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Gait VR - Gait rehabilitation in Virtual Reality Interactive Scenarios

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Master Degree in Computer Engineering

Supervisor:
PhD Octavian Adrian Postolache, Associate Professor with Habilitation,
ISCTE-IUL

November, 2022

TECNOLOGIAS
E ARQUITETURA

Department of Information Science and Technology

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Dedicated to my Grandmother Rosa.

Acknowledgment

In this noble dedication I want to honor all the people who have in some way supported me during the development of this project.

Months went by with so many challenges along the way. This dissertation has provided me with so much self-growth, and new discoveries about decisions that I had to make in my life, and the truth is, I would never have finished it without the right people by my side and for this reason my first words of gratitude goes to my parents, who have always supported me through all of my decisions, and have always provided me with all the necessary tools to get as far as possible. Without them I wouldn't be who I am today so thank you. I also need to thank my sister Leonor that despite not being in the area and not understanding much of the content of my work always gave me strength to continue and not give up.

Thank you also to Mariana and Gonçalo who have accompanied this work since the very first beginning and were the people who gave me the most support. Thank you for your availability, sympathy, and friendship that I will carry with me for life.

My sincere thanks also go to my supervisor Prof. Doctor Octavian Postolache, for supporting me all along the way, for helping me, and for providing me with all the necessary material to develop this project.

I would like to thank to Instituto de Telecomunicações that provided me the support, including the technical one, during the whole period of my thesis.

Thanks to my uncle Luis who helped me in moments of despair and always believed in me.

Thank you to all of my friends and family.

And my last words of gratitude goes to Sebastião, the number one person who held me up the most when everything around me was falling down and didn't let me give up.

To all of you who wanted to see me here, I made it!

To all of you who didn't want to see me here, look where I got to!

Resumo

A medicina e a tecnologia estão hoje ligadas por um enorme ramo de partilha de conhecimentos. É um facto que o exponencial crescimento das tecnologias de informação no sector dos cuidados médicos tem gerado grandes ondas de novas descobertas, tanto na oportunidade de acessibilidade da informação, não só nos dados dos pacientes, como dos profissionais de saúde, como também na organização e armazenamento dos mesmos. Fazer uma análise e um controlo periódico da marcha é um procedimento muito importante no mundo da reabilitação e da fisioterapia e pode ser capaz de diagnosticar precocemente doenças em pessoas com problemas relacionados. A reabilitação motora é mais frequentemente prescrita e indicada a pessoas com idades mais avançadas devido a alterações musculares, articulares e/ou neurológicas por elas apresentadas ser mais elevada, no entanto, é algo que pode ser prescrito em pessoas de todas as idades, desde crianças a adultos. Nesta tese, foi concebido e implementado um sistema designado por Gait VR, que funciona como uma ferramenta de ajuda a todos aqueles que necessitem de reabilitação nos membros inferiores do seu corpo, que condicione de alguma maneira o bom funcionamento da marcha. Este sistema permite aos pacientes darem continuidade aos seus tratamentos de uma forma mais motivacional, através do conceito de gamificação e Realidade Virtual. Este sistema foi desenvolvido utilizando ferramentas como o sistema Azure Kinect criado pela Microsoft, tecnologia assistida à saúde e a plataforma Unity 3D. Uma aplicação web foi também desenvolvida com o objetivo de suportar o trabalho desenvolvido pelos fisioterapeutas especializados na área.

Palavras chaves: *medicina, marcha, reabilitação, gamificação, Azure Kinect, Realidade Virtual*

Abstract

Medicine and technology are today linked by a huge branch of knowledge sharing. It's a fact that the exponential growth of information technology in the medical care sector has generated great waves of new discoveries, both in the opportunity of information accessibility, not only for patient's data but also for health professionals, and in the organization and storage of these data. Periodic gait analysis and monitoring is a very important procedure in the world of rehabilitation and physical therapy and may be able to diagnose diseases early in people with related problems. Motor rehabilitation is most often prescribed and indicated for people at older ages due to the higher muscular, joint and/or neurological changes they present, however it's also something that can be prescribed in people of all ages, from children to adults. In this dissertation, a system called Gait VR was designed and implemented, which functions as a tool to help all those who need rehabilitation in the lower limbs of their bodies, that somehow conditions the proper functioning of the gait. This system allows patients to continue their treatments in a more motivational way, through the concept of gamification and Virtual Reality. This system was developed using tools such as the Azure Kinect system created by Microsoft, health assistive technology and the Unity 3D platform. A web application was also developed with the objective of supporting the work developed by physical therapists specialized in the area.

KeyWords: *Medicine, Gait, Physical Rehabilitation, gamification, Azure Kinect, Virtual Reality*

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Acronyms

CHAPTER 1

Introduction

The way a person walks, especially when associated with known or unknown anomalies, may sometimes present a group of serious problems for people of any age, whether they are children, adults or elderly. These types of problems are mainly known as gait disorders and can be caused by various reasons such as, due to a fall, due to some birth conditions, hereditary problems, or even the most common causes related to age fragility.

In the medical/healthcare areas of Physiotherapy and Rehabilitation, the growing demand to improve the quality and efficiency of treatments, has led to a several number of experiments, developments, and implementations of multiple types of technologies and innovations in the past few years, in order to find a better and useful way to support patients during their rehabilitation processes. The use of physiotherapy methods carried out in hospitals and specialized clinics becomes an essential instrument to help people to recover from their physical disabilities partially or totally. In this sense, physiotherapy methods give people the opportunity to return to their daily and normal life activities. The usage of physiotherapy methods can be undertaken by any person who aims to improve their physical performance or overcome some limitations caused by an injury or a medical condition.

The application of computerized technology for supporting physical therapy exercises for patients that presents gait problems has been studied by many researchers both in technology and/or medical science fields. The evidence suggests that computerized programs can improve the quality of the patients care and increase patients compliance, which is really important but there is still a limited research on the impact of such programs on the physical therapist's own practice. This dissertation work explored the use of a device named Azure Kinect SDK, a device created by Microsoft that consists on a camera programmed with voice, image and motion sensors models, and the usage of games development in order to investigate the impact on the quality of the physical therapist's own practice.

Thus, this thesis serves as a research to discover how, together with smart systems, smart technologies, serious games and virtual reality dynamic scenarios can be built to help patients regain motor mobility in their lower limbs. It also helps to demonstrates how a virtual world can be developed and used to provide an immersive experience that is not limited to the physical world and can provide patients with a much-needed sense of presence and involve them in the rehabilitation process in a meaningful way, thus increasing their likelihood of success.

1.1. Background and Motivation

Technologies are growing at an exponential rate, which means that it's almost impossible for anyone to keep up with them in real time.

By looking at multiple and different sectors around the world, sectors not only connected with technology but also connected and related with multiple other areas as well, it's easy to understand that technologies are on the right track to modify those areas, the future and the world in a highly successful way.

In the healthcare sector, there have been major changes in the quality and effectiveness of patient care and in the evolution and treatment of diseases that some years ago were scarce of cures, presenting nowadays much more advanced treatments that give hope to the patients, which means an important approach to their life quality. Over the years, physiotherapy has been the great salvation for the recovery of certain parts of the human body. However, there are a various number of different approaches to physiotherapy treatment. In Gait rehabilitation, treatment sessions in general are not easy, for patients often have a sense of fear when performing the exercises proposed by the physical therapist for their treatment and, furthermore, rehabilitation sessions could become long and time-consuming processes for patients, that consequently leads to the lack of motivation and to the drop out of their rehabilitation processes.

One of the ways found to increase the motivation of patients and consequently reaches a higher positive results in treatments, was the implementation of **serious games**, a concept already used in a great amount of known fields[19] such as education, other areas of healthcare, military training, agriculture and so much more. Smart systems for ambient assisted living together with technology are very important and increasingly needed in various areas and sectors, especially in healthcare areas. In fact, there is a growing demand for improving people's quality of life and help them in various ways.

They can reduce the costs of daily life assistance of elderly people, they can monitor the physical and psychological well being of people that lives alone, they can detect behavioral changes that could be the sign of an early stage of degenerative diseases, and they can help with the continuity of several treatments apart from the classical treatment methods that everybody is familiar with.

There must be innovative ways to continue treatments, different ways which impact patients and the quality of their treatments. It's based on all of these goals and on all of this background that I consider the development of serious games in virtual reality scenarios as a form of therapy a very positive way not only to help patients in their recovery, but also to increase their motivation and the quality and efficiency of treatments. With this, it will be possible to optimize the work of health professionals, giving them an extra tool to help patients in a faster and more dynamic recovery, without necessarily having to be present during 100% of their treatment sessions.

1.2. Objectives

The objective of this dissertation work is to develop a system capable of, as a whole, encompassing serious Three Dimensional (3D) and Two Dimensional (2D) games, created on the Unity3D software platform, characterized by the use of a special 3D camera with digitized image models, voice , advanced Artificial Intelligence (Artificial Intelligence (AI)) sensors with motion sensors and object and color recognition, which is known by the name of Azure Kinect SDK.

There are three main objectives that were established very early during the research process for this work and in the development of the Gait VR system itself.

The main objectives are listed below:

- **Provide continuity of treatment at home:** This first point aims to provide a system/platform that allows patients to continue their treatment apart of the classic methods that they experiment in specialized clinics or/and hospitals. This continuity of treatment will be available from the hospitals or establishments where patients decide to have their treatments, so that in an initial phase they can be accompanied by a health professional who will teach them how to use the system, and perhaps in the near future it will be possible to give continuity of treatment from their respective homes or from establishments where they decide to perform the treatment system, without actually having to be in person in those hospitals and clinics, and without having to be 100% followed up by the health professionals. The continuity of treatment is very important, as it will allows the patient to be constantly monitored by health professionals and will also greatly improve the quality and effectiveness of the treatment itself, thus reducing its time.

- **Increase the Patient Motivation:** Motivation drives the choice of certain behaviors or actions over others. It directly affects the initiation, direction, intensity, and persistence of a behavior contributing to the achievement of the desired goal.[20]

  As mentioned earlier in this document, classic physical therapy treatments are usually based on the repetition of a set of exercises that helps to stimulate movement and rehabilitation of the patients' lower limbs. However, the action of repetition can become a boring and uninteresting concept, which isn't at all, a positive point in patient's favor and can really become a serious problem in the future, because they can quickly lose motivation and consequently give up the treatment. To avoid/prevent this situation, the solution built consists in a collection of virtual reality scenarios for serious games that will allow patients to give continuity to their rehabilitation process, and in a way help all those who need physiotherapy and rehabilitation, to gain enough motivation to never have to think about the concept of giving up again.

- **Personalize the System:** One of the main objectives this system needs to achieve is the possibility of it being adaptable to each user. The thought scenario was to develop two versions of the games, one build in a normal 3D space with virtual reality, and therefore in 3D augmented reality, and another in a 2D space in order to be adaptable for people with cerebral palsy.

  Cerebral Palsy (CP) is known as a disorder caused by non-progressive neurological injury to the developing brain that happens before, during, or soon after birth.[21]. Both children and adults with this type of disability presents poor walking abilities and manipulation skills [22], having the habit of crossing their knees while trying to walk. They also presents extreme difficulties in viewing a very complex 3D environment and it sense of depth, so one of the solution was to develop not only 3D therapy serious games for people who do not have any other conditions apart from gait disorders, and also build 2D serious games in a 2D augmented reality, simpler games that can be more targeted at people with gait disorders and the condition of CP.

1.3. Research Questions

Within the scope of the subject under study, the research questions that motivate the analysis prepared are presented below:

- What are the most urgent growing needs in the field of physiotherapy that are needed to improve the quality and effectiveness of treatments?
- What were the results analyzed and achieved in studies already carried out in relation to this research?
- How can smart systems contribute to the healthcare area.
- Will Gait VR be able to respond to all of gait disorders?
- What is the difference between classic gamification and the concept of serious games?
- What are the advantages of using gamification and virtual reality in patients rehabilitation?
- What are the different types of gait disorders and what are his most common patterns?
- How should serious games be built in order to be adaptable to different types of users with different types of pathology's?
- What are the innovative methods that allow to continue treatment remotely?
- How is it possible to adapt Gait VR system and serious games to children and adults with cerebral palsy, a disease that greatly affects the lower limbs and prevents people from performing the gait function?

1.4. Research Process

The subject of this research, requires an organized, guided and efficient investigation process, in order to achieve a large part of the objectives that it has set for itself. To achieve the goals established, it was followed the **Design Science Research Method** [23] which is a qualitative research method that has been becoming quite well known over the years by the investigators and that mainly focuses on assisting in the development of a solution or a problem to be implemented in stages. For these reasons it was a choice to use this method during the development of this work to divide the bigger practical problem into smaller sub problems, as demonstrated in the figure that follows.

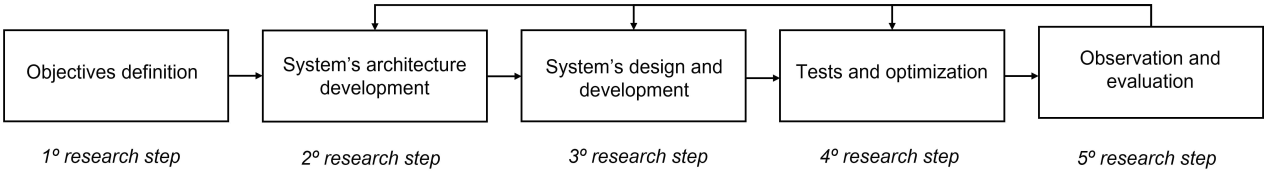


FIGURE 1. Design Science Research Method Flow

(1) **Objectives Definition:** In this step of defining objectives, the main purpose, as the name implies, is to define and establish which objectives are to be achieved during the construction of the system that will aim to help in the rehabilitation of the patients. It's in this first research step that happens the main decisions about what will be the techniques that will be used for the elaboration of the system, about the definition of the set of research questions that will help in future work and there's an investigation about all the functionalities and requirements.

(2) **System's architecture development:** During this research step, there is a division concerning the whole system architecture, making all the prototypes (low and high fidelity) of the desired functionalities of the system, reproducing also the necessary diagrams for the representation of important parts of the system, such as the database schema, the schema concerning the application's state map, the low fidelity mock ups of the therapeutic serious games to be developed, the hardware and software architecture of the system, such as:

- Structure Database for storage all the needed information;
- Developing Games Mock-ups in software platform Unity 3D;
- Web application, responsive for other types of devices such as mobile and tablet, targeted to physiotherapists, acting as a support to visualize their patient's information;
- System architecture of Gait VR.

(3) **System's Design and Development:** This step involves two main phases. These phases involve, first collecting and verifying the existence of all the necessary material for the development of the system and then the actual development of the entire system, ready to be tested with possible future users. It's a sequential stage that involves bringing together all the previous research steps.

(4) **Tests and Optimization:** After the Gait VR system is fully developed and free of incompatibilities, testing for results is a very important phase that cannot be ignored. This way, it will be possible to compare the obtained results with the main objectives previously established for the practical work, it will also be possible to make changes to the system if necessary, in order to optimize it and, finally, to have a working system 100% compatible with the user.

(5) **Observation and Evaluation:** This final research step is very important as the final solution build must be observed and evaluated.

The 2nd, 3rd and 4th investigations steps are cyclical, which means that it's possible to go back between steps whenever it's needed. At the end of the final step, if the final solution presented is in agreement and conforms to the targets set in the first step, the project is completed. If not, it will be required to analyze the problems or the improvements to be made and to return to the research step needed to overcome the difficulties between the initially defined aims and the final solution of the project.

