*	*40,11624*	*7,94232 m*	*8,388352 m*	*11,014896 m*
Average Velocity	*-*	*-*	*-0,102666667 m/s*	*-0,10133333 m/s*	*-0,10266667 m/s*
Average Acceleration	*-*	*-*	*-0,00222222* m/s^2	*0,003111111* m/s^2	*0,002888889* m/s^2

Table 32 - Data for 4º Person Puzzle Game 1º Experiment on Hard Level

	Right Controller Rotation (˚)	*Left Controller Rotation (˚)*	*Right Controller Position*	*Left Controller Position*	*Headset Position*
Mean Deviation	*1,452*	*14,664*	*1,684 m*	*1,236 m*	*1,304 m*
Standard Deviation	*9,4558926*	*7,004819*	*4,14457718 m*	*4,180776961 m*	*3,694335123 m*

Variance	***89,413904***	***49,06749***	***17,17752 m***	***17,478896 m***	***13,648112 m***
Average Velocity	***-***	***-***	***-0,110666667 m/s***	***-0,10466667 m/s***	***-0,10933333 m/s***
Average Acceleration	***-***	***-***	***-0,00233333 m/s^2***	***0,002333333 m/s^2***	***0,002555556 m/s^2***

Table 33 - Data for 4º Person Puzzle Game 1º Experiment on Very Hard Level

Box Game

For the 3 levels played by the 4º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Box game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***2,348***	***14,952***	***2,152 m***	***1,872 m***	***1,948 m***
Standard Deviation	***9,4792177***	***6,584153***	***4,4561149 m***	***4,29885194 m***	***3,877223749 m***
Variance	***89,855568***	***43,35107***	***19,85696 m***	***18,480128 m***	***15,032864 m***
Average Velocity	***-***	***-***	***-0,117333333 m/s***	***-0,11 m/s***	***-0,114 m/s***
Average Acceleration	***-***	***-***	***-0,00122222 m/s^2***	***0,001111111 m/s^2***	***0,001222222 m/s^2***

Table 34 - Data for 4º Person Box Game 1º Experiment on Easy Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***-0,78***	***14,46***	***2,364 m***	***1,94 m***	***1,984 m***
Standard Deviation	***11,690441***	***7,11781***	***4,513260462 m***	***4,336005535 m***	***3,809770597 m***
Variance	***136,66642***	***50,66322***	***20,36952 m***	***18,800944 m***	***14,514352 m***
Average Velocity	***-***	***-***	***-0,108 m/s***	***-0,104 m/s***	***-0,106 m/s***
Average Acceleration	***-***	***-***	***0,001222222 m/s^2***	***-0,001 m/s^2***	***-0,00022222 m/s^2***

Table 35 - Data for 4º Person Box Game 1º Experiment on Medium Level

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***1,748***	***11,84***	***1,448 m***	***1,056 m***	***1,548 m***
Standard Deviation	***8,6050432***	***7,413465***	***3,689205877 m***	***3,429276308 m***	***3,888452649 m***

Variance	***74,046768***	***54,95946***	***13,61024 m***	***11,759936 m***	***15,120064 m***
Average Velocity	***-***	***-***	***-0,122 m/s***	***-0,11733333 m/s***	***-0,12 m/s***
Average Acceleration	***-***	***-***	***-0,001333333 m/s^2***	***0,001222222 m/s^2***	***0,001222222 m/s^2***

Table 36 - Data for 4º Person Box Game 1º Experiment on Hard Level

Garden Care Game

For the level played by the 4º Person the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

Now we will present all the values recorded and saved to the Database specifically created for this project and will present these values, your interpretation and comparing these values with the values from another person that participates in these experiments and played the Garden Care game with different levels with main objective to collect and treat our data extracted from oculus Quest and controller's sensors.

Data:

	Right Controller Rotation (˚)	***Left Controller Rotation (˚)***	***Right Controller Position***	***Left Controller Position***	***Headset Position***
Mean Deviation	***1,56***	***13,868***	***2,776 m***	***2,36 m***	***2,512 m***
Standard Deviation	***7,372854***	***5,635154***	***4,685176624 m***	***4,601954367 m***	***4,124775873 m***
Variance	***54,358976***	***31,75496***	***21,95088 m***	***21,177984 m***	***17,013776 m***
Average Velocity	***-***	***-***	***-0,11 m/s***	***-0,10266667 m/s***	***-0,10666667 m/s***
Average Acceleration	***-***	***-***	***0,001222222 m/s^2***	***-0,001 m/s^2***	***-0,00111111 m/s^2***

Table 37 - Data for 4º Person Garden Care Game 1º Experiment on Easy Level

8.5.Data Treatment Analysis Criteria

Topics to comments from table displayed above:

There are 4 different types of criteria in the analysis of these results:

1º - 4 Different Persons -> #001 Volunteer
-> #002 Volunteer
-> #003 Volunteer
-> #004 Volunteer

2º - 3 Hardware Components -> Oculus/Meta Quest
-> Right Controller
-> Left Controller

3º - 3 Unity 3D Games -> Puzzle Game
-> Box Game
-> Garden Care Game

4º - 5 Treated Values -> Mean Deviation
-> Standard Deviation
-> Variance
-> Average Velocity
-> Average Acceleration

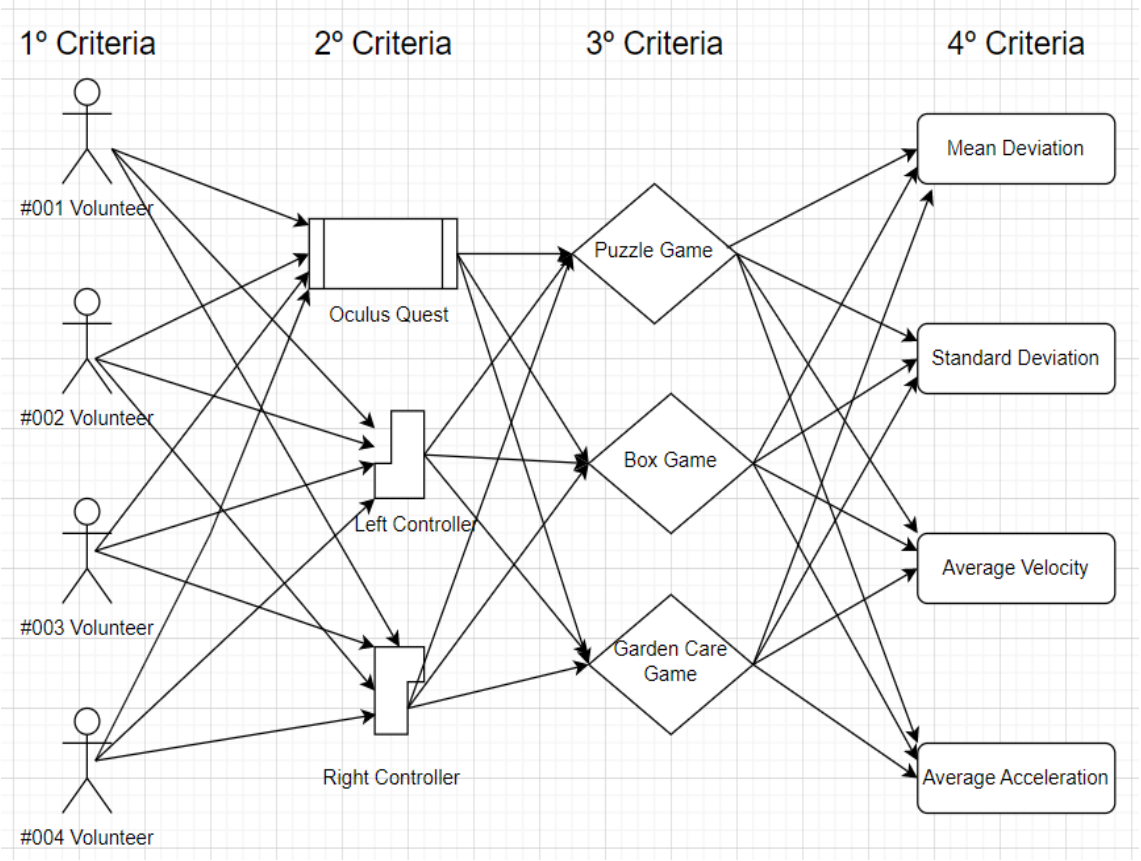

Fig.69. Four Criteria Diagram

Each person used the same Oculus Quest to carry out the experimental tests for the 3 games implemented.

Both in the Puzzle game and in the Boxes game and taking care of the Garden, the position of the Controllers and the Oculus Quest and the rotation of the controllers of the existing sensors in the Hardware components chosen for the practical project developed were measured.

After extracting that same information through the existing sensors in the described components, they are treated using a specific script for the purpose and are calculated, in order to proceed with the treatment of the collected information, starting the most important process in this work, the process of collection, processing of information, storage of information and subsequent analysis of that same set of a health professional who is treating the patient in question, taking into account a chronological sequence of each patient.

In the process of processing the information, the information on the positions and rotations of the 3 hardware components existing in the developed environment are treated and converted into 5 different types of values in order to be able to understand the impact and difference of these values considering the different criteria mentioned in the diagram presented above.

It should be noted that these same volunteers are not the target audience for the practical project, however, we thought it best to test with healthy and physically fit people as the use of Virtual Reality glasses can cause a certain insecurity to people who are physically weaker due to losing track of real space when playing any kind of game on these same glasses.

Because of this and the characteristics of our games, we have made a strong effort to implement all games in Augmented Reality to allow the patient greater peace of mind and confidence in the use of glasses.

In our opinion and with all the software components that we have reinforced, it is only a matter of the patient being able to adapt to a "New Reality" that today's new technologies allow.

Next, we will analyze the different criteria considered and then analyze the results obtained considering all the factors.

8.5.1. 1º Criteria - 4 Different Volunteers

In this first considered criterion, all the differences in each of the considered volunteers are considered, namely the weight, the size and the agility with which they executed the movements.

Not being our target audience, the data we have for analysis are only test data that may indicate whether there are notable differences considering the aspects mentioned above.

In the case of the 4 volunteers considered for a first approach to our experimental part, they are all healthy and in good physical condition, not having any motor or mental difficulty in carrying out the movements and activities required in the games requested in the developed project.

Since this project will continue to be developed, new tests and new improvements will be carried out with the main intention of being able to understand if this project has some kind of viability in its future use for eventual recoveries in rehabilitation clinics destined for this purpose.

8.5.2. 2º Criteria - 3 Hardware Components

In this second considered criterion, 3 components were used and, in this aspect, the material used to carry out the test was the same for carrying out the various tests with the 4 volunteers chosen to carry out the same.

Oculus/Meta Quest with the aim of extracting information from the positions of the glasses over the elapsed time of the game played, as well as the rotations of the respective sensors present in the right and left controllers in order to be able to understand the data and which movements they were performed by the volunteer.

In an issue more related to the perception of a patient's evolution, it will only be possible by comparing a considerable number of data over time, so these same tests will only be possible with a target audience, with a considerable period of time and with the adaptations and updates that will still have to be carried out within the scope of this same practical project.

8.5.3. 3º Criteria - 3 Different FisioAR Games developed and Played

Regarding the 3rd criterion that was considered, it is related to the games that were developed: the Puzzle Game, the Box Game and the Garden Care Game.

These 3 types of games also influence the user's movements and subsequently the value of the data that will be passed and treated properly in order to be able to visualize the physiotherapist in the App developed for this purpose, namely all aspects related to the positions of the Game Objects , the difference in distance between the Game Objects that will interact during each game, which has a different interaction in each type of game developed and the obstacles that will be encountered in order to hinder the goals set for each type of game.

Of course, these same obstacles will have to be analyzed and evaluated regarding their impact considering each type of patient, however, as we are still in the testing phase, we restrict ourselves to keeping the maximum number of obstacles that have been developed in each type of game. and which were previously mentioned in the description of the software system.

The game with the least obstacles is the Garden Care Game, the other 2 games are the ones that have more interaction between the idealized and implemented objects and, therefore, the user will have a greater distance covered and a greater number of different movements, which we will analyze all these situations in the analysis that we will do below.

8.5.4. 4º Criteria - 5 Treated Values

The 5 types of values considered in this analysis are mean deviation, standard deviation, variance average velocity and average acceleration values.

The values of mean deviation being able to conclude that the values are not or are far away from the average value that was acquired during each experiment itself.

The standard deviation values mean data are clustered or not around the mean, and high standard deviation indicates data are more spread out. A standard deviation close to zero indicates that data points are close to the mean, whereas a high or low standard deviation indicates data points are respectively above or below the mean.

The variance values also tell us that the values obtained through the controller and headset sensors data that refers to a statistical measurement of the spread between numbers in a data set. More specifically, variance measures how far each number in the set is from the mean (average), and thus from every other number in the set.

The velocity values could explain require much physical effort in the motor parts or any effort for the actions made in the games. With results demonstrates in the tables displayed above we can conclude that the values that we extracted are very low because the fact that this games does not require any extra movements to being well succeed in our purposed games-

The acceleration values are also very low and close to each other in relation to the controller and the headset, which could be explained by the short range of action that a person acts on is also small.

Caption for all graphics below:

#001V = #001 Volunteer
#002V = #002 Volunteer
#003V = #003 Volunteer
#004V = #004 Volunteer

Puzzle Game
Box Game
Garden Care Game

8.6.Right Controller Rotation Graphic Results Analysis

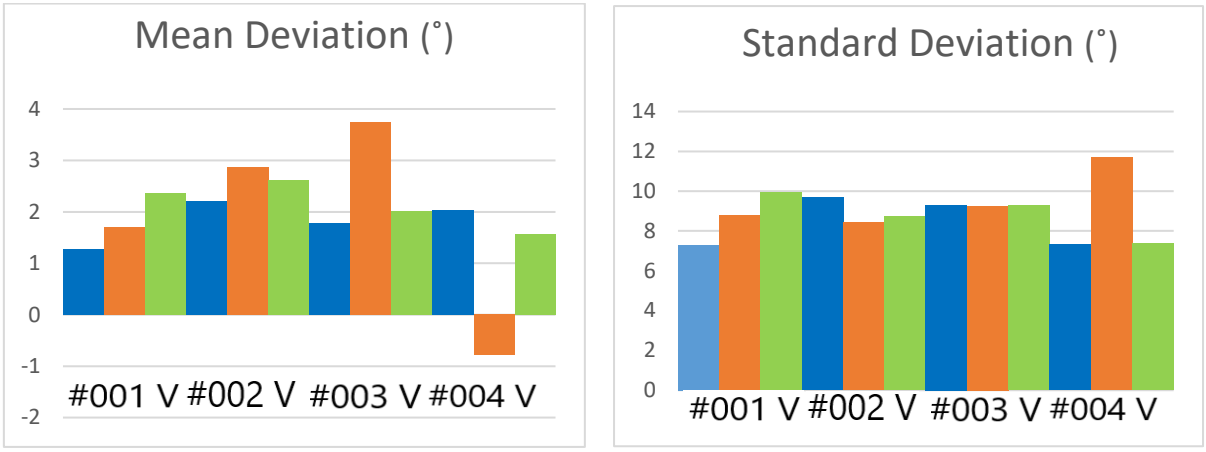

Fig.70. a) Mean Deviation for Right Controller Rotation b) Standard Deviation Values for Right Controller Rotation

The values of mean deviation (Fig.70.a)) are also relatively low and not too far from each other regardless of the game played.

These same close values can be explained by a great proximity of the values of the positions in the different 3D Scenes created in Unity. As the zone/space played on the Oculus Quest turns out to be quite similar, the values also end up being quite close regardless of the objects, and the interactions make the player not walk in the same places with the different games played, being able to conclude that the values are not far away from the average value that was acquired during each experiment itself.

The standard deviation values (Fig.70.b)) are also considered near to the average value because, are low values.

That means data are clustered around the mean, and high standard deviation indicates data are more spread out. A standard deviation close to zero indicates that data points are close to the mean, whereas a high or low standard deviation indicates data points are respectively above or below the mean.

8.7.Left Controller Rotation Graphic Results Analysis

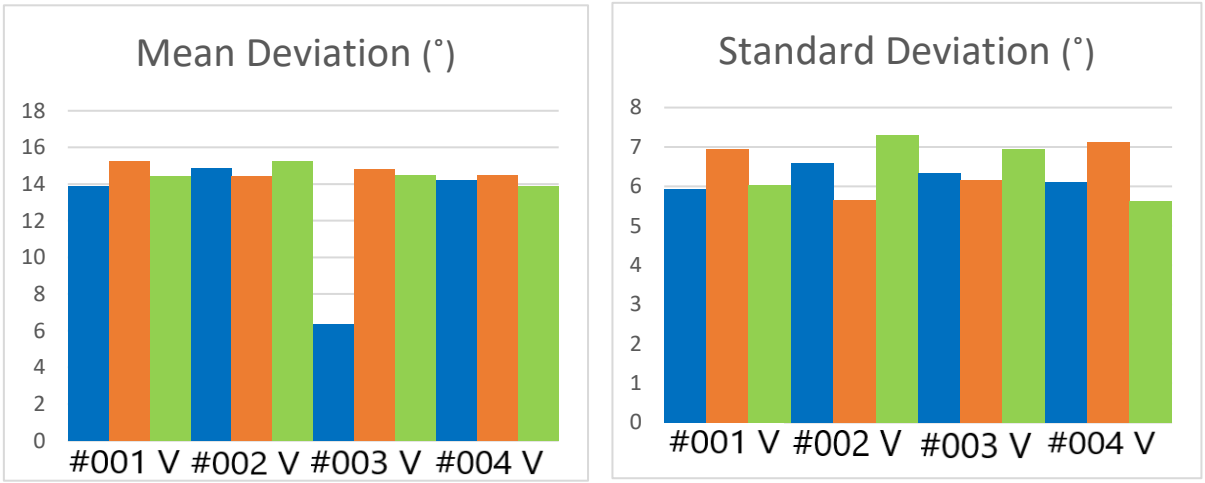

Fig.71 a)Mean Deviation for Left Controller Rotation b)Standard Deviation Values for Left Controller Rotation

Regarding the positions of the controllers and the Oculus Quest, it is natural that the same data in the graphics sampling are very similar with slight differences in the decimal values of each register since both the arms and the body are in very close positions when the values are being removed. by the sensors of both the wearable sensors and the Oculus Quest.

Hence the need to measure other parameters such as the Rotation of arm movement in order to understand the patient's agility and, subsequently, his evolution during the therapy sessions.

The values of mean deviation are also relatively low (Fig.71.a)), being able to conclude that the values are not far away from the average value that was acquired during each experiment itself.

The standard deviation values (Fig.71.b)) are also considered near to the average value because, are low values.

That means data are clustered around the mean, and high standard deviation indicates data are more spread out. A standard deviation close to zero indicates that data points are close to the mean, whereas a high or low standard deviation indicates data points are respectively above or below the mean.

It is very interesting this values because all the volunteers have more high values in the Left Hand than the Right Hand suggesting that the volunteers have more difficult to control our movements with your worse hand with the controllers, having a relation with your strong hand and the results of the rotation Values.

8.8.Right Controller Position Graphic Results Analysis

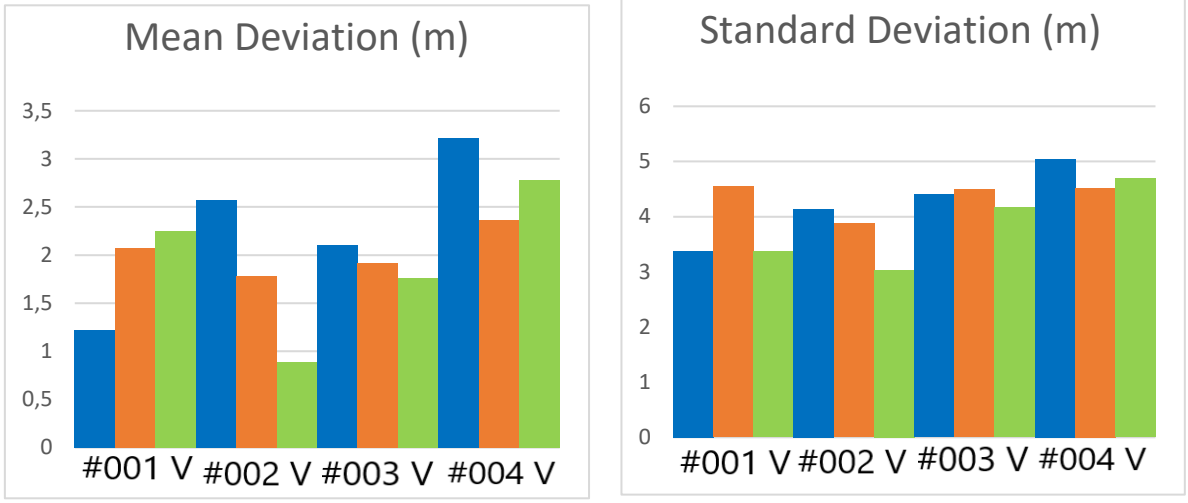

Fig.72. a) Mean Deviation for Right Controller Position b) Standard Deviation Values for Right Controller Position

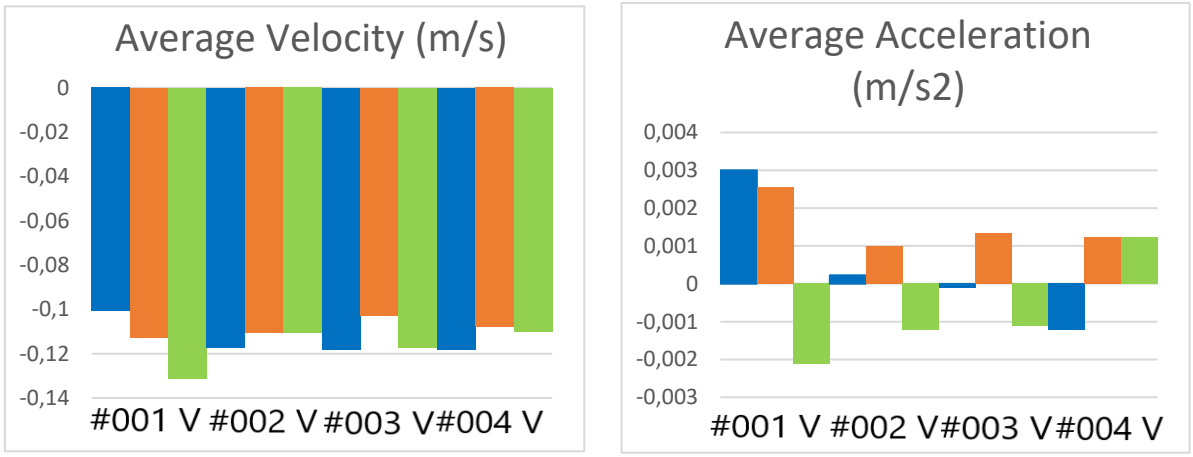

Fig.73. a) Average Velocity for Right Controller Position b) Average Acceleration Values for Right Controller
Position

The values of mean deviation (Fig.72.a)) are also relatively low, being able to conclude that the values are not far away from the average value that was acquired during each experiment itself.