1.5. Document structure

This dissertation work structure is composed by 7 chapters as follows:

- **Chapter 1 - Introduction:** This chapter, of which this section is a part, discusses the introduction, Background, and motivation for the development of this project, as well as the research process, and the most relevant research questions.

- **Chapter 2 - Literature Review:** This chapter presents all the research works of all the themes that are relevant and present directly and indirectly a connection to the built system.

- **Chapter 3 - System Description:** Chapter that deals with the description and explanation of the Gait VR system. Here are presented all the decisions adopted, the design and architecture of the whole application, the description and date extracted from the games, the structure of the database and a summarized user manual of the system.

- **Chapter 4 - Web Application:** This chapter presents the web application in brief. Here will be displayed all the functionalities of the system application, which are avail-

able for each type of user and will be exposed together with images of the application itself.

- **Chapter 5 - Results and Discussion:** This chapter presents the results and the discussion on these results that will be illustrated with images of graphs available on the web application.
- **Chapter 6 - Conclusions and Future work:** Presents the conclusions reached from this work and the future work that can be done from all the work presented in this dissertation. It also presents suggestions for improvements and possibilities of what can be implemented in the future.

After these chapters, a bibliographic reference is also included and the attachments which includes the scientific article accepted and published in EPE 2022 - International Conference and Exposition on Electrical And Power Engineering, accompanied by a certificate of participation.

CHAPTER 2

Literature Review

2.1. Chapter overview

This chapter presents the Literature Review and it's focused on a group of the most important topics related to this project research. It will start with an introduction to remote sensing technologies, accompanied by examples that served as inspiration for the development of the proposed system, followed by a short overview and explanation of what Azure Kinect is all about with a brief comparison between Azure Kinect and Kinect V2, an older version of the Azure one. It will present some applications on Virtual reality, will talk about the concept of serious games, and his applications in some areas and on the Gait rehabilitation.

2.2. An Introduction to Remote Sensing Technologies

Remote sensing technologies are the kind of technologies that can detect items at a great distance through intelligent sensors or even through radiation and electromagnetic waves in a way that can monitor the items in question and capture relevant data and information that can be used in various important applications and fields. In modern days, in medicine, this kind of technologies can have a wide applicability in most of the treatments and analyses performed on patients. One of the best known cases of remote sensing technologies is for example x-ray, a very old technique that allows capturing the inside of the body and visualizing parts that are not possible to see with the naked eye.

The difference between this type of technology and other existing technologies, and what makes it a great advantage, is that it is not a wearable technology, i.e. it is not embedded in anything that has to be worn or touched.

One of the big applications, that remote sensing are included is in virtual reality, Augmented Reality and serious gaming areas. These three topics will be discussed in more depth later in this thesis, however, it's important to present some applications already developed in these two major areas and that certainly served as an inspiration for the development of this proposed system.

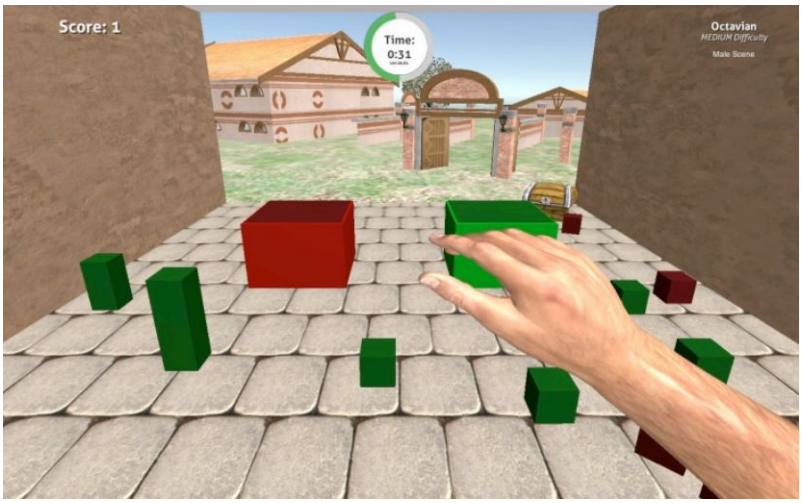


FIGURE 2.1. Serious Game based on Leap Motion Controller for upper limbs rehabilitation [1]

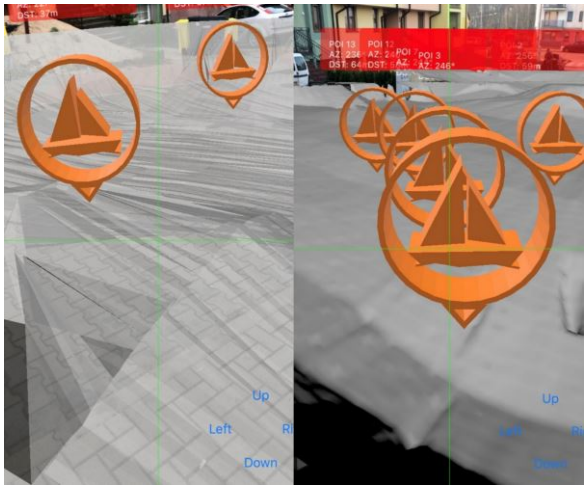


FIGURE 2.2. Example of the use of Augmented Reality in the navigation process made in [2]

2.3. Azure Kinect SDK

An unusual Human Gait can be an indicator that something is wrong in terms of health. Nowadays, there are several ways in which an unusual gait cycle can be detected. Physiotherapists can detect abnormalities quite simply by sight. However, in more complex cases, where the abnormal gait cycle is the result of an undetected disease, health care professionals need to perform more tests in order to get deeper results and reach to a certain conclusions.

Several advances have been made in the world of technology that have managed to revolutionize in a very positive way the treatments of some types of diseases. One of the technological advances that has been tested to help in rehabilitation of members of the human body was the use of the **Microsoft Azure Kinect camera**, that, as discussed in the previous section, uses a remote sensing technology. This camera is shown in figure below 2.3.

FIGURE 2.3. Azure Kinect SDK device represented in [3]

There are already on the market and even under development, projects that were made using all types of versions of Kinects, Kinect Version 1, Kinect Version 2, and the latest one azure Kinect. Below are some examples of projects developed with Kinect with a brief description of what the project is about:

- **NeuroParkinScreen [24]:** System developed for the upper limbs rehabilitation using Kinect camera, composed by a exergame. This term of "exergame" corresponds to games related to exercises. In this exergame the player has to raise his arm and pick up the apples from the tree, that can be green or red depending on the degree of difficulty. This system is composed by an user interface to complement all the work.

  The figure 2.4 below represents an example of the user interface of this system.

FIGURE 2.4. NeuroparkingScreen - Example of a Kinect application

- **Therasoup Game [25]:** Game developed for the upper limbs rehabilitation using Kinect V1. This is one of the serious games developed for this system where the player has to raise his arms and pick up the requested objects on the shelves that are at different heights. Measures such as the angles made by the joints and shoulders were considered.

The figure 2.5 below represents an example of the user interface of this system.

FIGURE 2.5. Therasoup Game - Example of a Kinect application

2.4. The Concept of Serious Games

Serious games are games with a purpose. They're designed to teach, build skills, and change behavior. They're used in education, business training, medical training, and more. They're also a growing field in games development and are starting to become a serious sub-field of game studies all their own.

VR-based games [26] are becoming more accessible nowadays. There's no doubt that immersive gaming experiences are fun, but they can also be a great tool for keeping people healthy and engaged in their daily lives. Researchers are exploring the potential uses of VR for treating mental health problems, helping people with disabilities maintain their independence, and providing therapeutic experiences for people going through difficult times. The applications for VR are almost endless, and it only makes sense to invest in the technology today while it's still a relatively novel and affordable one.

However, it is increasingly necessary to establish a line of difference between the concept of traditional games and the one of serious games.The following table 2.4.1 represents the main differences.

	Serious Games	**Entertainment games**
Task VS rich experience	Problem solving in focus	Rich Experiences preferred
Focus	Important elements of learning	To have fun
Simulations	Assumptions necessary for workable simulations	Simplified simulation processes
Communication	Should reflect natural (i.e., non-perfect) communication	Communication is often perfect

Table 2.4.1: Differences between entertainment games and serious games available in [16]

In the beginning, when the concept of video games started to show up, they had this purpose to captivate users and leave them glued to the screen, but, as time went by, this concept of "games" became an interesting object of study.

When we look at the figure above, we can immediately see the main big difference between the concept of serious games and the one of traditional games, and that is the theme of focus during their development.

A developer of a traditional game is always thinking about the users, but uses his interests for building games with rich experiences for the users, to make it addictive, to make it interesting. The concept of Serious games are a bit different, for they are no longer characterized by the interests of the developer, but by the interests of the actual users. The main focus here is the problem solving, the learning process and the reflection of natural communication, for example using the user's current language and not technical terms known only by people in the gaming area.

Within the world of serious games they can be divided into three categories [27]:

- **Message-based serious games:** Message-based serious games are a new genre of video games that use text-based messaging instead of graphics to tell the story and convey game play to the user (player). They offer a unique and powerful way to experience the thrill of video games and have the potential to reach users who might not be interested in traditional video games. This type of serious games has the principal goal of passing to the user a specific message on for educational purpose, informative or persuasive fashion.

- **Training serious games:** This kind of games is designed to help improve cognitive and motor skills and knowledge and can be used for a variety of purposes. The best way to understand how training games work is to think of them as a sort of simulation. They feature a set of realistic rules that allow the player to experience a situation or environment in a way that's similar to how the real thing works.

- **Simulation or serious play serious games:** Its main objective is not to evaluate users according to their performance in the game, but rather work as a simulation with a wide variety of potential uses.

2.4.1. Game Engine

Game engines are software platforms that aims to provide game designers with an amount of tools in order for them to develop games more quickly and more efficiently. Those platforms usually include several features for games to be built with the best possible quality. Among the most common features are:

- Graphic rendering to import 3D and 2D charts with the possibility of display them;
- Offer physics engines that have the primary purpose of simulating 3D and 2D physics and collisions;
- Allows the capability to add music and/or sound effects to the scenarios that are being constructed;
- Program scripts;
- Allows you to create animations directly on game objects
- Offers Artificial Intelligence tools;
- Provides the possibility to export the games to different platforms such as computer, mobile phone, tablet etc.

Over time, several game engines have been built. Among the best known are, for example: Unity 3D, Real Engine, Frostbite, Game Maker, Space Rogue and CryEngine.

2.4.2. Serious Games Applications

Over the past few years, serious games have emerged as an important tool for a wide range of organizations and sectors. From education to healthcare, from law enforcement to the military, and from food producers to financial institutions, serious games are being used to improve human performance in a variety of challenging situations and environments.

(1) **HealthCare:** Several tests and studies have been carried out over the years and it has been proven that the application of serious games in the health area has been a great help for improving cognitive abilities on older people (elderlies). [28]

In this area, several Random Controlled Trials (RCTs) were carried out in order to be able to generally study the impacts the introduction of this technology was having on patients and their treatments. Regarding alcoholic patients undergoing rehabilitation, it has been proven that the use of serious games during treatment sessions improves neuropsychological abilities more efficiently.[28]

The healthcare area is in a constant development and because it is such a so important area, due the fact that treats people's lives, it must be well studied weather the serious games to be applied in each field of medicine are indicated and effective, if they are not addictive, and if they are only being used for specific purposes. This innovative way is already being tried in many areas, such as physiotherapy, neurology or psychology, and has been proven to be, in some cases, even more efficient than some traditional treatments already used. However, there is still a need for more information about this world in expansion which is the one of serious games.

(2) **Aerospace and Defense:** One of the many applications, and surely a very important one, of serious games is in military training. They are used to train military personnel by creating virtual spaces that are very close to reality. The main purpose is to prepare the military for future training and actions, for real world situations that may happen, aiming to help them taking better and faster actions and decisions.[29]

(3) **Government:** Around the world, several governments are beginning to implement the use of intelligent systems and technologies. Serious games applied in this area are still being explored, however the proposal to use serious games to train various citizens to work as government civil servants is beginning to be implemented[30].

(4) **Education:** Game based learning is already a subsection of serious games, which is very much about exposing the importance that serious games can have or come to have in the world of education.

Educational games are aimed at teaching specific topics, for example identifying parts in the human body. Serious games also aim to improve the cognitive ability of the participants, for example mathematical inference, problem solving, attention, memory, etc. In this type of game, the ultimate goal is the improvement of the user[31].

2.5. Technology through Healthcare

Technologies in Medicine are a very critical part of healthcare's future. There are a number of challenges facing the healthcare system, such as an increasingly ageing population, an emerging crisis, and a lack of healthcare professionals numbers. These challenges have raised a need for new technologies to improve the patients care.

2.5.1. Mental Health

Society is evolving too fast and until a few decades ago, this sector of medicine that deals with mental health, was not much talked about, and had a lot of lack of knowledge on the part of health professionals. It is very difficult to understand mental problems as they are often only visible through the symptoms they cause and it's more than proven that mental illness will affect the rehabilitation of a patient due to the fact that there is no health to perform the proposed exercises and complete the treatment. The success of physiotherapy depends on the state of patient's mental health.

Mental health is one of the most emergent areas of healthcare that has genuinely benefited from a grown in the use of technology. A great amount of developments have the ability to potentially improve the lives of people that suffer from mental health issues everyday and, in certain cases, even help prevent them from occurring in the first place. While traditional methods of diagnosis and treatment continue to evolve, so do the ways in which people with mental health problems can get help.

One of the tools that is being proven to be very efficient is virtual reality. The usage of this tool in specialised clinics and hospitals in psychiatry and psychology fields of mental health sector, provides, in a certain way, the possible of making simultaneous diagnosis of mental illnesses and carry out physiological therapy through via synchronized registration of medical sign [32]. The diagnosis can be easily made with the development of serious games and the creation of realistic scenarios that cause the patient to experience the traumatic effects that his illness brings in a controlled and safe environment, helping him to lose his fear and to communicate more with his mind. Among the most well-known and common mental illnesses we have [33]:

- Anxiety Disorders
- Depression
- Post Traumatic stress Disorder (PTSD)

A project was founded by the UK's National Institute for Health Research (NIHR) [34] with the name gameChange, a tool for VR theraphy mainly direct for people with social anxiety issues.

The figure 2.6 below shows the possible scenarios that can be found in this interesting project. There are six scenarios in all, starting with the simplest and then getting more complicated. The objective will be for the patients to be placed in scenarios where they have to have a social interaction and do simple actions, making an order in a coffee shop [C], being in places that are silent and uncomfortable [D], going from a safe place to an unknown place [A], and even in situations that they can feel trapped [E].

FIGURE 2.6. The six gameChange [4] scenarios.

2.5.2. Diagnostics Error Reduction

The more data and the more information there is about a patient, the less likely there is to appear errors and have failures in the diagnoses made by health professionals especially in the physiotherapy field that that data is very important to determine the evolution of a patient.

2.5.3. Surgery

Virtual reality and other technologies such as AR, allow medical surgeons to practice surgical procedures without any compromises to put patients at risk. The use of information technology tools for medical training has been very successful in this area.