The standard deviation values (Fig.72.b)) are also considered near to the average value because, are low values.

A standard deviation close to zero indicates that data points are close to the mean, whereas a high or low standard deviation indicates data points are respectively above or below the mean.

The variance values also tell us that the values obtained through the controller and headset sensors data that refers to a statistical measurement of the spread between numbers in a data set. More specifically, variance measures how far each number in the set is from the mean (average), and thus from every other number in the set.

The speed values (Fig.73.a)) are very low, close to each other in relation to the controller and the headset and all negative even with different volunteers and Games

which could be explained by the short radius of action that a person acts on is also small and by the fact that the game does not require much physical effort in the motor parts, a since they are sensitive areas for the target audience of this same project and should be worked on gradually according to the evolution of each patient.

The values of average acceleration (Fig.73.b)) in Puzzle Game are positive in #001 and #002 Volunteer and is negative in #003 and #004 Volunteer. In Box Games all Acceleration Values are positive in all Volunteers and in Garden Care Game the #001, #002 and #003 Volunteers are negative and #004 Volunteer has positive value.

The acceleration values are also very low and close to each other in relation to the controller and the headset, which could be explained by the short range of motion that a person acts on is also small.

These values also change in direction and since the values are quite small, it is natural that there is a greater ease in changing the direction of the respective acceleration values.

8.9.Left Controller Position Graphic Results Analysis

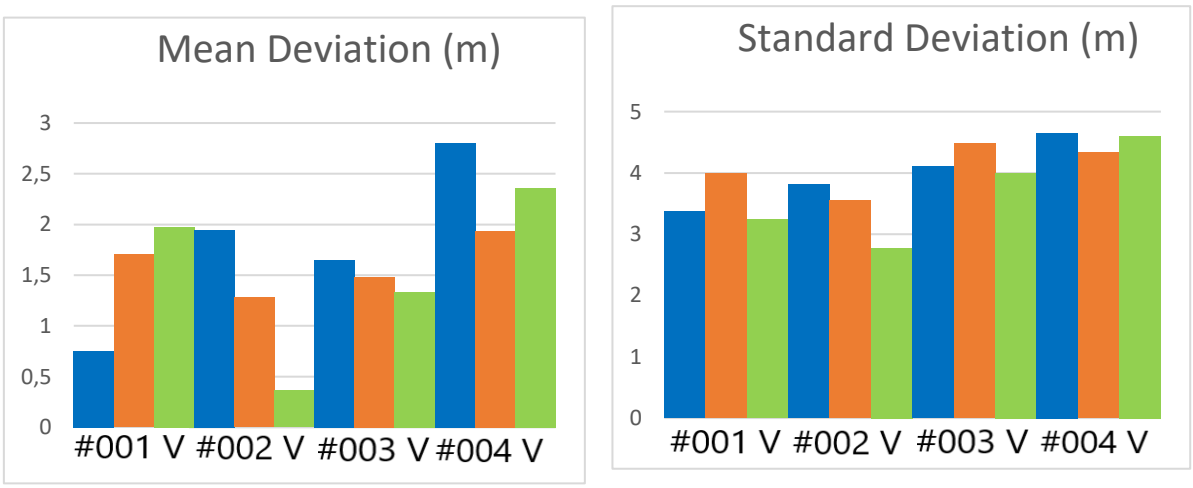

Fig.74. a) Mean Deviation for Left Controller Position b) Standard Deviation Values for Left Controller Position

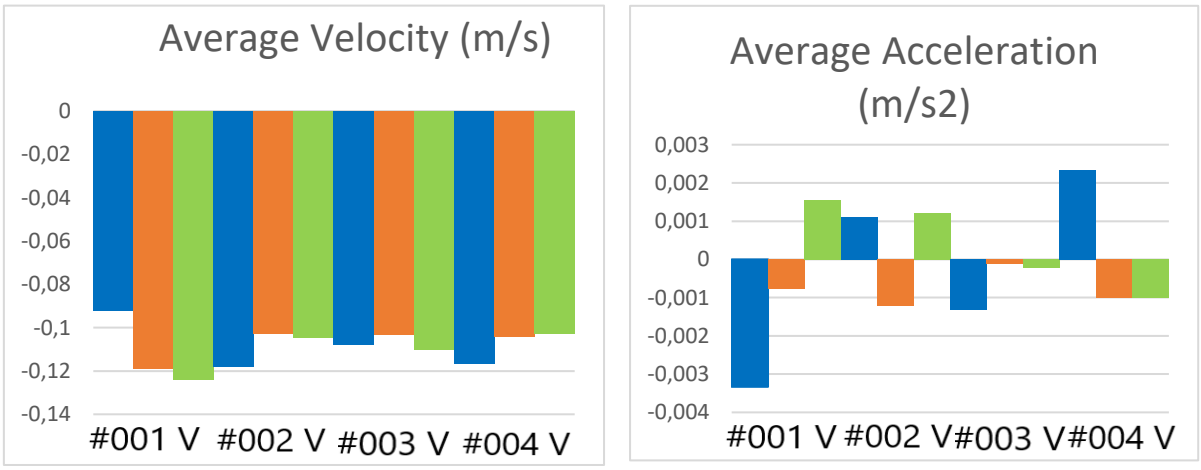

Fig.75. a) Average Velocity for Left Controller Position b) Average Acceleration Values for Left Controller Position

The values of mean deviation (Fig.74.a)) are also relatively low, being able to conclude that the values are not far away from the average value that was acquired during each experiment itself.

The standard deviation values (Fig.74.b)) are also considered near to the average value because, are low values.

That means data are around the mean, and high standard deviation indicates data are more spread out. A standard deviation close to zero indicates that data points are close to the mean, whereas a high or low standard deviation indicates data points are respectively above or below the mean.

The variance values also tell us that the values obtained through the controller and headset sensors data that refers to a statistical measurement of the spread between numbers in a data set. More specifically, variance measures how far each number in the set is from the mean (average), and thus from every other number in the set.

The speed values are very low (Fig.75.a)), close to each other in relation to the controller and the headset and all negative even with different volunteers and Games which could be explained by the short radius of action that a person acts on is also small and by the fact that the game does not require much physical effort in the motor parts, a since they are sensitive areas for the target audience of this same project and should be worked on gradually according to the evolution of each patient.

The values of average acceleration (Fig.75.b)) in Puzzle and Garden Care Games the values are negative in 1º and #003 Volunteer and positive in #002 and #004 Volunteer. In Box Games all Acceleration Values has negative values in all Volunteers.

The acceleration values are very low, close to each other in relation to the controller and the headset and has negative values which could be explained by the short range of action that a person acts on is also small.

Compare each of the results in more detail by suggesting and analyzing each of the existing tables and drawing a possible conclusion.

8.10. Headset Position Graphic Results Analysis

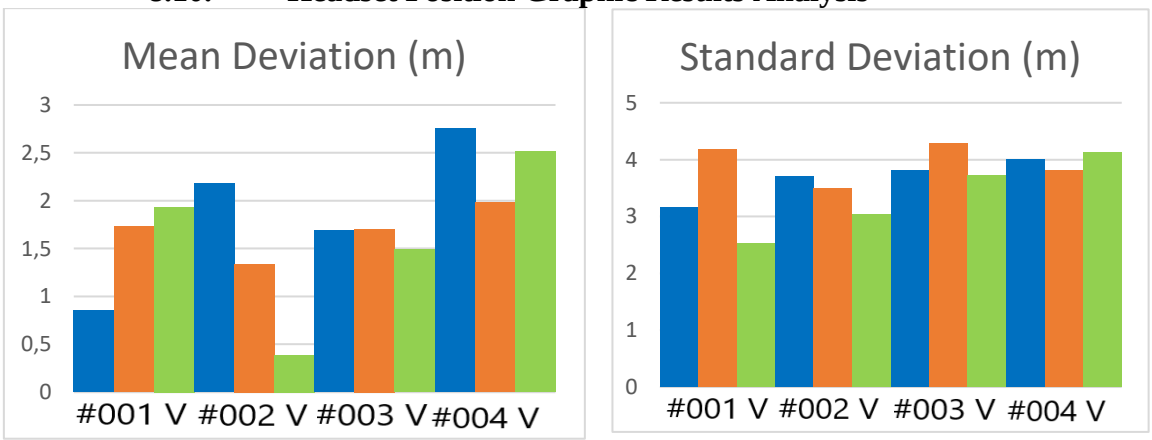

Fig.76. a) Mean Deviation for Headset Position b) Standard Deviation Values for Headset Position

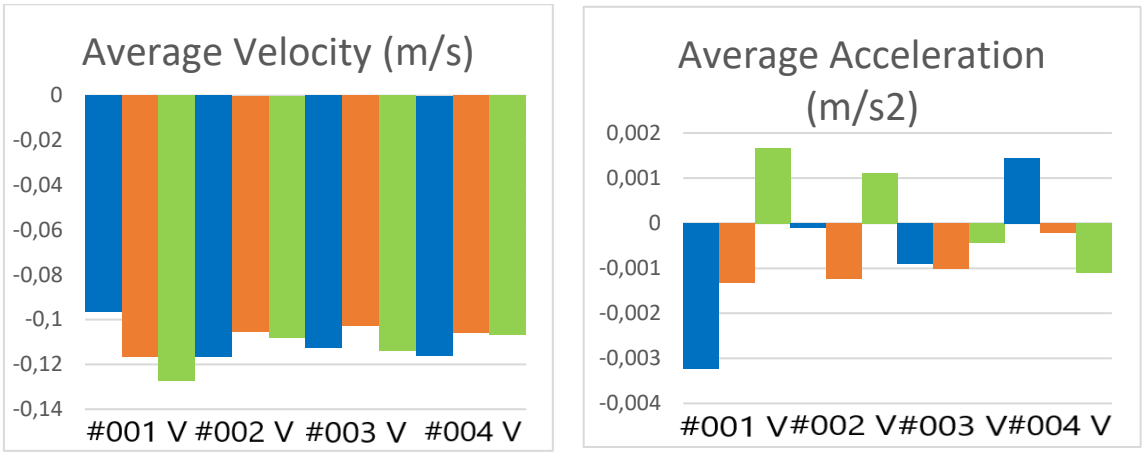

Fig.77. a) Average Velocity for Headset Pos. b) Average Acceleration Values for Headset Pos.

The values of mean deviation (Fig.76.a)) are also relatively low, being able to conclude that the values are not far away from the average value that was acquired during each experiment itself.

The standard deviation values (Fig.76.b)) are also considered near to the average value because, are low values and that means that data are clustered around the mean, and high standard deviation indicates data are more spread out.

The variance values also tell us that the values obtained through the controller and headset sensors data that refers to a statistical measurement of the spread between numbers in a data set. More specifically, variance measures how far each number in the set is from the mean (average), and thus from every other number in the set.

The speed values (Fig.77.a)) are very low, close to each other in relation to the controller and the headset and all negative even with different volunteers and Games which could be explained by the short radius of action that a person acts on is also small and by the fact that the game does not require much physical effort in the motor parts, a since they are sensitive areas for the target audience of this same project and should be worked on gradually according to the evolution of each patient.

The values of average acceleration (Fig.77.b)) in Puzzle and Garden Care Games the values are negative in 1º and 3º Volunteer and positive in #002 and #004 Volunteer. In Box Games all Acceleration Values has negative values in all Volunteers.

The acceleration values are very low and close to each other in relation to the controller and the headset, which could be explained by the short range of action that a person acts on is also small.

8.11. Conclusion of Data Results Analysis

With all these values that this FisioAR Game System give to us, we can calculate important parameters that can give some physiotherapists a better idea for the evolution of the AVC's patient such as mean deviation, standard deviation, variance, acceleration and velocity.

With this perspective, we can measure a lot of parameters and a lot of results, that physiotherapists and other specialists can evaluate the evolution of each patient that use this work/project to do our recover and to do all the steps to conclude successfully and with really good results in all phases of treatment.

With these 5 types of measured parameter values, we were able to find out if the values were very close or not and if some constraints affected the performance of these same values.

The values and results of these values are similar since a person is a present body and that the sensors considering the presented values are in meters, and that makes perfect sense, since these values are relative to the displacement of the person along the path of the virtual game.

In the near future, it will make sense to add new attributes regarding the patient's 3-dimensional movement, which is an increase in values and a facilitating factor in the analysis of results by physiotherapists.

The values collected daily will refer to the minimum and maximum amplitudes for each patient, considering their movements with the sensors of the controllers and the Oculus Meta Quest.

Also, these parameters have a significant impact in all recovery and in mental health because the effectiveness of all results are a good way to make a study about tis two big concepts directly affected by this disease: Mental and Physic Health.

And to finish this article I will make a strong message about this to important concepts that are essentials in our daily routine: We have to make a balance between these two strong words because in life nothing as to be too exaggerated or too scarce.

And effectively this game that we've been designed has this incredible balance to people that suffers this frustrating, and this disabling disease can recover with maximum profitably and maximum comfort ensuring the patient all requirements and all safety mechanisms to do that is appropriated time and with great results in the shortest time possible.

Chapter 9 - Conclusions and Future Work

9.1. Conclusions

This dissertation consists of a system that was developed to be used in physiotherapy, specifically in physical and motor rehabilitation of hands and fingers. The designed technology aims to help healthcare professionals improve their work by effectively monitoring patients and objectively evaluating the results of physiotherapy sessions.

The system consists of a serious physiotherapist gaming system that combines wearable sensors and VR scenarios. The used technology for the VR component was Unity 3D with different scenarios being carried out.

The development phase of the project began with a survey to better understand how serious games should be created and adapted to the needs and preferences of each patient. Subsequently, serious games were developed to respond to those needs and preferences.

The system provides two main tools, a game application that allows patients to perform therapy exercises by playing serious games in virtual reality environments, and another for physiotherapists to visualize the results and manage patients. Patients will also be able to access your data in the mobile application. All the most relevant information, such as exercise scores or movement data collected, is stored on a remote server, which allows communication between the two applications.

Using this system, the physiotherapist can follow the patient during the prescribed training plan for days, weeks or months. Considering the recorded data associated with Wearable and IoT Technologies Application for Physical Rehabilitation ISCTE-IUL.

Thus, Box Game and Garden Care Game were developed for motor rehabilitation and Puzzle Game for cognitive rehabilitation. The values delivered by the system for each one of these different approaches can be used for objective evaluation of physical rehabilitation helping to optimize the training plans based on serious games.

The results displayed and discussed about this project here successfully measured but we want more tests and more upgrades in the future because we believe this kinds of projects are essential for the future of this to big areas: Engineering and Medicine.

It would be great benefits combining this two big areas and with more tests and results we think this project will be a great acceptance between the health workers and with some adjustments about our needs and because some specific patients have different needs. There’s another approach, the adjustment that we has to be considered in this kind of project.

But we believe that the results in our patients will happen soon and that’s the purpose of the continuity of this project.

9.2. Future Work

The project was long and challenger keeping many parts that can be improved in the future. In this way some points can be mentioned:

Performing of an extended study on regarding the selection of the movements that are more appropriate for finger and hand rehabilitation. Through the study, will be performed new games with different themes, allowing a greater variety of exercising plans;

Make serious games even more adaptable to patient characteristics increasing the game personalization, in addition, an improvement of the own virtual environments would make the exercises even more interactive for those who use the system.

For future work we will continue this project work and research because we think this kind of prototype is the beginning of rehabilitation patient not only in the area of stroke, which was the area of injury in which this thesis focused and focused more, but also in an entire process and the most varied injuries, whether small injuries or even injuries with greater severity.

As future work can be underlined the development of new metrics related to motor and cognitive rehabilitation as so as the development of AI models based on the acquired data.

We will continue this project and will made more updates involving Artificial Intelligence, Machine Learning and with the addition of new sensors in order to increase the data extraction for a better analysis of a physiotherapist or other health professional during the recovery process and with more measure considering the 3-axis perspective.

For measuring this 3- axis we will be a more accuracy about the results and we can extract a better analysis for physiotherapist and for that we will adapt this new values with new columns for the existing tables developed.

We also will upgrade all the menu’s game to a more easy interaction between the user and the games interface allows the user to use the laser point that the controller has and avoid loss of time just for a simple scene change during the game playing.

It was a very interesting developing, learning and testing this project because it englobed several technologic systems, all of them essential for an efficient approach to the most varied fields of work that intended to develop similar works or try new ideas with new tools that are appearing in the market more and more quickly.

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Appendix A – User Manual

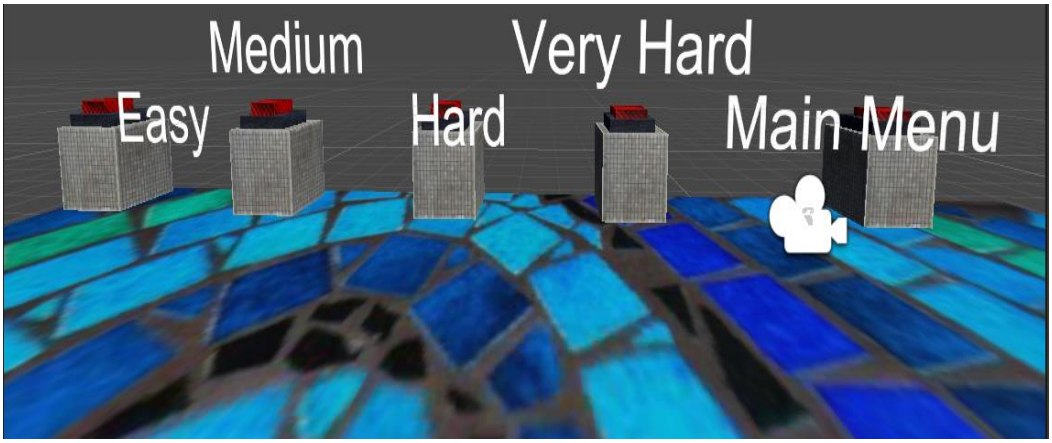
This manual aims to present the features available in the FisioAR Project applications and explain how they work.
Chapter 1 is intended to demonstrate the functionalities of the FisioAR project application for the computer, which is intended for patients in the physiotherapy clinic or home.
Chapter 2 demonstrates the functionalities of the mobile application, which serves as a support to the clinic manager, enabling the management of its physiotherapists and physiotherapists to manage patients.
Chapter 3 is intended to explain the method of installation of the above mentioned applications.

Chapter 1 – Unity 3D Games Application

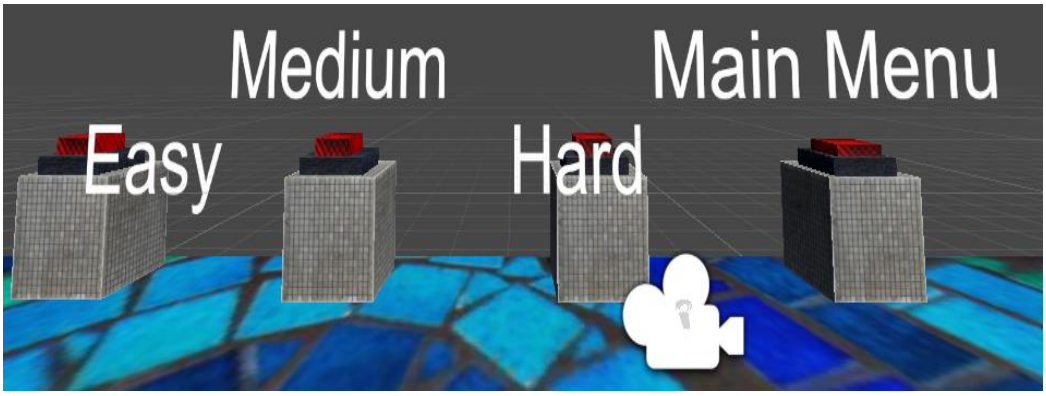
1. Overview and Application Description

In this first screen we have to put your credential created in outsystems app registration.
After you put your credentials correctly the login is successfully done.

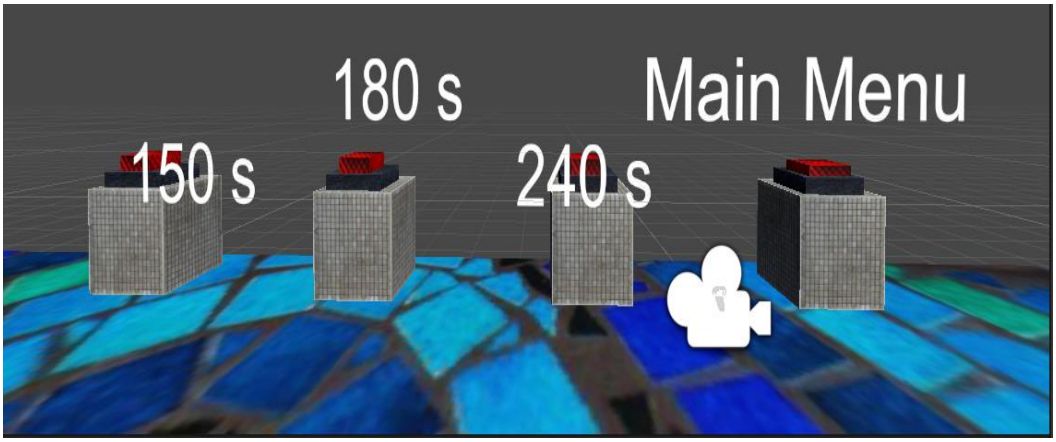
In this second screen you have to choice what was the game previously planned by your physiotherapist.
You can find these same data in the tasks to be performed part of the FisioAR app.