Rather than attending medical school, learning the intricacies of human anatomy, and operating on real patients, interns nowadays can learn these skills in realistic virtual environments and learn from the best, without ever being put to the test. There is massive potential for this technology. It can be used to teach patients how to take better care of their bodies by giving them access to diagnostic tools and medical records from a doctor, or to better understand their health conditions by giving them access to a doctor's diagnosis.

In the following 2.7 figure we can find an example of VR application in a surgery training of a multi training platform of a knee surgery [35].

FIGURE 2.7. FundamentalVR's [5] multi-person training platform on knee surgery

2.5.4. Physiotherapy

Physiotherapy, also known as physical therapy, is the branch of medicine that aims to improve a patient's physical health by keeping them fit, and treating certain related conditions.

Physiotherapy is composed of several areas of treatment with the most common being the following [36]:

- **Cardiopulmonary :** As the name implies, cardiopulmonary becomes the junction between heart conditions and lung conditions. This type of physiotherapy helps all kinds of people who have this types of problems. Usually in this type of physiotherapy

breathing exercises and a lot of physical exercise are practiced so that the health professionals specialised in this area can acquire a lot of data during the training and in this way help the patients not to have a limited life.

- **Geriatrics :** As a person gets older, the fragility of his body increases and physiotherapy may be necessary in order for the patient not to lose mobility and independence.This type of physiotherapy is aimed at the older age group.

  This type of physiotherapy is not so focused on the more common treatments of the other physiotherapies. This type of physiotherapy is more focused on gaining strength and agility by this age group that with time ends up getting weaker.

- **Neurologic :** When a person presents some neurological disease that interferes with their mobility, their independence and their strength, either because of an accident that happened during their life, or because of a condition caused by birth, this type of physiotherapy becomes highly essential to help recover and restructure a missing or damaged limb.

- **Orthopaedic:** This type of physiotherapy is one of the most important as it can be applied to the entire muscular system of the human being.

  The rehabilitation of the lower limbs and gait, which are the focus of this dissertation, fall within this type of physiotherapy.

- **Paediatrics:** The age group of children is very important as they represent the future of our society.Sometimes babies and children have conditions such as cerebral palsy, late development, autism or many other conditions that cause limitations to their bodies so this type of physiotherapy is aimed only at paediatrics, which includes the age range of babies, children and adolescents up to recent ages.

The huge increase in information technology systems has allowed an improvement also in this sector of medicine, with the use of artificial intelligence and virtual reality tools. The figure 2.8 below shows some examples of the application of technology in the physiotherapy sector.

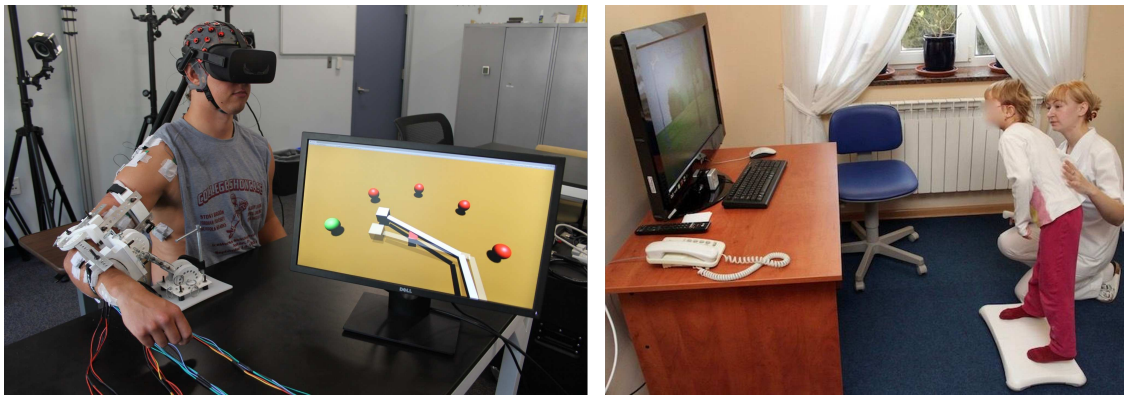


FIGURE 2.8. In the Left Image VR physiotherapy with smart glove represented in [6], In the right image children with CP playing a serious game represented in [7]

2.6. The Gait Cycle

A gait cycle is the time period or the succession of events or movements during walking in which a single foot enters into contact with the ground when that same foot comes back into contact with the ground, and involves the propelling of the centre of gravity in the direction of the movement. A gait cycle typically entails both left and right leg and foot cooperative movements.

The individual gait pattern is influenced by a lot of factors, such as age, personality, mood, sociocultural factors, and so on. There are essentially three stages in a human gait pattern, which are usually called **Gait Phases** represented in figure 2.9.

The first one, is where the first contact with the ground happens. Using a more technical term, it's called a **Stance**[37]. This first phase takes up most of the gait cycle (about 60%) and is composed of some events, mentioned below:

- **First Contact** : The first event of Stance is the period in which the body weight is balanced over both feet and there is no movement in the centre of pressure. This is called the first contact or the contact phase.
- **Foot Flat**: Immediately follows the second event, which occurs when the plant of the foot is entirely placed along the floor.
- **Mid Stance**: Is the middle event where the femur happens to be directly aligned with the standing foot.
- **Heel Off**: Event which, again as the name implies, happens at the right moment the heel lifts off the ground.
- **Toe Off**: Last event of this phase which, again as the name implies, happens at the moment the toe lifts off the ground. This event makes the transition between the two phases.

The second phase is called **Swing** and it takes about 30% of the cycle, which means that represents all of the the remaining part of the gait cycle. Here there are three main events:

- **Acceleration** : Is the one that happens just after the toe lifts off the ground and goes until maximum knee reflection occurs. This event can be also known as the Initial swing [38] in which the person tries to speed up the process of moving the legs.
- **MidSwing**: A middle event in which the person prepares the process of slowing down in an unconscious way.
- **Deceleration** : This event, the last one of the cycle, occurs when the person tries to deaccelerate the movement of both legs to stop them for next initial contact.

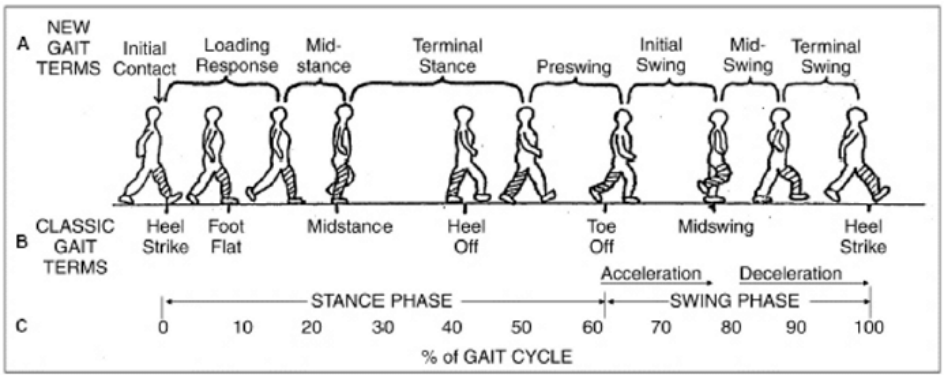


FIGURE 2.9. Illustration of different phases of the gait cycle[8]

The gait cycle is a very important object of study for health professionals, because it helps to diagnose various types of diseases. In normal gait[39], the foot moves forward and backward, side to side, and rotates in circles in a coordinated way. The body goes through all the events described above in an unconscious and natural way.

On the other hand, in a pathological gait, other sequences of gait phases can be observed. The patient may walk slowly, stopping at the end of every few steps, or making large movements of the extremities, which seem to cause the body to lose contact with the substrate. The posture of the body may also be altered in a pathological gait. Patient may adopt a legs-down or standing posture, often with a bent upper back, and may drag the heels when walking. The arms and/or legs may be swayed excessively or the arms may be held in a fixed position.

2.6.1. Abnormalities of Gait and Posture

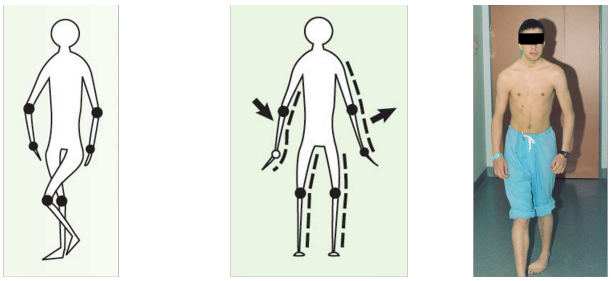
In general, gait disorders are more likely to occur in the elderly, due to a lot of factors such as, loss of bone and muscle strength, age-related balance and memory loss. In fact, many of the neurological and musculature problems found in patients can be more easily identified by looking at the way a person walks. That is why it is so important to have a method of assessing a person's gait and identifying any problems immediately.

According to a research done in [11], the type of gait problems a person may have can be divided into 3 rather important levels:

(1) **Lowest-level gait disorders:** At this level are included people with sight disorders, where they cannot have a well-defined sense of spatial location and have a lot of difficulties in orientation and even in their position, or all those who present some abnormalities in the musculoskeletal system. Problems that are part of this level are the ones that can be easily identifiable by all specialised health professionals in this area. Most common examples are people with blindness, loss of limbs and people using artificial limbs.

People in older ages who may develop issues including fear of falling, loss of balance and increased bone fragility may also be included at this level.

(2) **Middle-level gait disorders:** In this middle level are allocated all the gait disorders that are caused due to prosthetic and locomotor disabilities different from those which are defined as ”correct” by our nervous system. People suffering from this type of disorders do not normally have difficulties to start the walking process but the gait cycle that was defined as a standard is typically abnormal. These types of abnormalities are those with which neurologists feel more familiar treating as they are already more serious problems than the ones in previous level and sometimes those are the disorders that can prevent walking for good. Examples of gait problems that belong to this middle level are for instance spastic gait or more commonly known as scissor walking, where patients walk with their knees half reflected, with the feet turned outwards; ataxic gait and dystonic gait.



(a) Scissors Gait (b) Cerebellar Ataxia (c) Dystonic Gait

FIGURE 2.10. middle-level’s Gait disorders types [9] [10]

(3) **Highest-level gait disorders:** Problems at this level are much more complex problems that affect the person’s balance and their motor movement. It is usually the posture and the locomotion part of our body that are able to respond to the surfaces we step on, and what the correct body position. This type of problem is the least understood by specialised health health professionals and are the cause of many studies by them, because they are untreated diseases. In the figure 2.11 below it is possible to visualize some of the characteristics of these types of diseases and how can they manifest in the patient’s body. We can see that in the Cautious gait disorder type there is no Dementia , no Aproxia and no frontal release signs. That’s also not related to

Parkinson's disease and pyramidal signs or Urinary incontinence. In other way there's a lot of gait disorders that are characterized as the highest-level ones that presents all of the characteristics shown in the figure below. The serious ones (the ones that causes more physical symptoms for the patients) are Frontal disequilibrium and frontal gait disorder.

Type of gait disorder	Dementia	Apraxia*	Frontal release signs†	Parkinsonism‡	Pyramidal signs	Urinary incontinence
Cautious gait	No	No	No	No	No	No
Subcortical disequilibrium	No	No	No	Occasional	Occasional	No
Frontal disequilibrium	Common	Occasional	Common	Occasional	Occasional	Yes
Isolated gait ignition failure	No	No	No	No	No	No
Frontal gait disorder	Common	Occasional	Common	Occasional	Occasional	Yes

* Examined by the ability to perform actions to command or mime gestures with arms or legs.
† Frontal release signs included gegenhalten (a variable increase in muscle tone often accompanied by an inability to relax during passive limb manipulation), grasp reflexes (hand and foot), and rooting responses.
‡ Hypokinesia, difficulty executing rhythmic and repetitive alternating or sequential movements.

FIGURE 2.11. Highest-level gait disorders, study made by [11]

2.6.2. Gait Rehabilitation Methods

Gait rehabilitation can be a very complex task and it requires both patients and specialized health professionals to work as a team. Usually, this team work is performed by using classical methods of physiotherapy, such as a repetitive set of exercises. It has been proven that if the human body repeats the same exercises several times, it will learn that same exercises and will eventually get used to them. Nevertheless, these exercises and this process of physical therapy for patients, can become boring, repetitive or uninteresting, which can be quite risky, for it makes patients lose interest in the treatment and not end it properly or, in the worst case scenarios, even quit them.

2.6.3. Implementation of VR in Gait treatments:

Virtual reality is a quite famous term and not only in the world of information technologies. A virtual reality system is an intelligent system which is able to give user the perspective of immersiveness in a synthesized/built environment.

"VR can be defined as the simulation of a real or imagined environment that can be experienced visually in the three dimensions of width, height and depth and that may additionally provide an interactive experience visually in full real-time motion with sound and possibly with tactile and other forms of feedback"[40]. This technology offers the user a rich virtual experience that makes it seem as if he has entered in a completely different world from where he was just a few minutes ago.

The figure 2.12 below shows a person experiencing a virtual reality experience.

FIGURE 2.12. Virtual Reality Entertainment Game experienced

Virtual Reality applications have branched out into numerous domains, from education to entertainment, from agriculture to medicine/healthcare.[41] Each of these domains bring everyday challenges to developers, who have to address issues concerning the immersive nature of Virtual Reality, such as how to keep users immersed, how to avoid motion sickness, how to provide a best-in-class user experience, and more.

Talking about the immersiveness and the user inclusion, the virtual reality scenarios have to be built with the correct perspective, which means that users need to feel that the scenarios are real, they need to believe that they are really in a different place, because deep down the main goal is to motivate and capture his attention, and that won't be possible if the user thinks, at any moment, that something is out of place. User's brains need to be entertained. People like to be entertained, so there's nothing better than a game that captures their full attention and makes them want to be there playing more and more.

The unique nature of VR applications has also inspired developers to come up with new ways to interact with the virtual world. Some of the most interesting and engaging applications take advantage of the unique characteristics of VR to create new ways for users to interact with the virtual world. For example, a user could reach out and touch a virtual table in a "room" in virtual reality, rather than using a mouse or keyboard to click on a virtual "table" on a computer. This allows users to have a more immersive experience, strengthens their connection with the virtual world and provides new ways to interact with this same virtual world.

The figures 2.13 that follow show two applications of virtual reality in very different scenarios. In the first image we can see the use of this type of technology in the military suing mostly for training, and in the second image is possible to see virtual reality using in cows to provide them a happy place where they can feel happier such as a green field.

FIGURE 2.13. On the left VR application in a military train and on the right Virtual Reality for Livestock

The process of rehabilitation itself really depends on the frequency and effectiveness of the physical rehabilitation sessions. One successful solution that can serve as a complementary therapy to the rehabilitation methods, is the remote physiotherapy self training at home.[39] The rehabilitation is expected to progress faster and with better results due to the remote nature of the intervention. The rehabilitation at home requires more time and effort, which may be difficult for some patients to maintain, but it also has the potential to create, enhance and reinforce patient's existing rehabilitation regime and, ultimately, may improve the outcome of the rehabilitation process. The success of the rehabilitation process also depends on patients' motivation and ability to adhere to the rehabilitation programme, which is challenging in the remote setting.

Gait rehabilitation using virtual reality scenarios is a dynamic way of obtaining something more than visual feedback in a simple static state [42], it offers users a sense of immersiveness, solving some of the spatial and safety problems that occur during walking practice sessions.