In this third screen, you can choose the different Puzzle game levels that were previously selected by your physiotherapist according to your specific diagnosis.



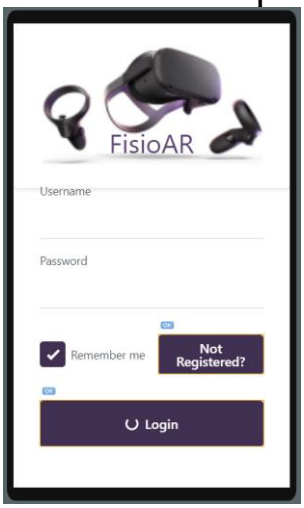
In this third screen, you can choose the different Box game levels that were previously selected by your physiotherapist according to your specific diagnosis.



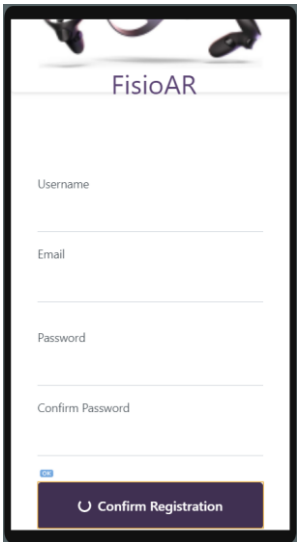
In this fourth screen, you can choose the time that you will expend according to your physiotherapist recommendation.

Chapter 2 – Physiotherapist Mobile Application

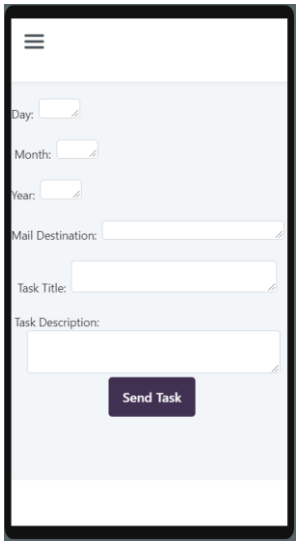
1. Overview and Application Description



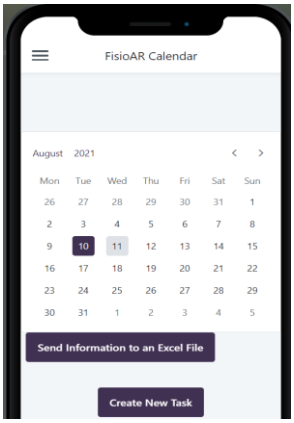
This first screen is destinated for the login of your app.
If you are registered you have to click on the button with the String “Not Registered” and after you put all the required information you will be able to start surfacing the fisioAR app.



This screen app you have to put all the credentials required.



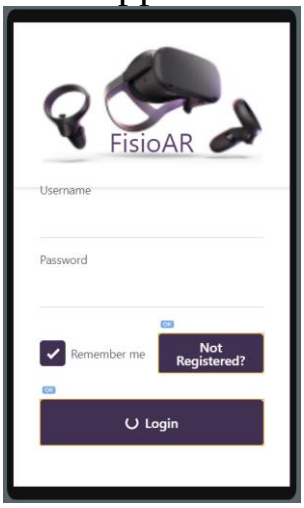
In this screen app the fisiotherapist will put some specific task for a specific patient.



Were are date picker that be able physiotherapist to view all the datas and all the games and all the patients that played this 3 games specifically developed.

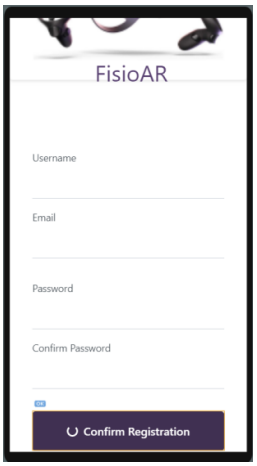
Chapter 3 – Stroke Patient Mobile Application

1. Overview and Application Description

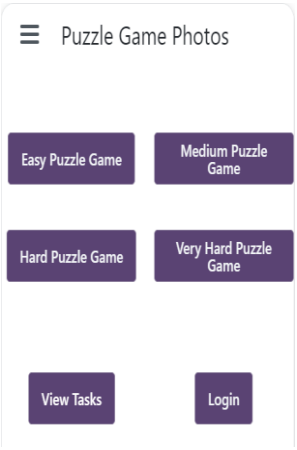


This first screen is destinated for the login of your app.

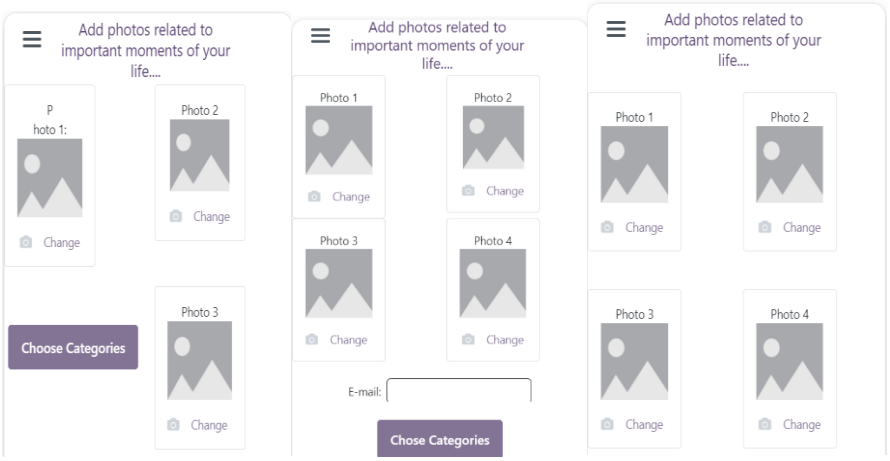
If you are registered you have to click on the button with the String “Not Registered” and after you put all the required information you will be able to start surfacing the fisioAR app.

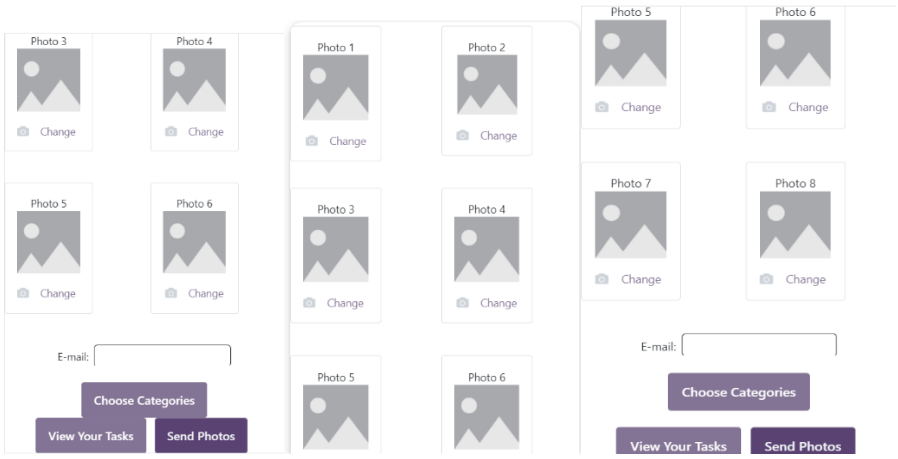


This screen app you have to put all the credentials required.

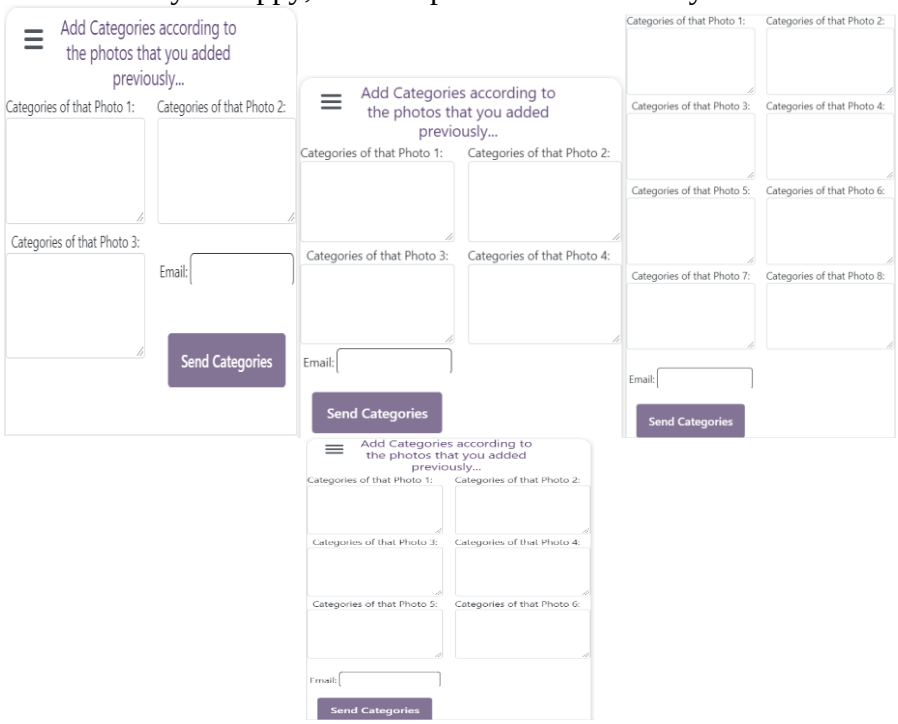


Main Menu of Patient’s Application

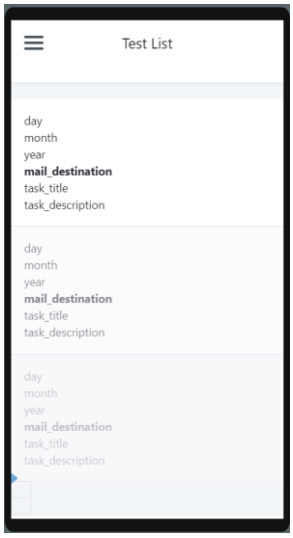




In this screen you have to put your email and chose three, four, six or eight photos that make you happy, some important moments of your life.



In this screen you have to put your email and chose three, four, six or eight photos to play Puzzle Game Memory.



In this screen the patient will visualize all the tasks that your own physiotherapist prepared for him.

Oculus App and Oculus for Developers Account

Oculus App is a great widget for Oculus Quest monitoring as it gives us information such as:

- the percentage of energy available for right and left

Wearable Sensor (these sensors are powered by alkaline cells).

- All options for Oculus Quest headset Wi-Fi

Connection.

- An option to show in a Chromecast device Oculus Quest headset overview.
- Other settings such as energy definitions, unlock pattern, change language, programmer mode and advanced settings.