A study made in [12] conducted on neurological patients with gait disorders, demonstrated the efficiency and effectiveness of using virtual reality as an aid in training and rehabilitation sessions. Patients were first placed on a treadmill without the VR and, for example, walked as if they were doing the classic sessions. With the results of the study, represented in figure 2.14 below, it is concluded that the walking speed with the use of VR tools is much faster than without the implementation of virtual reality technologies. The same happens with healthy patients.

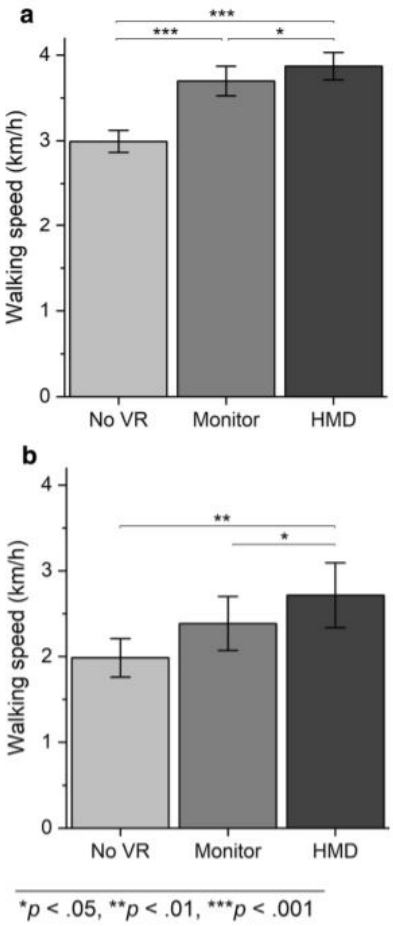


FIGURE 2.14. Average walking speed in gait rehabilitation for healthy(a) and neurological patients(b) with gait disorders from.[12] study

The walking speed parameter is really a very important one for physical therapists are able to measure the patient's evolution during gait rehabilitation. One of the goals that professionals in this health area want to achieve is exactly to prove that is possible the increase in walking speed with virtual reality.

2.7. Proposal

Virtual reality is a simulated experience which can be either similar or completely opposite to what we are seeing and experiencing in the real world. It has already been proven by numerous studies and investigations that technology is turning rehabilitation treatments into a far more efficient and positive processes, giving a massive support to the classic methods of physiotherapy, already used for a very long time, and with gait rehabilitation it is no exception.

This thesis aims to build a system/solution, designated by Gait VR, that contributes to help with lower limb rehabilitation more specifically with gait rehabilitation, using virtual reality scenarios.

CHAPTER 3

System Description

3.1. Overview

This chapter aims at presenting the description of the Gait VR system proposed in this thesis, a solution developed and designed to support gait and lower limb rehabilitation performed by patients in hospitals or specialized clinics, in accordance with the necessities of the patients. This system is structured with 3 important components, which are the web application, the game application and the database, which will be discussed in more detail throughout this chapter.

3.2. Gait VR System

As mentioned previously, Gait VR is a system/solution that was developed with the main purpose of supporting the Gait physiotherapy for patients, who mostly need motivation to keep up with it and do not give up.

Many studies conducted in recent years, have shown that the use of technology in various areas of medical science has been increasing the effectiveness and quality of various treatments, and the treatments for gait disorders have are no exception.

FIGURE 3.1. Gait VR System Design

Within the system developed for this dissertation, there are four main components:

- **Web Application:** Application built by the Angular framework and ASP .Net Core, which serves as a tool for specialized health professionals to support their patients so that their trainings have higher quality and become more efficient. In this application they can have access to all of games results and visualize them in charts form.

- **Games Application:** Application built by the software platform Unity 3D that serves as a tool for patients to practice and therefore be able to play the most appropriate serious games for their types of disorders.
- **Database:** Stores all the necessary data that will be used for visualisation in the applications and also stores the data that is extracted from each training session of each patient.
- **Azure Kinect:** Natural User interface. Has a direct connection to the game application and is the responsible to the movement of the game player due to its sensors.

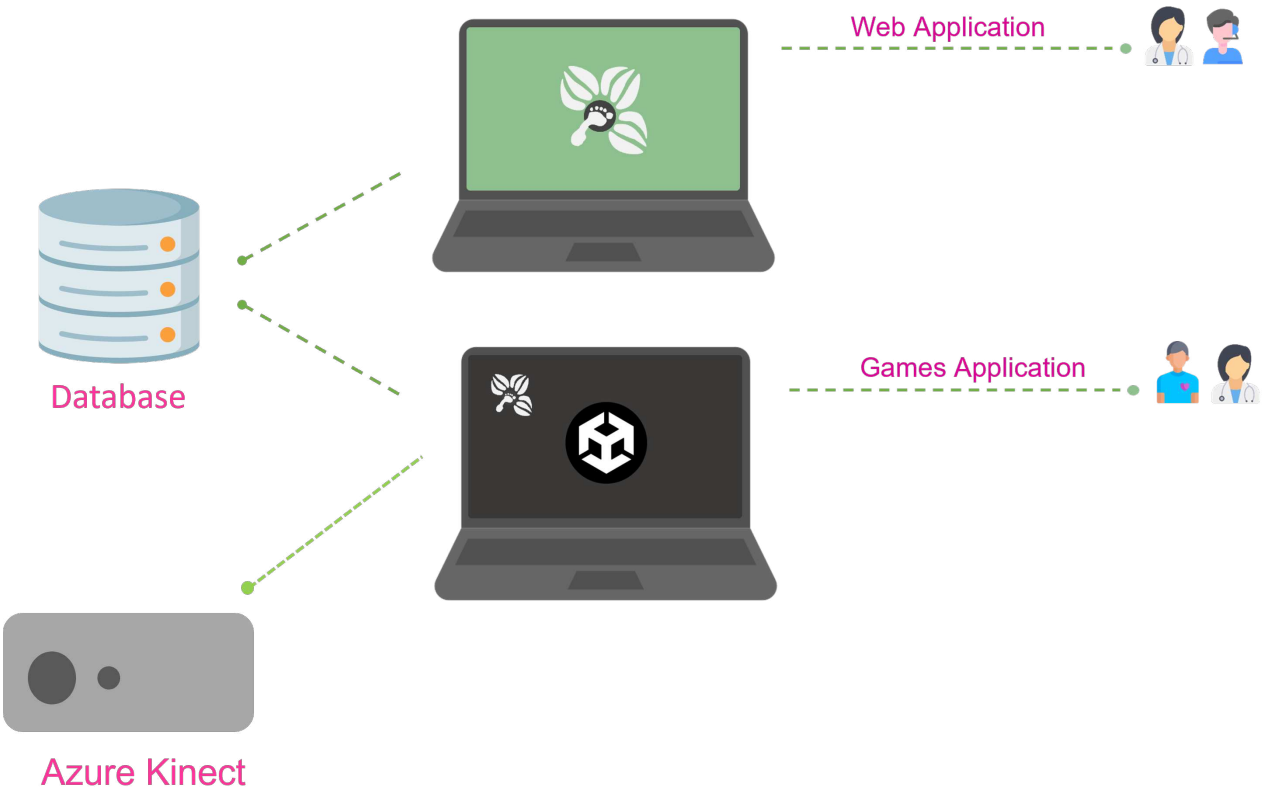


FIGURE 3.2. The Main components of System GaitVR

Bellow, in figure 3.3 we can have access to a block diagram which serves as a representation of the Gait VR architecture system, going through all the detailed steps by which it was built.

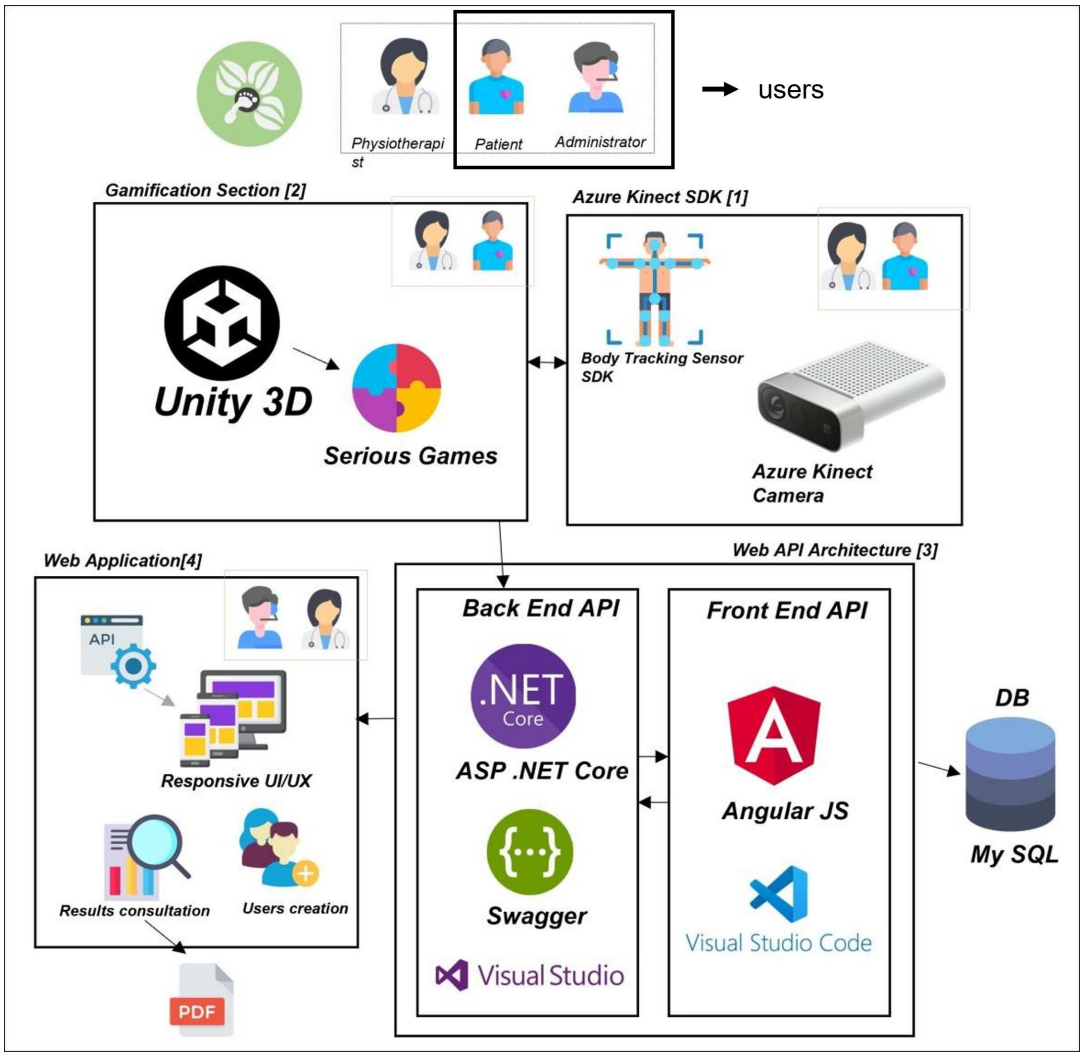


FIGURE 3.3. Representation in a Block Diagram of the Gait VR system architecture

This system encompasses three types of users:

(1) **Administrators:** Administrators are defined as the users who have access to everything inside the web application. They can have access to a complete table with all the information of all the existing user types, either they belong to ”physiotherapist” or ”patient” categories. This type of users doesn’t have the ability to create users of the type ”patient” however only it can create users of the type ”physiotherapist”. In other words, is known as the web application manager.

(2) **Physiotherapists:** This type of user has access to the two main sides of the system, the web application and the complete interface where patients can do their trainings by playing the serious games developed. Within the application, this user type is controlled by the application administrator, however it is he who controls the ”patient” user type, they can create patients and associate them with themselves. They can also have access to all their private information, their data storage from the games and trainings and create the sames.

(3) **Patients:** Patients are the types of users that will only have access to one side of the system, which is the games and their interface, where they can log in and start the workouts prescribed by their physical therapists. This type of user does not have access to the web application that completes the GaitVR system.

3.2.1. Azure Kinect SDK

The Azure Kinect SDK is a low-cost camera device launched by Microsoft, that can display and collect images, including Red, Green and Blue (RGB) images, infrared images, and depth images [43]. The interesting concept about this kind of camera is that, it can detect up to twenty five joints of the human body, being equipped to recognize up to six human bodies at the same time, which is very beneficial because it allows a person to stand in front of the camera and track their entire body, all its joints, its movements, measure the world and local coordinate positions, angles, and so can allow patients to have a more realistic experience during their rehabilitation processes, without having to use wearable devices.

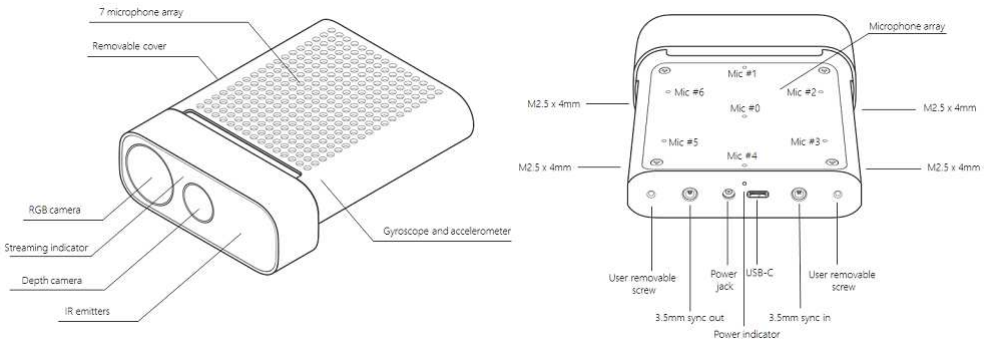


FIGURE 3.4. Azure Kinect SDK device architecture represented in [3]

The camera is equipped with 2 main channels that function also as cameras, the **RGB camera** and the **Depth camera**, both composed of sensors of the same type respectively.

- RGB Camera : Highly complex camera where the main objective is to visualize a world in 2D and can have a resolution up to 4K.[44]
- Depth Camera: This camera displays a depth map generated from a set of z-coordinates of each pixel in the displayed image, which in this case is what the camera is looking at.[45]

3.2.2. Body Tracking SDK

Body Tracking SDK is a library that belongs to Microsoft Azure Kinect which from its RGB camera and its depth camera can reproduce 3D human poses in real time, according to the person that stands in front of the Azure camera, using data from the depth sensor. Body-tracking aims at identifying users within a scene and segmenting them in significant parts or, equivalently, representing them in ordered arrays of skeleton joints.[46]

For the Gait VR project, this library was used to detect the joints belonging to the patients human body, and to extract data in real time while they perform their gait rehabilitation training. The camera was then connected to the Unity 3D software platform, detecting the joints from a 3D avatar model, using depth sensors through the depth camera shown in figure 3.5.