For the perfect usage of Oculus Quest Technology in Unity we need to follow some steps:

1. Download Oculus App into your phone and Unlock Developer Mode on Oculus Quest App.
2. Install Android Tools. Download Android Studio.
3. Install and run Unity.
4. Create new Unity project.
5. Install OpenVR and XR Legacy Input packages.
6. Set Project's Build Settings in XR Settings, enabling VR Mode and add Oculus to the VR list mode.
7. Setup Oculus Quest Controllers.
8. Setup VR scene.

Appendix B – Technical Manual

Department of Information Science and Technology

Master in Telecommunications and Computing Engineering

INSTITUTO UNIVERSITÁRIO DE LISBOA

FisioAR

Serious Game Augmented Reality in Unity 3D

Advisor: Octavian Postolache

Co-Advisor: João Monge

Miguel Gil Ferreira Vaz Gaspar

November 2022

Chapter 1 – Introduction

Overview

In this chapter I will present all the source code explained according to the games realized in Unity 3D game.

C# Classes:

Scripts	Meaning
Database Login.cs	script that checks if the username and password match the data entered when registered.
Score_Garden.cs	script related to the number of plants that have been watered.
Load Scene.cs	script that serves to change the scene after a certain action
Puzzle_Easy_Script.cs	script that makes the easy puzzle game playable.
Puzzle_Medium_Script.cs	script that makes the medium puzzle game playable.
Puzzle_Difficult_Script.cs	script that makes the difficult puzzle game playable.
Puzzle_VeryDifficult_Script.cs	script that makes the very difficult puzzle game playable.
Script Boxes Game	script that makes the box game playable.
SnapObject	script that serves to grab the objects that are included in the puzzle game
Change_Material	Script that change colors of the boxes in all Boxes Levels Game
Choronometer	Script that count all game times
Databasecategories_Easy	Script that puts the categories chosen by the patient that play the game in Easy Puzzle Game
Databasecategories_Medium	Script that puts the categories chosen by the patient that play the game in Medium Puzzle Game
Databasecategories_Hard	Script that puts the categories chosen by the patient that play the game in Hard Puzzle Game

Databasecategories_Very_Hard	Script that puts the categories chosen by the patient that play the game in Very Hard Puzzle Game
Databasephotos_Easy	Script that puts the photos chosen by the patient that play the game in Easy Puzzle Game
Databasephotos_Medium	Script that puts the photos chosen by the patient that play the game in Easy Puzzle Game
Databasephotos_Hard	Script that puts the photos chosen by the patient that play the game in Easy Puzzle Game
Databasephotos_Very_Hard	Script that puts the photos chosen by the patient that play the game in Easy Puzzle Game
VR_Button	Script that allows to Load other Scene that patient want to change
Snap_To_Location	Script that glue the pieces of the puzzle to the corresponding category in all Level of the Puzzle Game

The difference between the puzzle easy, medium, difficult and very_difficult script it is mainly in the number of the column where the image that is with the blob type will be searched, this image will be the one that will be displayed, obviously separated by each of the cubes (puzzles) existing in the game space.

How to test the Unity games in Oculus Quest

For testing the Unity games, you have to click on file, click on Build Settings, select Android Settings and then you have to active the oculus headset, accept all the requirements, interconnect the oculus headset with the USB cables, chose the oculus headset option and click on build and run.

Then, we able to put the game on Oculus headset. You have to waiting a few times to update all the games component but after that you can play the game on unknow sources option.

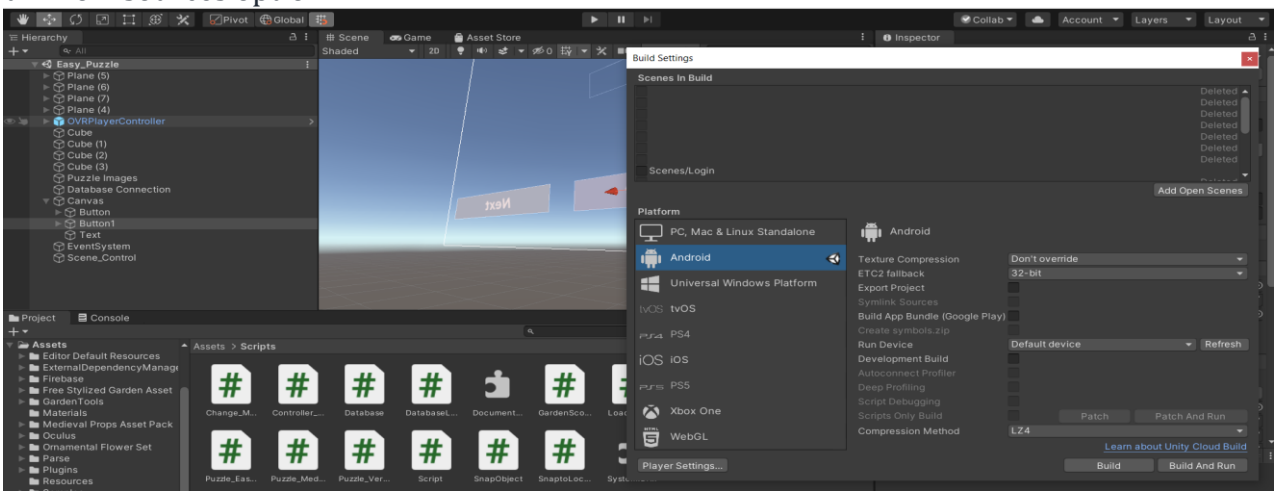


Figure 1 – Build Settings in Unity 3D

Chapter 2 – Database Diagram

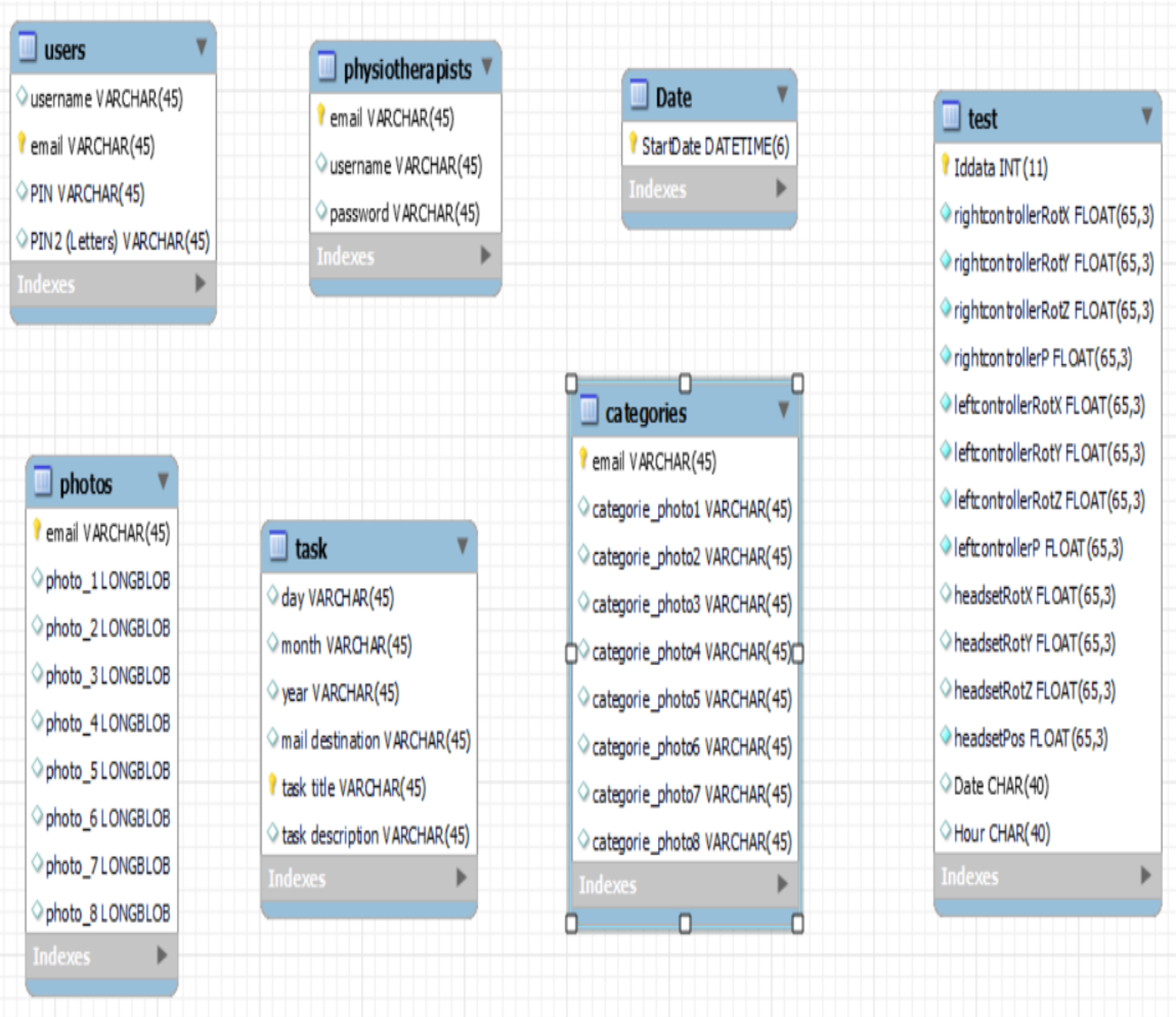


Figure 2 – Diagram Database

Appendix C – Article Published

Unity 3D Augmented Reality Game for Physical Rehabilitation

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***Abstract* - In this paper, are presented the advantages that augmented reality can give in a Stroke rehabilitation recovery process comparing traditional rehabilitation. Thus the work focuses on an Augmented Reality system specifically developed and designed for physical rehabilitation and Several Augmented Reality games were developed for Meta Quest platform that provides parameters for health professional to extract information about rehabilitation process outcomes. Additionally, two different Applications were developed to be used by a physiotherapist and a patient with the main purpose of better interaction between both. These applications provides essential information so that the interaction and performance of augmented reality games is carried out. Validation results of the system with several volunteers are also included in the paper.**

***Keywords*: Stroke, Physical Rehabilitation Process, Augmented Reality Serious Game, Meta Quest, mobile APP**

I. INTRODUCTION

Stroke is very common cause of death and a very dangerous disease that could cause a large deficit or multiple disorders dependent of each case or situations [1].

This disease is very unexpected but with severe consequences such as in mobility of the stroke patients or irreparable damage to certain and specific parts of the body with a high chance of people even stop walking or moving upper or lower limbs.

According to World Health Organization (WHO), each year over 15 million people suffers stroke with 33%-66% of stroke survivors having upper limbs associated problems, a giant and scary number considering this high percentage of have some disability after a stroke event [2].

Patient's strokes also lost simple and daily routine tasks such as cooking, bathing, dressing, running, eating, using telephone and others because this sudden accident have a real impact in anyone and no one can be safe and aware that a particular event or action cannot have serious effects or consequences with this type of occurrences [3].

Associated with these sudden changes in daily routine can be others' problems with a negative and a very prejudicial impact in stroke patient's because after cerebrovascular accident, patient will have to face a lot of recovery process and multiple new things and routines in daily routine and all these changes can cause easily mental problems such as anxiety, marked demotivation, depression or even a cognitive loss [4].