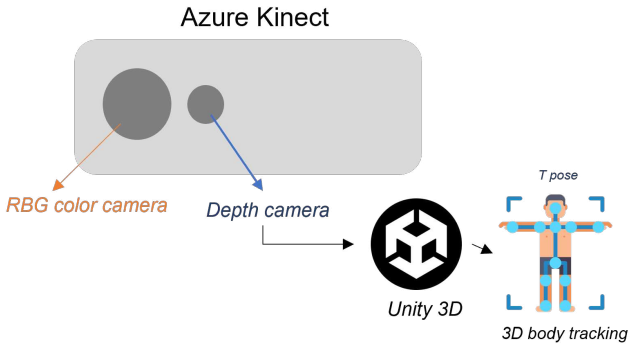


FIGURE 3.5. Representation of Azure Kinect Camera using Body Tracking SDK in Unity 3D

The placement of a Kinect sensor significantly influences the performance of measuring kinematic parameters, especially for dynamic tasks. A Kinect sensor is usually placed around 2 to 2.5 m in front of a subject, around one meter above the ground, with zero tilt angle in the horizontal plane to capture static postures as referred in [47] 3.6

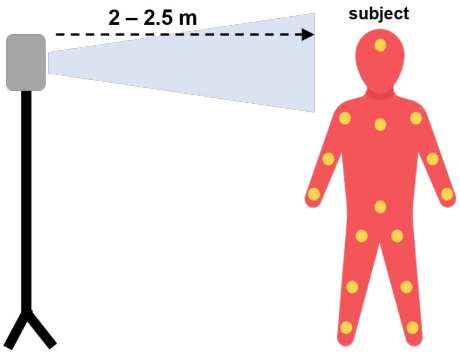


FIGURE 3.6. Optimal position representation Azure Kinect

3.2.3. Kinect V2 and Microsoft Azure Kinect Comparison

Until very recently, the Kinect Version 1 (V1) and Kinect V2 cameras also released by Microsoft in the year of 2010 and 2014 respectively, have been studied accurately in order to be able to upgrade the sensors and all the features acquired by them. This is where Microsoft Azure Kinect was created.

Below is presented a table 3.2.1 with the main differences between Kinect V2 and its latest version.

	KINECT V2	**AZURE KINECT**
1 depth camera + 1 color camera	YES	YES
RGB Camera Resolution	1920x1080 px @30 fps	3840 x 2160 px @30 fps
IR Camera Resolution	512x424 px	1024 x 1024 px
Depth Camera Resolution	512x424 px @ 30 fps	NFOV unbinned - 640 x 576 @30 fps NFOV binned - 320 x 288 @30 fps WFOV unbinned - 1024 x 024 @15 fps WFOV binned -512 x 512 @30 fps
Framerate	30 fps	30 fps
Field of View IR Camera	70 x 60 degrees	75 x 65/120 x 120 degrees
Field of View RGB Camera	84 x 53 degrees	90 x 59/90 x 74 degrees
Depth Sensing tecnology	ToF (Time of Flight)	ToF (Time of Flight)
Number of Joints that can detect	20 joints	25 joints
Face Key Points	NO	YES

Table 3.2.1: Table representing the main differences between Kinect V2 and Azure Kinect. NFOV (Narrow Field of View), WFOV (Wide field of View)

As it can be verified by the direct visualization of the table, it could be noticed that in many features the most recent version of the camera created by Microsoft (Azure Kinect) shows more compliancy than in Kinect V2 camera. Both features a colour camera more commonly known as RGB camera, and a depth camera but their resolutions are quite different.

The Azure Kinect RGB camera highest resolution is 3840 × 2160 Pixel (px) at 30 Frame Per Second (fps), but in Kinect V2 the maximum resolution only goes until 1920 x 1080 px, half of the previous value range. The exact same happens with the Infrared Sensor (IR) camera for

the Azure Kinect that presents a resolution of 1 megapixel, with a size of 1024×1024 pixels, the kinect V2 camera maximum resolution goes only until half of that value range.

Both of the cameras sensors uses as depth sensing technology the Time Of Flight (ToF) rule in their cameras. A 3D time-of-flight (ToF) camera is a type of depth sensors which modulates its illumination Light-Emitting Diode (LEDs) and measures the phase and the amplitude of the returned signal with its Charged-Couple Device (CCD)/Metal Oxide Semiconductor plus Active-Pixel Sensor (CMOS) imaging sensor at each pixel. [48] By also comparing the two cameras, the more recently created Azure Kinect SDK camera has a higher accuracy than its more recent version belonging to Kinect V2.

3.2.4. Azure Kinect Constitution

Azure Kinect is a camera made up of 2 main channels: the **RBG channel** and the **Depth channel**, the channel used for detecting the patient's body. In this project, this camera is utilized with the main purpose of using the library already provided by Microsoft for the Unity 3D software platform known as Body Tracking SDK. This platform called Unity 3D was essentially for the games development, and serious games, and is the software platform that will have a direct connection with the Azure Kinect camera.

This camera is composed of two inputs on the back, the one in the left side is called a power input. The other input is an USB-C entrance input that mainly serves to makes the connection between the camera and the computer.

For the camera to be working properly, a white light must be on permanently.

FIGURE 3.7. Azure Kinect Camera

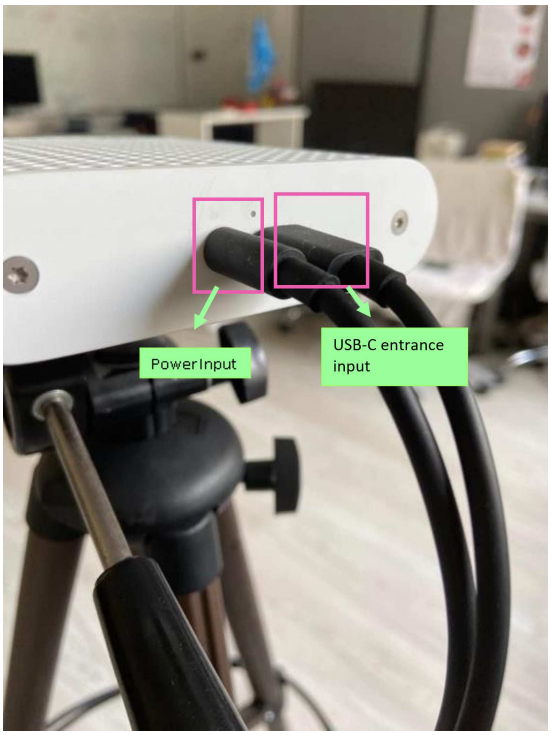


FIGURE 3.8. Azure Kinect camera inputs

3.2.5. Gamification Section

This section is the one dedicated to the serious games and is what gives patients the access to an interface created on Unity 3D software platform, where they can automatically authenticate themselves and have access to the training sessions prescribed by their physiotherapists. Their training's can be composed by only one game or a collection of games, chosen by the healthcare professional, that will work as a complementary support for their physical therapy.

It is important to highlight that the existing games in this system were not only developed thinking about people with only gait disorders, but also about people with neurological issues too, more specifically for people suffering with the cerebral palsy condition.

After a long period of research about what would be the better game engine [49] to utilize for the development of the Gait VR system, it was decided to work using the multi-platform software Unity 3D since it is a very affordable software multi-platform, free for students and at the same time allows and compensates for offering great capabilities and tools for rendering games.

The free version of Unity was used in this project, but before entering the platform to be able to develop the games, we have to go through a visual interface called **Unity Hub**, shown in the figure 3.11 below.

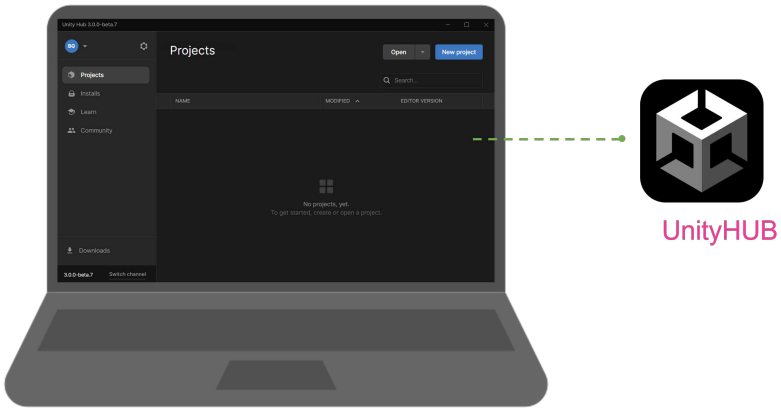


FIGURE 3.9. Unity HUB interface

The Unity HUB is an Manager Application [50] that allows users to do installations and all workplace set up in the Unity 3D application, in order to facilitate later project development. There are a lot of spaces where users can have quick access to projects, an installation space where you can access all the existing versions of Unity already released, whether new or older, and also access to the existing installed versions. Users can also access to two space full of tutorials, and access to unity community where there is quick access to various features such as blogs, questions and answers forums, and sites where you can access various projects already developed and even talk to the developers themselves.

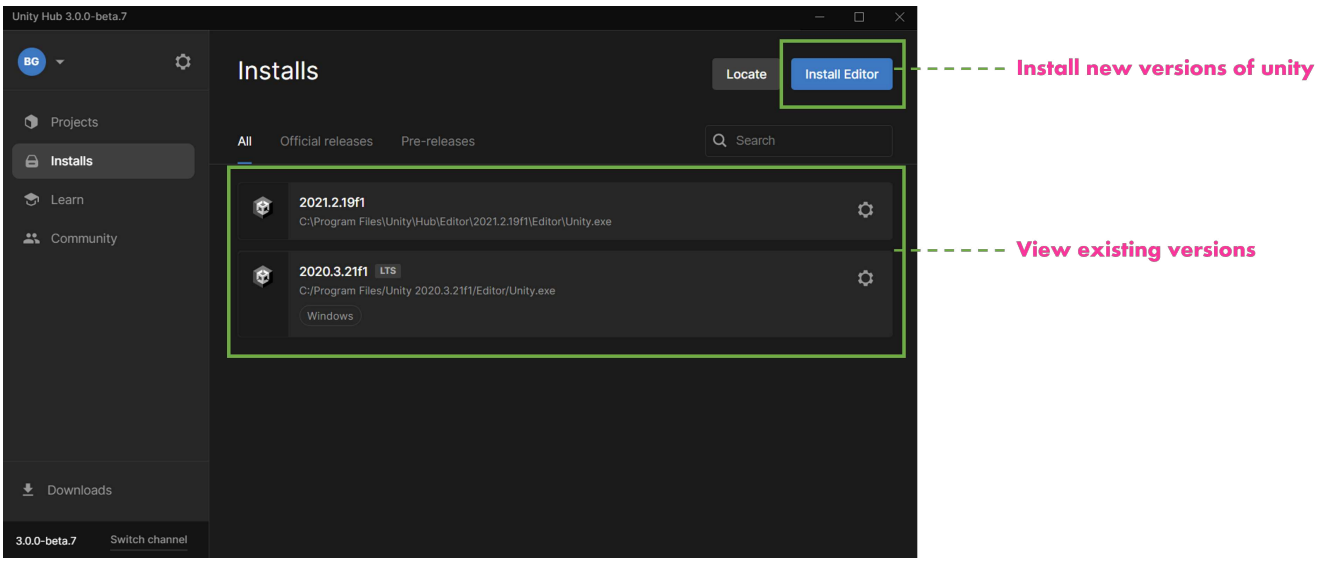


FIGURE 3.10. Unity HUB installs

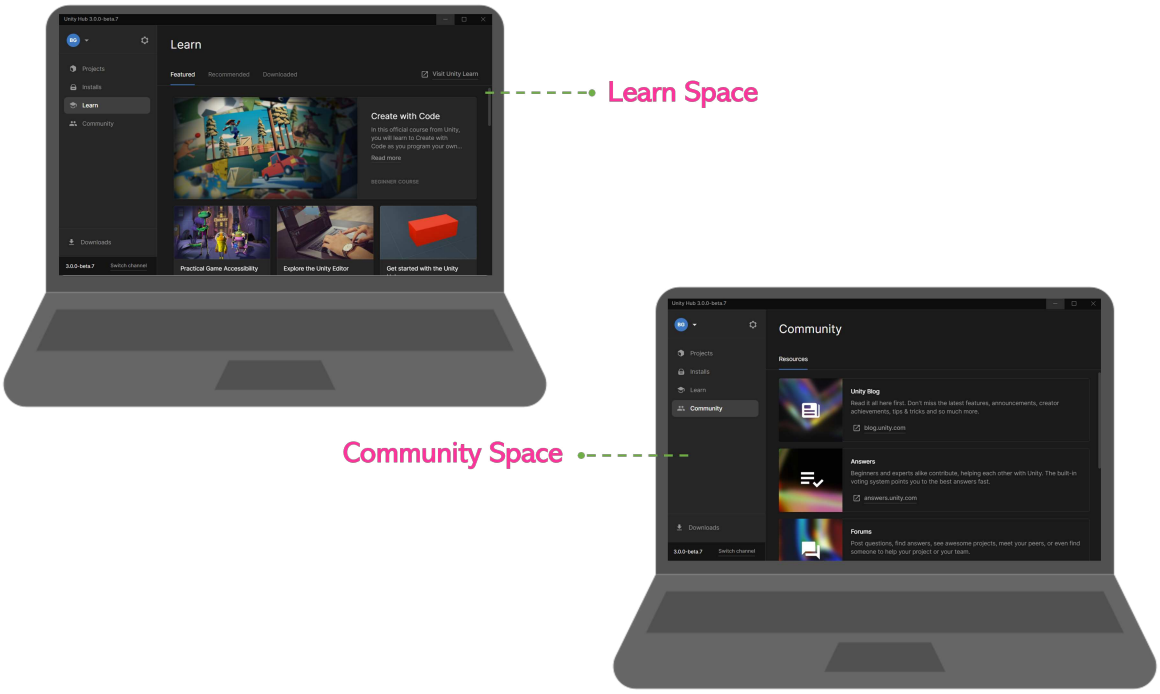


FIGURE 3.11. Unity HUB Spaces

Unity 3D is known for having a lot of advantages, and it was this many advantages that assisted in making a reasonable decision as to why to choose to use Unity 3D as the game engine. Below are presented some examples of such advantages.

(1) It is a program that at first sight is very intuitive to use due to its simple and organised interface.

(2) The platform-related operations are encapsulated in its internal, the complex game object-relations are managed by different visual views, and JavaScript, C or Boo scripting languages are applied to program a game [51].

(3) When the games are finished it is possible to export them out of the Unity application

(4) Has a large asset store [52], where it is possible to directly import models of game objects.

(5) Microsoft has available one free sample project for people to test body tracking SDK [53] with Azure Kinect in Unity 3D.

Unity's interface is quite intuitive and it has several possible features that can be organised as the developer requires. For the development of the project proposed in this dissertation, the interface was organised as follows in figure 3.12.

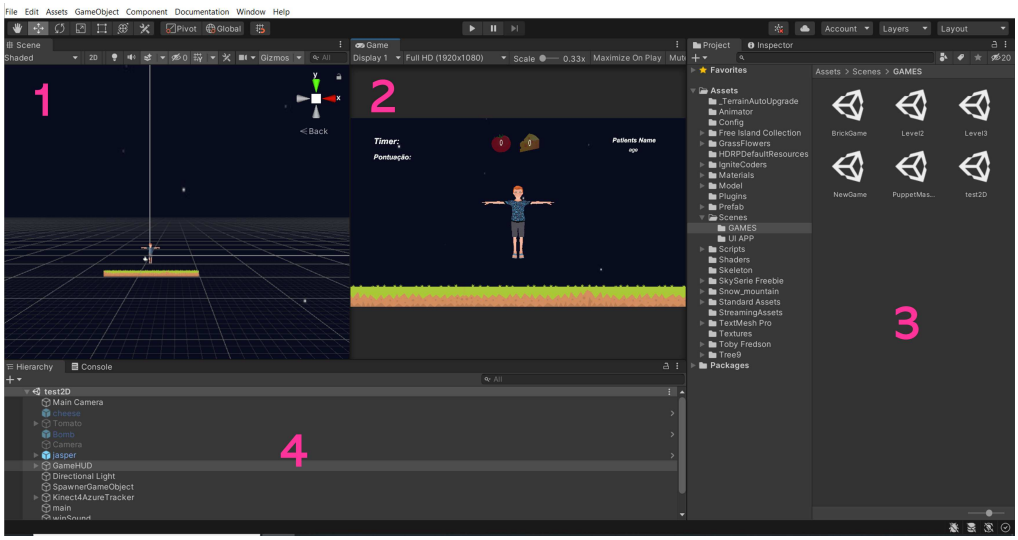


FIGURE 3.12. Unity Interface

(1) **Scene:** The scene is the master workspace for the developer. This is where it is possible to make the game scenes, interact with the game objects the ones that are going to be present in the game, such as moving the objects, doing rotations, climbing the objects, moving in 360° the whole world.