The rehabilitation is strongly dependent to the frequency and effectiveness of the physical rehabilitation sessions, and in this conditions the remote physiotherapy self-training at home represents a complementary a successful solution, that contribute for reduction of the rehabilitation period.

Self-training based on classical rehabilitation processes always require professional supervision and the usage of equipment that doesn't provide

any type of information regarding the rehabilitation process [5].

The concepts of physical rehabilitation and functional training which are proposed by [7] are; 1) It should be patient-centered and consider the needs of patients for functional rehabilitation; 2) Functional training should be linked to the patient's daily life, focusing only on the training of functional activities.: 3) Patients should be encouraged to perform functional activities as often as they can, instead of being limited to 5% of the daytime daily, under the guidance of the therapist; it is best to keep the patient in a skill learning environment.

II. Related Work

The mixed reality and IoT technologies are frequently used as part of smart physical rehabilitation. Thus, in [8] is presented a solution for physical rehabilitation of upper limbs using technologies such as mixed reality (MR) and Internet of Things (IoT). In this case a set of serious games were developed using Unity for MR scenario. The Meta Quest 2 was used as MR interface. Additionally smart sensors inserted onto a pair of gloves that are used to perform real-time of force and acceleration during training sessions .[8]

Other reported solutions are referring the solutions based on virtual reality (VR) for physical rehabilitation of upper limbs where therapeutic serious games are considered. The interaction with VR scenario is caried out using smart sensors embedded in a headband and gloves. [9]. Smart equipment for physical rehabilitation assessment is reported in [10].Thus, during gait training a walking aids is used by the patients affected by lower limb impairments. The system can deliver information that can be used on VR or MR scenarios associated with serios games for physical rehabilitation.

The smart physical rehabilitation becomes a new reality and challenge regarding the technology adoption by the users increased costs. In this context in [11] the authors are presenting a smart physical rehabilitation system that combines augmented reality serious games and wearable sensor network to improve the patient engagement during physical rehabilitation.

An interesting solution is reported in [12] that describe a measurement system and methodology for motor rehabilitation of hands and fingers. The interaction with serious games developed in Unity 3D game engine is performed using a natural user interface based on Leap Motion Controller.

What´s brings new in the proposed solution is the functionalities of the patient's APPs has the interaction and the possibility to adapt the game area for you and to have the best place to do all this rehabilitation process and this three different games that have the main objective of patient has different types of recovery such as: cognitive and motor rehabilitation.

Garden Care Game is a game more specific for motor rehabilitation, Box Game is destinated more for cognitive rehabilitation and puzzle game as this two important types presented in your game area.

III. System Description

The developed rehabilitation system is characterized by the usage of MR interface expressed by Meta Quest (Fig. 1). For this MR interface were developed different serious game for physical rehabilitation. Two apps and a database were developed to save and process all relevant data.

Fig. 1 Meta Quest and two wearable sensors integrated.

The interface Meta Quest was chosen as reliable interface for the user that perform the motor rehabilitation considering the AR scenarios and interactions.

Based on this MR the user act in a virtualized world, being concentrated on the game objectives.

Meta Quest is characterized by built-in wearable sensors that helps to make more usable for the user during the training session.

Regarding the programmer’s side, the chosen system makes all the automation of gameplay processes much more easier, such as grabbing objects with the controllers, throwing objects around or make any adaptation on Meta Quest OVRCameraRig vision due to the Oculus

Integration package already having these functional scripts ready to be used.

What is Online Virtual Reality (OVR)?

OVR offers software plugins for anyone developing digital and virtual content in Unity or in Unreal engines.

For this implementation we used OVRPlayerController game Object that simulates Meta Quest and our controllers in Unity program and OVRGrababble/OVRGrabber scripts.

On the user's side, since with wearable sensors it can have a greater sense of the space in which it is located compared to the virtual objects found in the game made in Unity 3D. The interaction between the main system components associated with FisioAR games are presented in Fig.2.

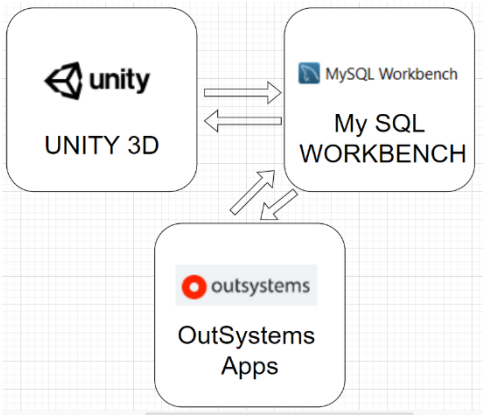

Fig. 2 FisioAR Game System Software Architecture

As can be observed three different software technologies were used. For the MR implemented scenarios the Unity 3D was used considering the existence of drivers for Meta Quest but also analyzing the VR and MR technologies used by the research group. Related to database the MySQL workbench was used while the mobile APP was developed in OutSystems. The implemented serious game for motor rehabilitation are following described.

IV. SERIOUS GAMES

To provide appropriate interaction between the user and MR scenario according with rehabilitation plan a set of three serious game were developed.

A. Boxes Game

The first developed game called Boxes Game, has six cubes displayed with different colors number of spheres depending on difficult level. There's three different levels and the main goal of this game is to put the maximum number of spheres in a box with the same color and with minimum travelled distance (Fig. 3)

Fig. 3 Box Game MR Scenario.

To make the game more attractive and difficult the boxes change color every few seconds. If you put a sphere in the correct box (with the same color) another sphere will immediately appear in a random place and with the same color of the sphere that is placed inside the box. In this game, to achieve realistic feedback about the user's performance we added Scores and four game play periods characterized by limited times.

B. Puzzle Game

Puzzle Game, presents a white screen with the same number of divisions as the existing cubes in the implemented scenario.

For easy mode we have three pieces, for medium mode we have four pieces, for hard mode we have six pieces and for very hard mode we have eight pieces to complete the puzzles (Fig.4).

The goal is to form an image with all the pieces of photos scattered around the environment. This game will require that the patient moves the knees and arms, managing to adapt the difficulty of the game to the weaknesses and abilities of each person. Also, this game is quite interesting because it will work not only, the physical part, the cognitive part but also the affective and sentimental part of the player since the photos will be chosen by the user through the PhysioAR APP.

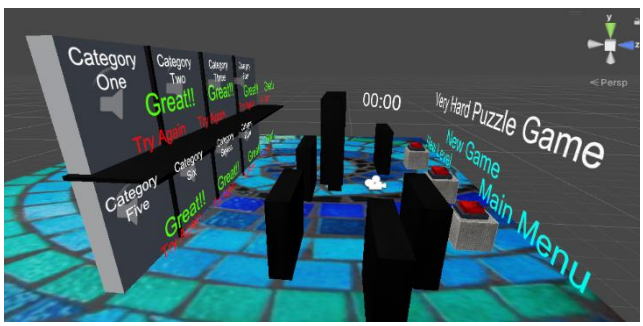

Fig. 4 Puzzle Game MR scenario

C. Garden Care Game

The third developed serious game is called Garden Care Game. Its scenario was made with prefabs and materials from unity asset store to simulate a realistic garden, with a watering can, fences and a set of flowers (Fig.5).

The main goal of this game is to water the flowers. This simple goal is related with the measurement of the wrist rotation made by the patient through wearable sensors while watering each flower.

Fig. 5 Garden Care Game MR scenario

V. OUTSYSTEMS APPS

OutSystems is one of the most powerful low-code platform on the planet for development of mobile and web enterprise applications, which run in the cloud or in hybrid environments. It is fully built from the ground up for high performance. In this project we have Two different OutSystems APPs: were designed and implemented.

The first one was considered for physiotherapists assuring data analyses but also to create new training tasks.

The other APP was developed for stroke patients presents functionalities such as: register patient data in data base, to add personal photos that will be displayed in puzzle game and to know every new task that was added by physiotherapists as part of the training.

I. Physiotherapists App

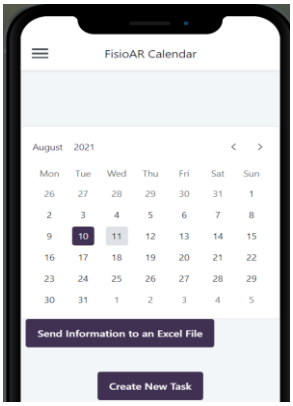

Fig. 6 FisioAR Calendar Screen.

In this screen, if a physiotherapist click on a specific day, will automatically display on screen a list of patients that played the FisioAR games.

If physiotherapist click on “Send Information to an Excel File” button it will create an Excel File with all sensors data from a specific patient and in this File the professional will can analyze sensors information.

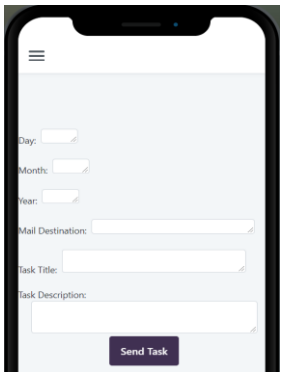

Fig. 7 AVC Patient’s New Task Screen.

In New Task Screen, Physiotherapist must add the day, month and year that have planned the task and mail destination to send all the task description planning to the patient’s mail destinated to do this training games rehabilitation sessions.

II. AVC Patient’s App

Fig. 8 AVC Patient’s and Physiotherapist’s Register PhysioAR App.

In this Screen, Patients must Register your data to the FisioAR database to have the possibility of try Unity FisioAR rehabilitation games.

After Confirming your registration data will be able to use all the resources of PhysioAR project.

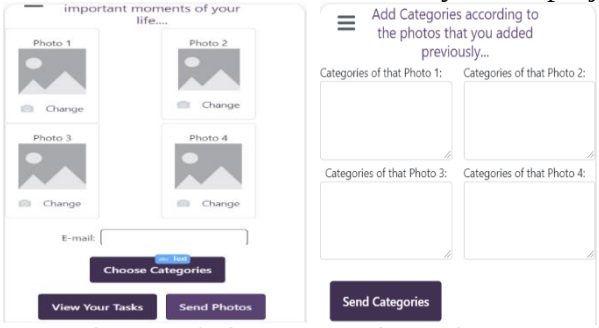

Fig. 9 and 10 Patient’s Photos Screen and Patient´s Categories Screen.

In Photos Screen, Patient's must to choose pictures that automatically remember positive feelings in their lives.

After the AVC's patient click on "Send Photos" button, the four pictures chosen by the patient will be saved in FisioAR database and later will be used in the puzzle games, a game described in Section II.

VI. Results and Discussions

In this section, the results provided by the system given are presented and the relations between the analyzed results and the information offered to the physiotherapists that assure objective evaluation of the patient's outcome during physical rehabilitation process.

The acquired data are processed to extract values of metrics such mean deviation, standard deviation, acceleration, trajectory, and rotation that are important for objective evaluation. The data set include:-Right Controller Rotation; Right Controller Position; Left Controller Rotation Left Controller Position; Meta Quest Position.

So the values that will be treated in the sections belong to five different persons that who volunteered to contribute to enrich the results of my PhysioAR thesis and whose experience was about to understand how the results could help the physiotherapists in your analysis during the process of rehabilitation and if there would be any evolution.

In the performed tests, the gaming period of time was 150s the time being controlled by a chronometer presented in the project. Each volunteer has the same conditions of the space and time to compare all the results with maximum precision possible.