(2) **Game:** This space will be showing the developer the actual looking of the game, with the right lights and with the objects in their actual space. This is where the magic happens, as soon as the user presses the play button, everything that was done in the previous scenario (scene) happens. It is the end result of all the work.

(3) **Project:** This is the project organisation area, where is possible to visualise all the available scenes, view all the assets and materials imported to the project and all the developed scripts.

(4) **Hierarchy:** As the name suggests, this area shows all the game objects present in the scene in a hierarchical way. Here you can delete objects, create new ones, and even edit the hierarchies.

3.2.6. Azure Kinect Usage with Unity 3D

Microsoft created a repository where provides a tool that permits the usage of Azure Kinect with the software game engine Unity 3D, that tool is a library already mentioned earlier in this document called **Azure Kinect Body Tracking SDK**. It was not an easy task to put all together because it's necessary the installation of a set of programs and a lot of configurations but once everything is set, with a little changes it works fine. The configurations are described as follow:

- Have all Hardware requirements necessary for this library to run. The requirements filled was:

(1) A computer with Seventh Gen Intel® CoreTM i7 Processor

(2) A Graphics Processing Unit (GPU) NVIDIA GEFORCE GTX 1050 an adequate operating system, in this case it was used Windows 10.

(3) A large set of memory

(4) Have a USB3 port to connect the Azure Kinect camera

- Download and install Azure Kinect Sensor SDK, that consists in a set of tools and libraries that provides the development of an application with Azure Kinect, and also comes with a program that I used a lot to test my camera that is called Azure Kinect Viewer. A representation of that program is shown in the figure 3.14 below:

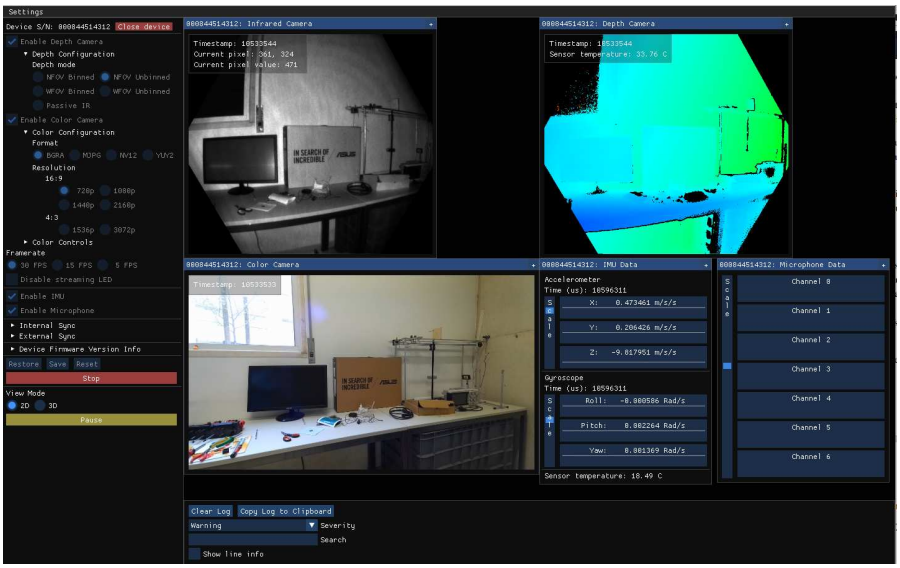


FIGURE 3.13. Representation of Azure Kinect Viewer

- Download Azure Kinect Body Tracking SDK existing in the Microsoft repository.
- Have a version of Game Engine software installed that is compatible with the library mentioned before, in this case it was used the version 2019.4.24f1.

Once everything is installed, it was still necessary to make some changes in order to work properly. Below is a representation of how it is organized the folder of the Kinect Body Tracking SDK. The folder used in the unity project was the folder that is highlighted on the left side of the image.

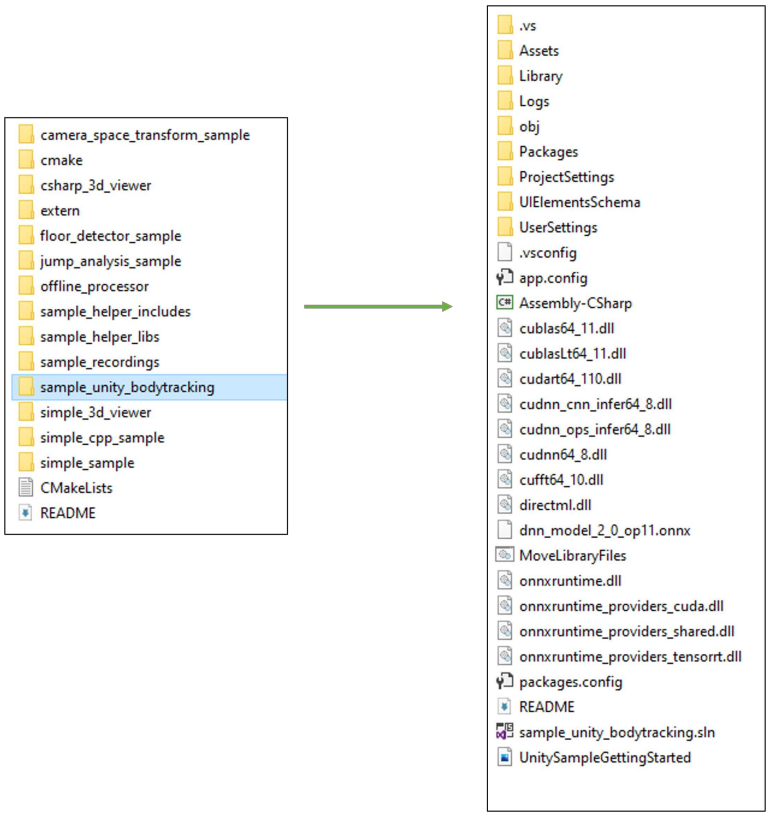


FIGURE 3.14. Representation of Azure Kinect Body Tracking Folder

3.2.7. Serious Games Description

Considering for this project , four games were developed in Unity 3D multi platform game engine. all games were built, taking into consideration various technical aspects such as careful game conceptualization and scenario design using prefabs available on platforms like Unity Prefab Asset Store[54] and Turbosquid [55]:

(1) **The Match Game:** The main objective of this game is for the patient score as many goals as possible in the constantly moving target. To shoot the instantiated balls, the patient doesn't need to be in movement, but it is necessary that his feet and leg to move and apply force in the target direction (forward). The user wins a point every time a ball enters inside the moving target. The total score is defined as soon as the playing time is over.

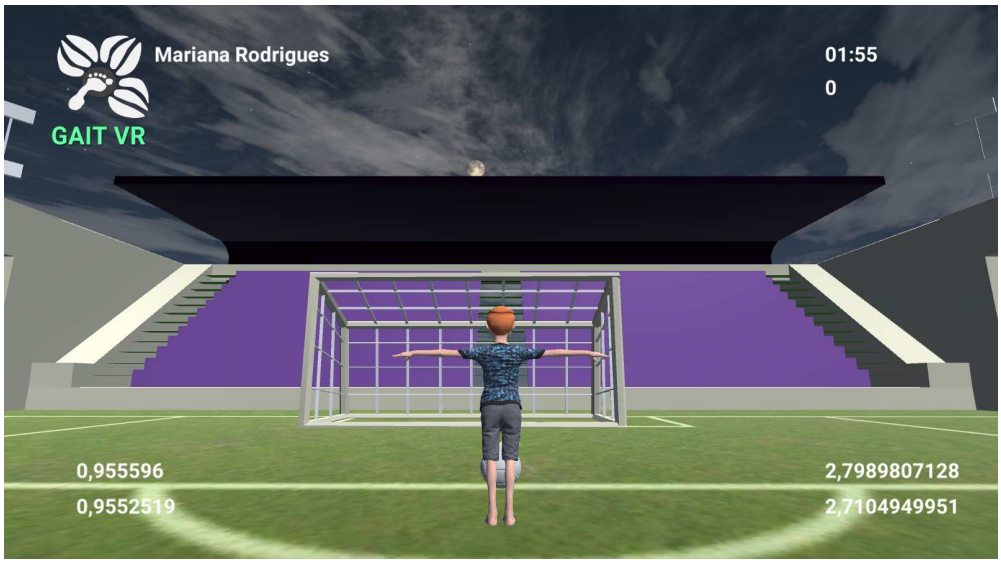


FIGURE 3.15. Match Game

Data	**Purpose**
Total Score	It can draw conclusions about the player's speed, the higher the score, the greater their flexibility and movement.
Number of balls shot	Shows how many times the player has touched the ball with his feet and can give information about his movement, speed and flexibility
Time	Values that represent the playing time and is important because it can provide information about the player's behaviour during the game.
Left Knee Angle	Angle measurement range, that can draw conclusions about knee flexibility
Right Knee Angle	Angle measurement range, that can draw conclusions about knee flexibility
Spine Angle	Measures the player's balance in 3D space
Z Value	It shows how high the player's foot can reach in 3D space. It can draw conclusions about their flexibility and balance, because while one foot is in the air, the other is on the ground

Table 3.2.2: Data extracted from the Match Game and its Purpose

Adaptability of this game according to the patient's limitations: Patients express their disabilities in different ways, and it is therefore important that the games have some flexibility in order to be adaptable to all types of patients and adapt to their physical and psychological limitations. For those reasons, this game allows health professionals to adjust two main elements values: the value of the speed at which the goal moves from one side to the other, and the value of the playing time. In a situation where the patient has very limited mobility, it is necessary for the goal to move at a speed proportional to that which the patient can move. The less mobility the patient has, the more difficult it will be to shoot the balls and score points. For this reason it may sometimes be necessary to extend the playing time in order to improve playability for that patient.

Some scrips developed for this game:

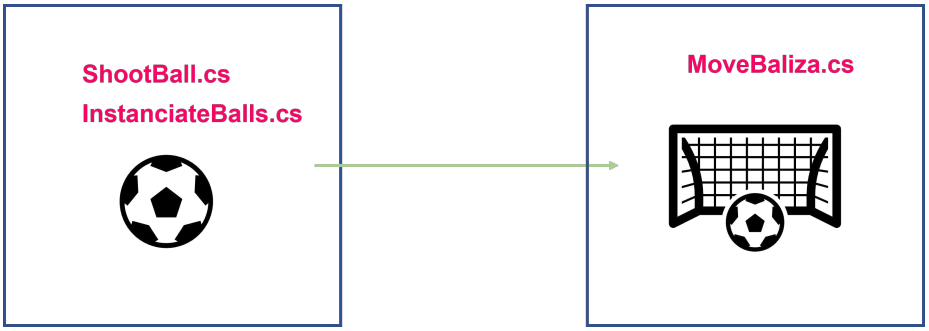


FIGURE 3.16. Scripts scheme for The Match Game

- **ShootBall.cs:** Script which takes as arguments the speed, that can be controlled from the game by the person who sets up the game before it starts, and the ball prefab itself which will be the object of the scene where the methods specified here will be applied. Inside this script, is implemented a method named as **OnCollisionEnter(Collision collision)**, that executes when in the game there is a collision between the player and the object named collision that in this game will be the ball in the scene.

- **InstanciateBalls.cs:** Simple script that instantiates the soccer ball model in the game environment, always in the same position, with a time frame of 10 seconds. This time can be increased depending on the needs of the person playing the game.

- **MoveBaliza.cs:** script associated with the goal model on the soccer field that makes the goal, once the game starts, always move at the same speed from left to right in order to make it harder for the player to shoot.

In the figure 3.17 below is a flowchart that presents the main scripts and how they work within the application. During the beginning there are two main functionalities that are the authentication and the choice of the game, from here, the scripts developed

are used during the course of the game. As soon as the game time ends the end of the game is represented by the leaderboard page.

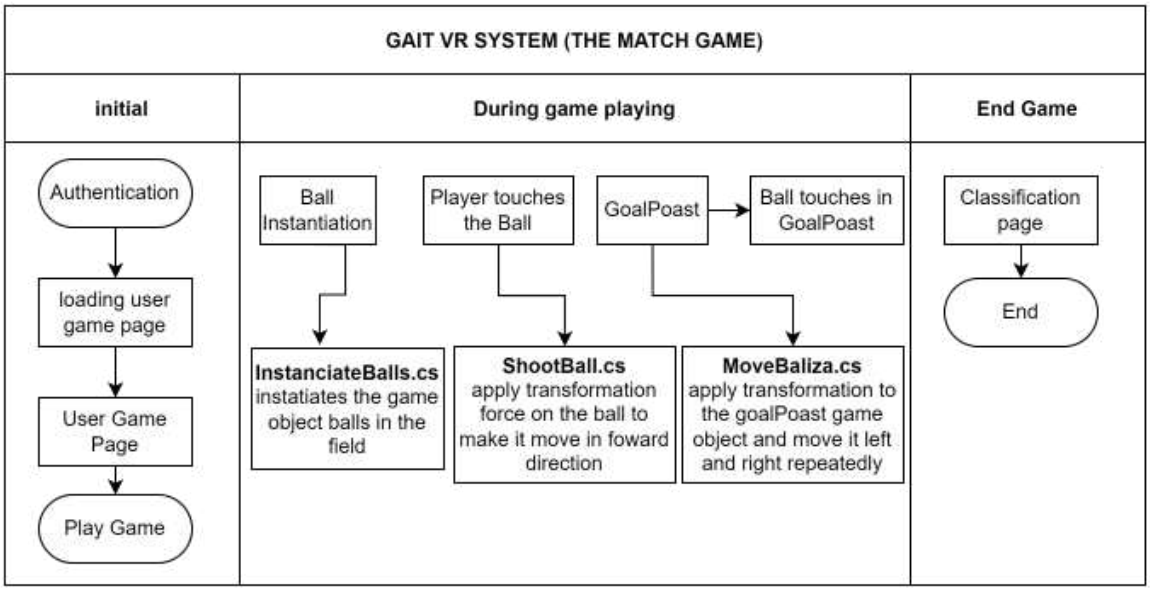


FIGURE 3.17. The Match game flowchart

(2) **The Color Sequence Game:** The main objective of this game is to follow the color sequence presented on the screen. The patient must then step on all the colored sequences in the correct order to gain and collect points before the playing time is over.

During the rehabilitation, by playing this game, the patient will be able to exercise the main necessary point, which are his gait, training his flexibility and the level of openness of his legs (calculated by the distance between his foot), as well as the speed with which he can execute the different sequences of colors. Besides this training allowing a gait rehabilitation accompanied by the above mentioned aspects, it also allows a cognitive rehabilitation that will allow the patient to perform while looking at the sequence of colors that appear on the screen and thinking about how to execute it.

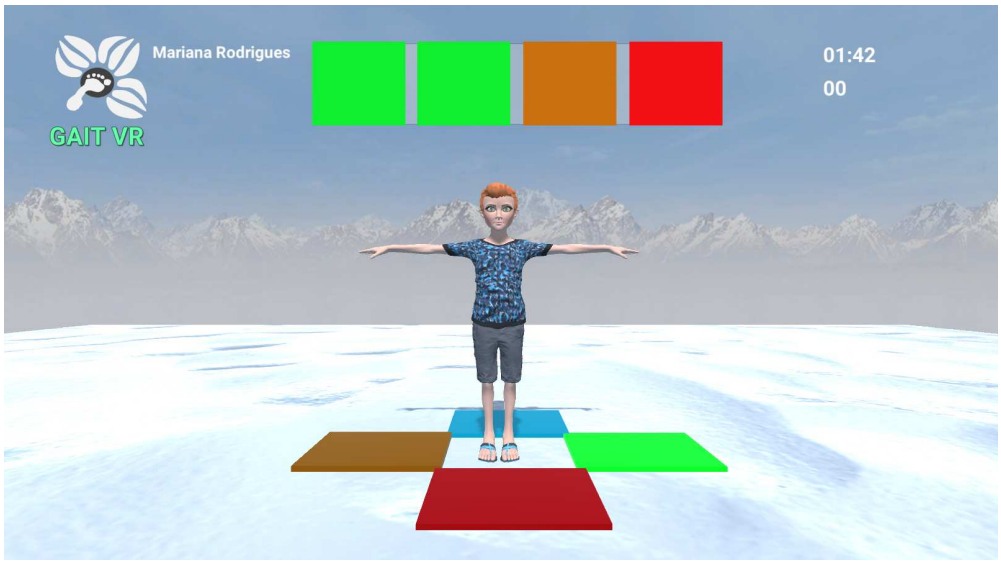


FIGURE 3.18. The Color Sequence Game

Data	Purpose
Total Score	It can draw conclusions about the player's speed, the higher the score, the greater their flexibility and movement.
Number of Sequences	It shows how many total sequences the player can complete by stepping on all the colours in the correct order. This information can be very important not only for player speed purposes, but can also be indicative for cognitive and memory studies.
Time	Values that represent the playing time and is important because it can provide information about the player's behaviour during the game.
Spine Angle	Measures the player's balance in 3D space, in this case in a x-z coordinators world

Table 3.2.3: Data extracted from the Color Sequence Game and its Purpose

Adaptability of this game according to the patient's limitations: Patients express their disabilities in different ways, and it is therefore important that the games have some flexibility in order to be adaptable to all types of patients and adapt to their physical and psychological limitations. For those reasons, this game allows health professionals to adjust one main elements value: This value is the playing time that the player will be proposed to. When a patient has some kind of condition or problem

(conditions that affect the lower limbs and consequently the mobility), the mobility limitation is often affected and for that reason it may be necessary to ex- tend the game time so that the player has time to evolve and also so that the health professional can extract valuable data for his conclusions.

In the figure 3.19 below is a flowchart that presents the main scripts and how they work within the application. During the beginning there are two main functionalities that are the authentication and the choice of the game, from here, the scripts developed are used during the course of the game. As soon as the game time ends the end of the game is represented by the leaderboard page.

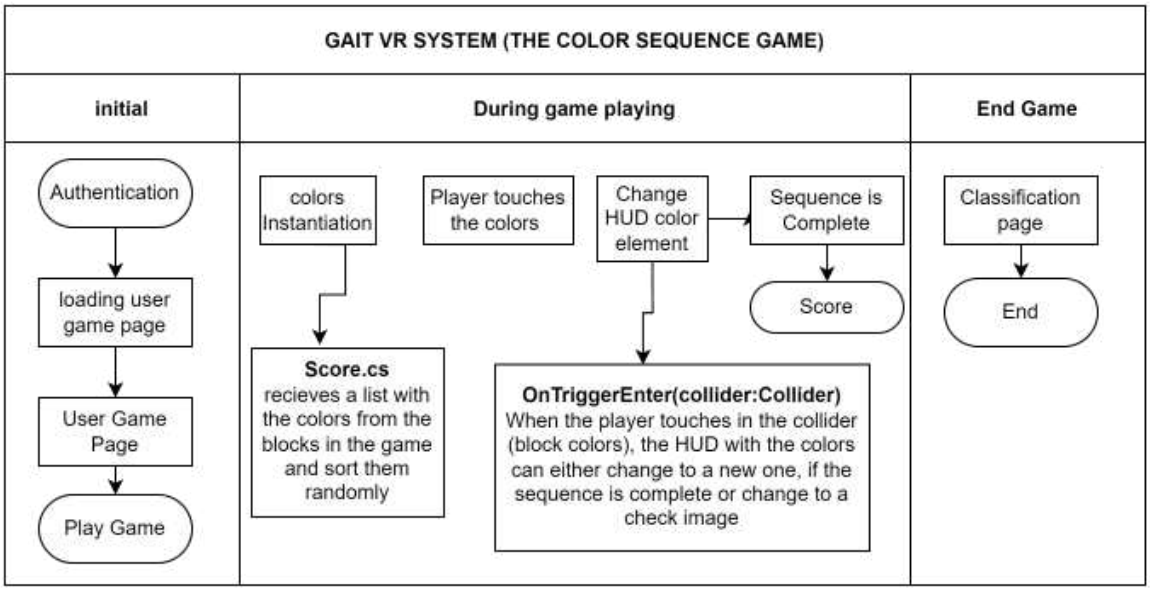


FIGURE 3.19. The Color Sequence organized Flowchart

(3) **The Pipes Game:** The main objective of this game is for the patient not to let the pipes touch his body. He has to stay in the same place and reflect his knees every time the moving pipes are passing by him. During the game, the pipes appear at different height levels so the user will need to reflect his knees to a greater degree every time that happens. The scenario of this game was created without any notion of 3D depth and is not a complex game to play in order to be adaptable for people with cerebral palsy that presents mobility and cognitive problems.

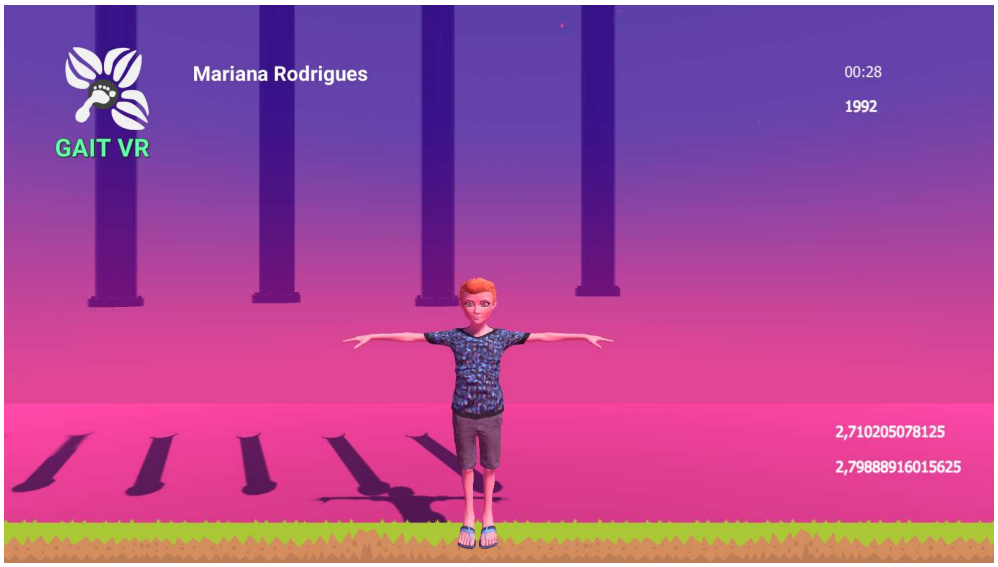


FIGURE 3.20. The Pipes game

Data	Purpose
Total Score	It can draw conclusions about the player's speed, the higher the score, the greater their flexibility and movement.
Time	Values that represent the playing time and is important because it can provide information about the player's behaviour during the game.
Left Knee Angle	Angle measurement range, that can draw conclusions about knee flexibility
Right Knee Angle	Angle measurement range, that can draw conclusions about knee flexibility

Table 3.2.4: Data extracted from the Pipes Game and its Purpose

Adaptability of this game according to the patient's limitations: Patients express their disabilities in different ways and it is therefore important that the games have some flexibility in order to be adaptable to all types of patients and adapt to their physical and psychological limitations.For those reasons, this game allows health professionals to adjust three main elements values: The first value that can be modified is the value of how fast the pipes move horizontally. The faster the speed of the pipes, the greater the number of pipes in play and the player will need to be very flexible in their knees to accumulate as many pipes as possible. A patient who has limitations in his gait may also have limitations in the flexibility and in the movements at the level of the knees, so it' s essential that the value of the speed of the pipes be a value possible to

be changed in order to increase the efficiency of the game for this type of players.The pipes appear in the game at different heights in order to force the player to bend his knees at different angles. However, players may have some kind of more serious limitations than others which might make some heights inaccessible for them. Therefore, the second value that can be changed by the health professionals is the range of values of heights up to which the pipes can go, in this case at the level of the Y coordinate values.Finally, the third and last value which can be edited by the physiotherapists in order to make the game more efficient and with more quality for the patients is the value of the playing time.

Some scrips developed for this game:

- **ScorePipe.cs:** Script developed with the main purpose of managing the player's score during the course of this game. This script also consists of a method called **OnTriggerEnter(Collider collider)** which is used to take points from the player whenever his head touches one of the pipes, that in this case is the collider.
- **InstantiatePipes.cs:** Simple script that instantiates the pipes prefabs in the game scene every two to three seconds.

In the figure 3.21 below is a flowchart that presents the main scripts and how they work within the application. During the beginning there are two main functionalities that are the authentication and the choice of the game, from here, the scripts developed are used during the course of the game. As soon as the game time ends the end of the game is represented by the leader board page.

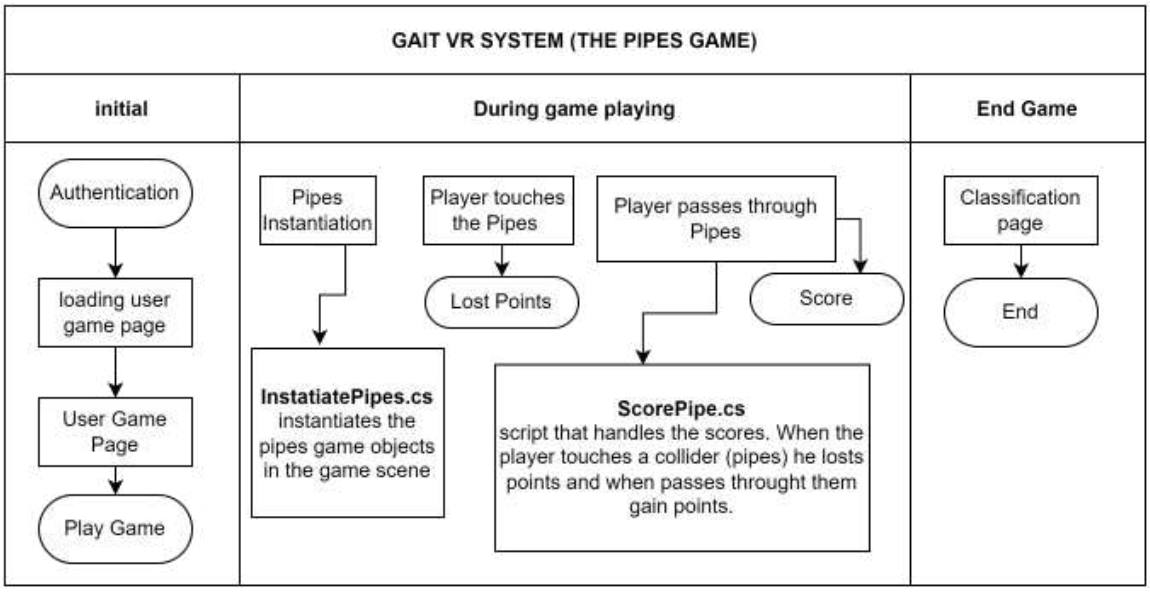


FIGURE 3.21. The Pipes Game organized Flowchart

(4) **Magic Ingredients:** The main objective of this final game is to catch as many falling ingredients as possible in a constant movement. The user will have to be careful and dodge the bombs that can fall at any moment. He must earn as many points as possible before the game time runs out. The scenario of this game was created without any notion of 3D depth and with simplicity in order to be adaptable for people with cerebral palsy that presents cognitive and motor problems.

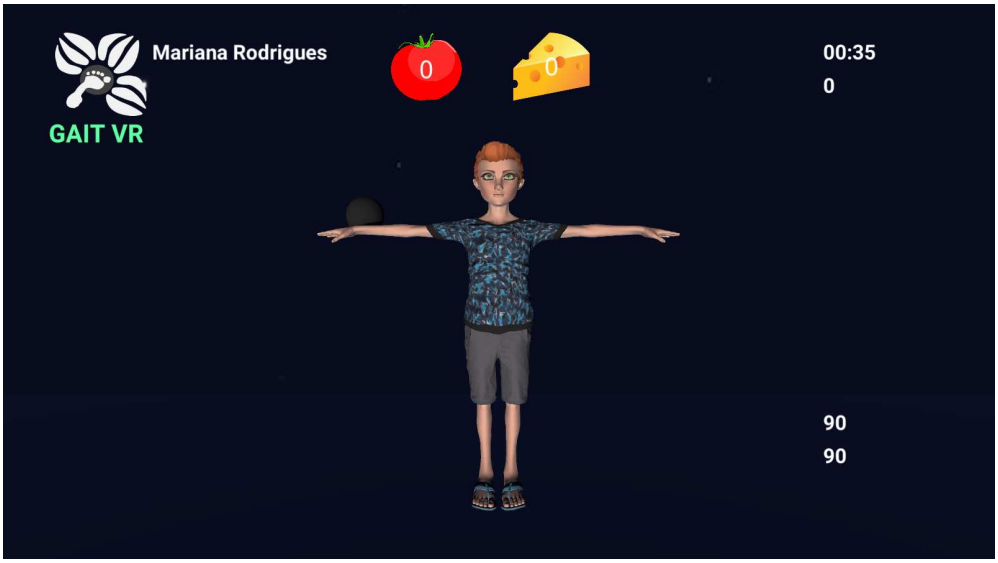


FIGURE 3.22. Magic Ingredients game

Data	**Purpose**
Total Score	It can draw conclusions about the player's speed, the higher the score, the greater their flexibility and movement.
Time	Values that represent the playing time and is important because it can provide information about the player's behaviour during the game.
Tomatos Score	It can give information about the player's speed.
Cheeses Score	It can give information about the player's speed.
Left Foot Position	Angle measurement range, that can draw conclusions about knee flexibility
Right Foot Position	Angle measurement range, that can draw conclusions about knee flexibility
Foots Distance	Can draw conclusions about knee flexibility

Table 3.2.5: Data extracted from the Pipes Game and its Purpose

Adaptability of this game according to the patient's limitations: Patients express their disabilities in different ways, and it is therefore important that the games have some flexibility in order to be adaptable to all types of patients and adapt to their physical and psychological limitations. For those reasons, this game allows health professionals to adjust three main elements values.