III. Data Treatment of PhysioAR Thesis Project

With all these values that this FisioAR Game System give to us, we can calculate important parameters that can provide to physiotherapists a better idea for the evolution of the AVC's patient such as mean deviation, standard deviation, acceleration and trajectory.

For example, with the data displayed and obtained with the volunteer #001 we can calculate all these 3 parameters for Right Controller Position, Left Controller Position and Headset Position and 3 parameters for Right Controller Rotation and Left Controller Rotation: Mean Deviation, Standard Deviation and Average Velocity.

$$\text{Mean Deviation} = \frac{\sum \text{ni}\,(\text{xi} - \text{m(X)})}{N} \quad (1)$$

Where M(X), N and Xi are average value of the data set, number of data values and data values in the set, respectively.

$$\text{Standard Deviation } x = \frac{\sqrt{(\sum(\text{xi} - \mu)2)^{2}}}{\text{N}} \quad (2)$$

where N, Xi and μ are the size of population, each value of the population and the population mean, respectively.

$$\text{Average Velocity} = \text{V} = \frac{\sum \text{ni}=1\,((\text{x} - \text{x0})/(\text{t}-\text{t0}))}{N} \quad (3)$$

Where x, x0, t, t0 and N are final and started position, final and started time and the size of population, respectively.

IV. Training Results

In these sections these Data Treatment Analysis will be an explanation of the results above calculated in each game played and comparing the values with each different persons that made these experiments.

In order to treat and make an analysis about the number that has been a result of these 4 experiments and all tests that has been recorded, saved the important values presented in controllers and headsets sensors in Oculus Quest, now it's time to make an interpretation about all these values and what actually they say to us and if exists any difference or any point that influenced unexpected results in PhysioAR games 1º Person experiment: Puzzle Game that has 4 different levels according to number of phots, Box Games that has 3 different levels according to number of balls and boxes and Garden Care Game.

V. Puzzle Game

For the 4 levels played by the #001 volunteer the following 5 parameters are calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

In Table I are presented the results that are stored in the Database specifically created for this project.

TABLE I
PUZZLE GAME DATA RESULTS FOR #001 VOLUNTEER

Data	Right Controller Rotation	Left Controller Rotation	Right Controller Position	Left Controller Position	Headset Position
Mean Deviation	**8,811E-15**	**12,656**	**-3,4106E-15**	**4,1211E-15**	**1,8474E-15**
Standard Deviation	**7,8703**	**6,437744**	**3,6292**	**3,3526**	**16,9373**
Average Velocity	**-**	**-**	**0,06933**	**0,08133**	**0,07933**

VI. Box Game

For the 3 levels played by the #001 volunteer the results for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

In table II are presented some values recorded and saved to the Database specifically created for this project.

TABLE II
BOX GAME DATA RESULTS FOR #001 VOLUNTEER

Data	Right Controller Rotation	Left Controller Rotation	Right Controller Position	Left Controller Position	Headset Position
Mean Deviation	**1,708**	**15,252**	**2,076**	**1,704**	**1,732**
Standard Deviation	**8, 7731**	**6,956628**	**4,5492**	**3,9904**	**18,5822**
Average Velocity	**-**	**-**	**-0,1126**	**0,1186**	**0,1166**

VII. Garden Care Game

For the 1 level played by the #001 volunteer the results are different for the 5 parameters measure and calculated: Mean deviation, standard deviation, variance, velocity and acceleration.

In table III some values, recorded and saved to the Database, are displayed for a comparing results with other volunteer results in Section VII.

TABLE III
GARDEN CARE GAME DATA RESULTS FOR #001 VOLUNTEER

Data	Right Controller Rotation	Left Controller Rotation	Right Controller Position	Left Controller Position	Headset Position
Mean Deviation	**,352**	**4,4332**	**2,252**	**1,972**	**1,932**
Standard Deviation	**,9491**	**6,0282**	**2,252**	**3,2332**	**18,4182**
Average Velocity	**-**	**-**	**0,13133**	**-0,124**	**-0,1273**

VII. DATA ANALYSIS

A. Interpretation of #001 Volunteer Data Results

The values of mean deviation and standard deviation are relatively low, being able to conclude that the values are not far away from the average value that was acquired during each experiment itself.

The speed values are very low and close to each other in relation to the controller and the headset, which could be explained by the short radius of action that a person acts on is also small.

VIII. Comparing results of #001 Volunteer to others

In this section we will comparing #004 Volunteer Data Values with #002 Volunteer Data Values for 1 level that Garden Care Games are composed, and the results are different for the 3 parameters measure and calculated: Mean deviation, standard deviation and velocity.

Topics to comment from table displayed above are mean deviation, standard deviation and average velocity values for:

- *Puzzle Game*
- *Box Game*
- *Garden Care Game*

IX. Mean Deviation Values

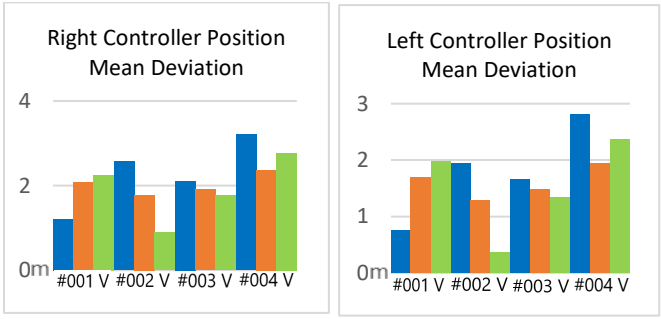

Fig. 11 and 12 Mean Deviation Right Controller Values and left controller position for 4 Volunteers (V) in different scenarios.

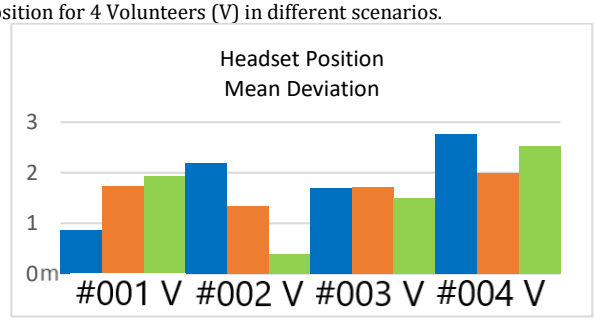

Fig. 13 Mean Deviation headset position values for 4 Volunteers (V).

X. Interpretation of Mean Deviation Data for all experiments

The **mean deviation** is defined as a statistical measure that is used to calculate the

average deviation from the mean value of the given data set.

The values of #004 Volunteer are highest than other volunteers and in Puzzle Game #001 Volunteer and Garden Care Game 002 Volunteer the values are very close to the average value.

The values of mean deviation #001 Volunteer and #003 Volunteer are very similar and bigger than the mean value.

XI. Standard Deviation Values

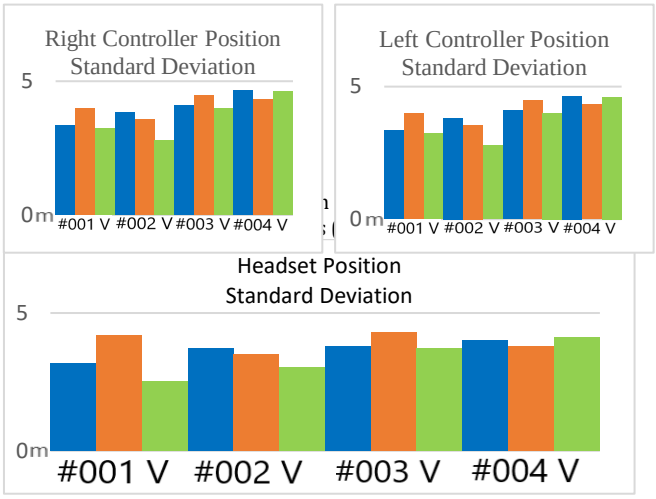

Fig. 16 Standard Deviation values headset position for 4 Volunteers (V) in different scenarios.

XII. Interpretation of Standard Deviation Data for all experiments

A **standard deviation** (or σ) is a measure of how dispersed the data is in relation to the mean.

The standard deviation values of #001 Volunteer and #002 Volunteer are considered normal values, such as the standard deviation values of #001 Person and #003 Person and the same values for #001 Person and #004 Person being able to conclude that these results do not have much difference with the mean deviation value.

XIII. Average Velocity Values

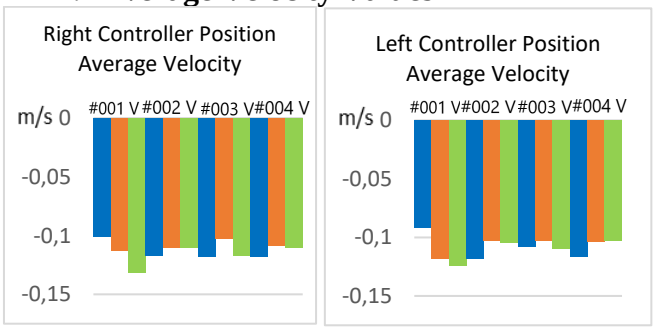

Fig. 17 and 18 Average Velocity values values in right controller and left controller position for 4 Volunteers (V) in all scenarios.

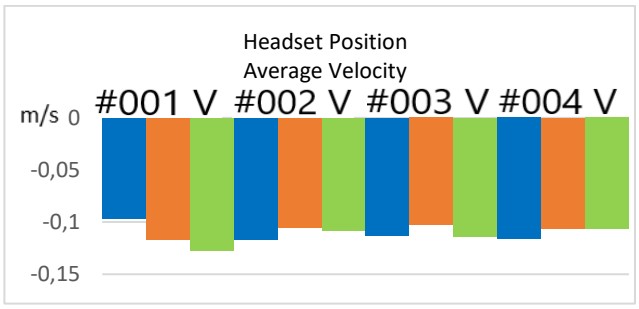

Fig. 19 Average Velocity values values in headset position for 4 Volunteers (V) in all scenarios.

Interpretation of Average Velocity Values Data Results for all experiments

Average Velocity is defined as the change in position or displacement (Δx) divided by the time intervals (Δt) in which the displacement occurs.

Both average velocity values of #001, #002, #003 and #004 Volunteer are both very low and close to each other in relation to the controller and the headset, which could be explained by the short radius of action that a person acts on is also small and by the fact that the game does not require much physical effort in the motor parts, a since they are sensitive areas for the target audience of this same project and should be worked on gradually according to the evolution of each patient.

VIII. Conclusion and Future Work

The FisioAR Game System assures data that are used to calculate important parameters that can give to physiotherapists information about the evolution of the stroke patient such as mean deviation, standard deviation and average velocity.

Several MR serious games were successfully implemented with two different approaches for a stroke patient's rehabilitation: cognitive and motor rehabilitation.

Thus, Box Game and Garden Care Game were developed for motor rehabilitation and Puzzle Game for cognitive rehabilitation. The values delivered by the system for each one of these different approaches can be used for objective evaluation of physical rehabilitation helping to optimize the training plans based on serious games.

As future work can be underlined the development of new metrics related to motor and cognitive rehabilitation as so as the development of AI models based on the acquired data.

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