In the figure 3.23 below is a flowchart that presents the main scripts and how they work within the application. During the beginning there are two main functionalities that are the authentication and the choice of the game, from here, the scripts developed are used during the course of the game. As soon as the game time ends the end of the game is represented by the leader board page.

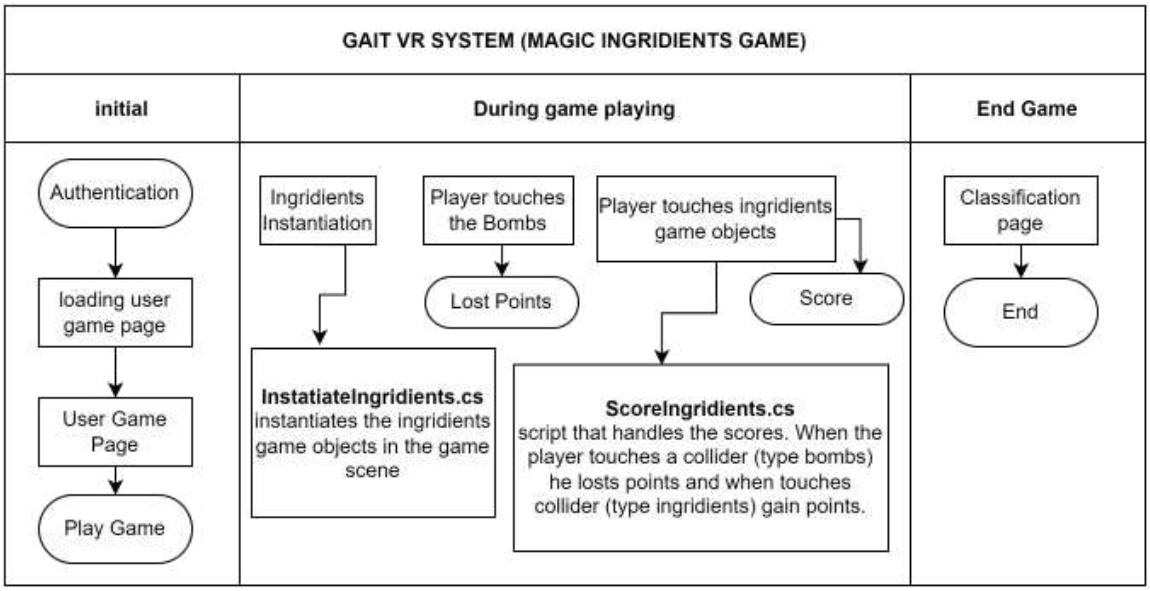


FIGURE 3.23. The Magic Ingredients Game organized Flowchart

At the end of each game session, a folder with a JSON file is generated, if it does not already exist, where the established data from each player's game session will be stored. If the file already exists, an update will be given over it with the data from the new game session.

This data is sent directly to the database for the respective data table of the game played. For the data to be saved, the game session must be finished, i.e., the player must be redirected to the final page of the score (that will be shown later in this document), otherwise, if the game is interrupted, a game session will be saved with its id but without the data.

3.2.8. Game HUD

As it is possible to observe from the previous figures that are used as a reference to show the games that have been developed for this system, they all have the same feature in common which is a HUD made up of several components, that is represented in the figure 3.24 below.

- On the left superior side the logo and the name of the application is always present
- Right by side of the logo and the name is going to be possible to see the patient Name, the name of the person who is playing the game in that moment.
- On the right superior side is displayed two elements, the first one the timer that will show the countdown time of the game play, when that timer reaches the 0 value that is an indicative that the game is over, and finally the points which will accumulate as the game time progresses.

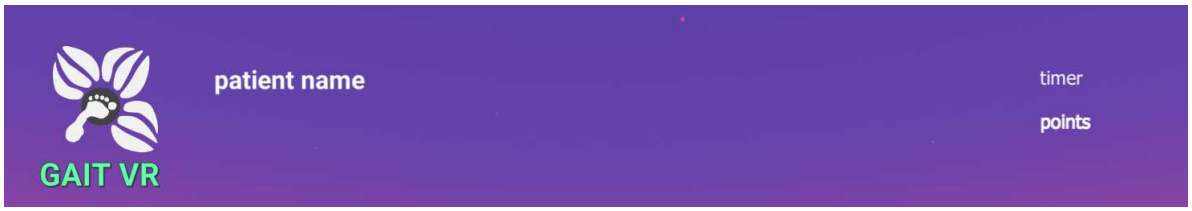


FIGURE 3.24. Game application common HUD

3.2.9. UI components and screens of Game application

Before a player can start playing the games he has to perform the authentication inside the game application. It is a simple authentication form where the user only needs to fill the fields with the right information. In this case, it's necessary to fill the fields with the email and the password.

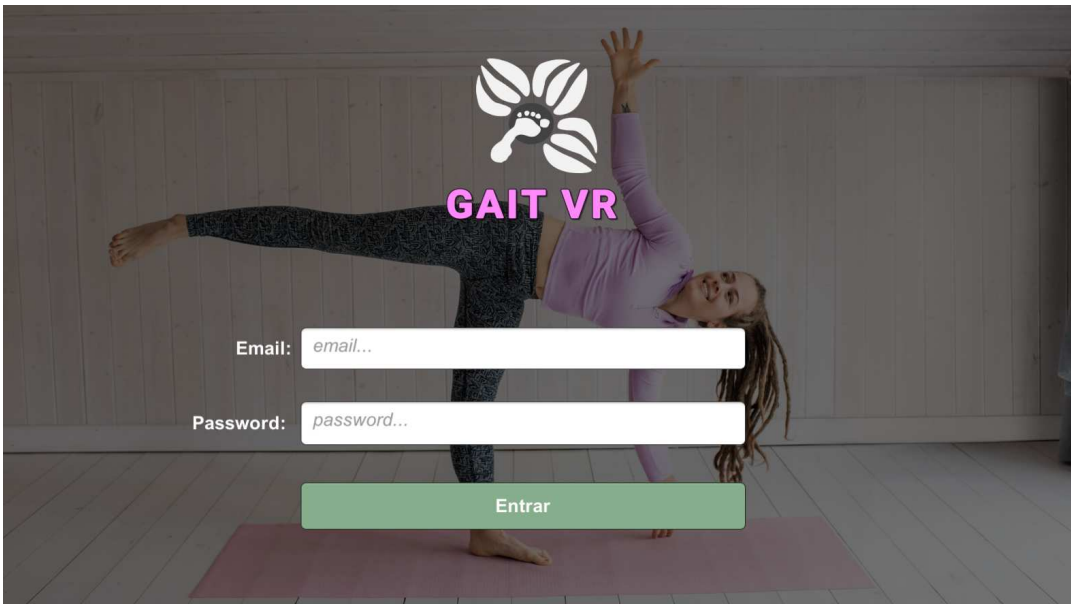


FIGURE 3.25. Authentication screen of Game application

Once all fields are filled in properly, the application launches a welcome page for the user while loading their active training sessions.

FIGURE 3.26. Welcome screen of Game application

After the welcome page and the active trainings of the patient in question have loaded successfully, the application launches the new screen which is the one that displays the main menu with the active trainings, represented by the figure 3.27. This screen is represented by important elements such as the name of the user who has recently logged in, located in the upper left corner, in order to then be coherent with the game HUD already explained earlier in this chapter, and the date of the day in the upper left corner.

In case there are no active trainings for the user in question, a message will be displayed on the screen saying that the user has no active trainings.

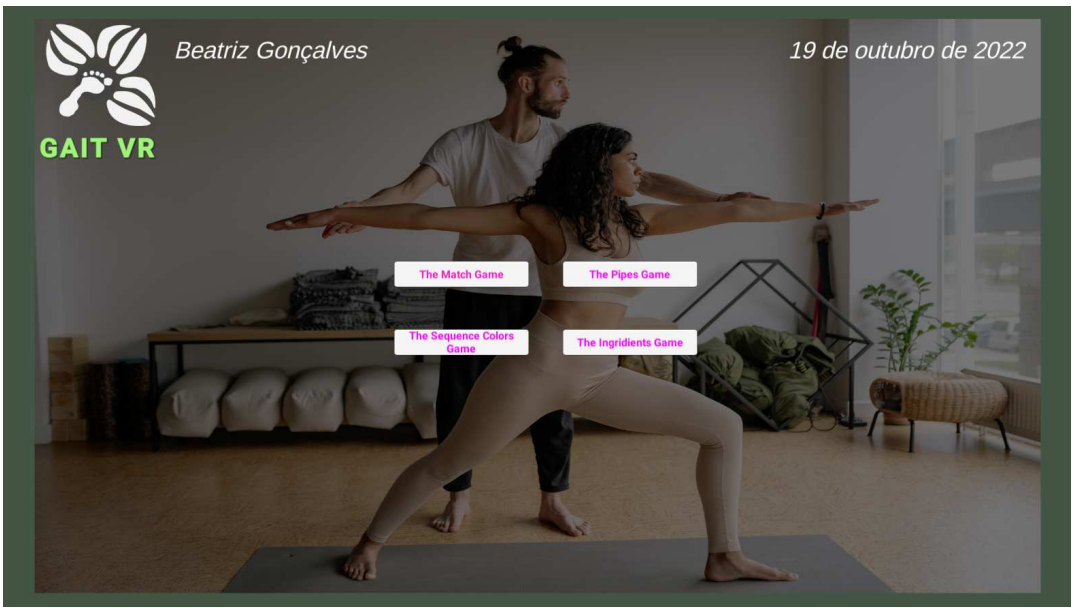


FIGURE 3.27. Main screen of Game application

Each time a game session ends, the user is automatically redirected to an information page represented by the following figure 3.28

FIGURE 3.28. Main screen of Game application

3.2.10. Web API Architecture

Besides the serious games section and the Azure Kinect Camera, connected to Unity 3D platform that allows the patients to perform and complete their gait rehabilitation, a web application was also developed, and his development can be divided into two main parts.

(1) **Back End API:** Build with the Active Server Pages (ASP) .Net Core programming language, directly connected to a local and/or remote my Structured Query Language (SQL) database. It also provides access to a very useful and important tool named Swagger that link directly to an https web page where is possible to test all the existing API methods created for the web application.

(2) **Front End API:** Build with Angular JavaScript (JS) open-source framework for developing dynamic web applications. This framework does a connection with the back-end API and works as a platform for the health professionals to access to visualize all the necessary information and results according to the trains performed in each session. This application is prepared to be used by two types of user's roles: Physiotherapists who can create patients, associate them to his patients, see their results in a graphic type of form, and access to all their private information; and Administrators, the users who can have access to all of the other roles users and can create physiotherapists to start using the application. Patients won't have access to this web application for now.

3.2.11. Web Application

The junction Web API between the front-end development and the back-end development. This Web application has a responsive design, which means that is ready to be used in the three types of devices: computers, tablets, and phones. It allows to health professionals to create patients type users, associate them with them and create the right trains for them. Each train can have one or more serious games. The patients will receive that information on Unity 3D, where they will perform and complete every training exercise.

3.3. Database

During the patient's rehabilitation sessions, after the end of every game, data is collected so that it can be consulted by the physiotherapist on the web application. In order to obtain a detailed assessment of the patient's data, a MySQL database was implemented in this project, developed first in a local database,and later and final one in a remote one using MySql workbench program.[56]

3.3.1. Selection reasons

The correct selection of a Database in order to develop a software program that needs to store a large amount of data and information is a very important task and one that requires some research.

In my point of view, usually the process of researching for a particular database to be used in a project, regardless of its size, is a job that must be done prior to the development of that specific project for a simple reason, and that reason is the various aspects to be considered, the research questions that the project proposes, such as compatibility with the programmes used in the development, and the purposes of the system to be developed.

In order to make an intelligent and informed decision, the first thing to do was to know the existing and most important types of databases and select what are going to be the main priorities for the development of the GAIT VR System. The most important ones to consider are two types of databases, relational, and non-relational.

- **Relational Databases:** The relational database started out as being the most widely used in various types of applications. This type of database relates data to each other using programming languages such as SQL, allowing connections to be simpler, and demonstrable in tables. Each table used in this type of database can contain several columns of various types and has an identifiable key which is usually known as primary key. Relational databases have a number of advantages regarding their design and data organisation. Most of the information is stored in the database itself and not in the application, it is easy and fast to perform necessary sql functions like insert, update, delete, and one of the most positive features is that since it presents a tabular structure it is easier to change anything that needs to be changed.

- **Non-relational Databases:** Non-relational databases, as the name implies, do the opposite of relational databases in that they do not use relations, such as tables, to storage the data, but instead they use a more recent model using NoSQL.

Relational Databases	**Non- Relational Databases**
Uses SQL as Query language	Uses NoSQL
Storage data in tables	Can store data for example in JSON format and in graphs
the data presented in tables have connections between themselves (direct connections, foreign keys...)	Data can be structured, unstructured or even semi-structured
Primary Key	Key Value Stores
Data is organized in a easy way for a search work	Data in not organized in a structured group
Provide a better consistency	Compromise on Consistency
The inserted data has to fit in a tabular schema	The data can be inserted at anytime without having to define a schema
Do not support high scalability	Support high scalability
MySQL, SQL Server, Oracle Database	MangoDB, Firebase

Table 3.3.1: Differences between Relational Databases and Non Relational Databases inspired by information in [17]

Being this system intended for medical usage, it is necessary that it can store a wide variety of data about the patients training, and about their average and personal information but it also needs to be a flexible application that is easy to use and has a good consistency of data. Furthermore the application will be an application for the time being, not with many features, performing only basic functions in order to be user friendly for the physiotherapist to use, in order to be as efficient as possible.

Taking all these aspects into consideration, and putting into perspective the previous experience that I already had with relational databases, the choice of the database to be used for this system was then the MySQL relational database, using more specifically **the MySQL Workbench** software tool.

This program has several benefits, and a variety of tools that allows to both code and program, as well as make a connection to the ASP .Net Core (programme language to develop back end API of the web application of the system) and obtain and create table and data through it in a easy and efficient way.

In this programme it is possible to create several links each to several databases, as it is possible to see in the figure 3.29. The connections can be either local or global, and these become accessible to everyone with the correct credentials.

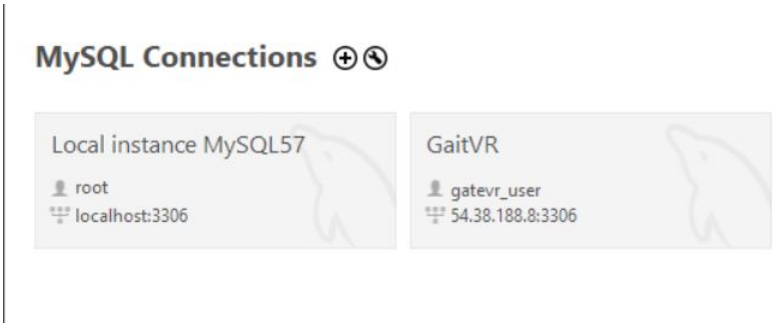


FIGURE 3.29. MySQL connections in software tool MySQL Worbench

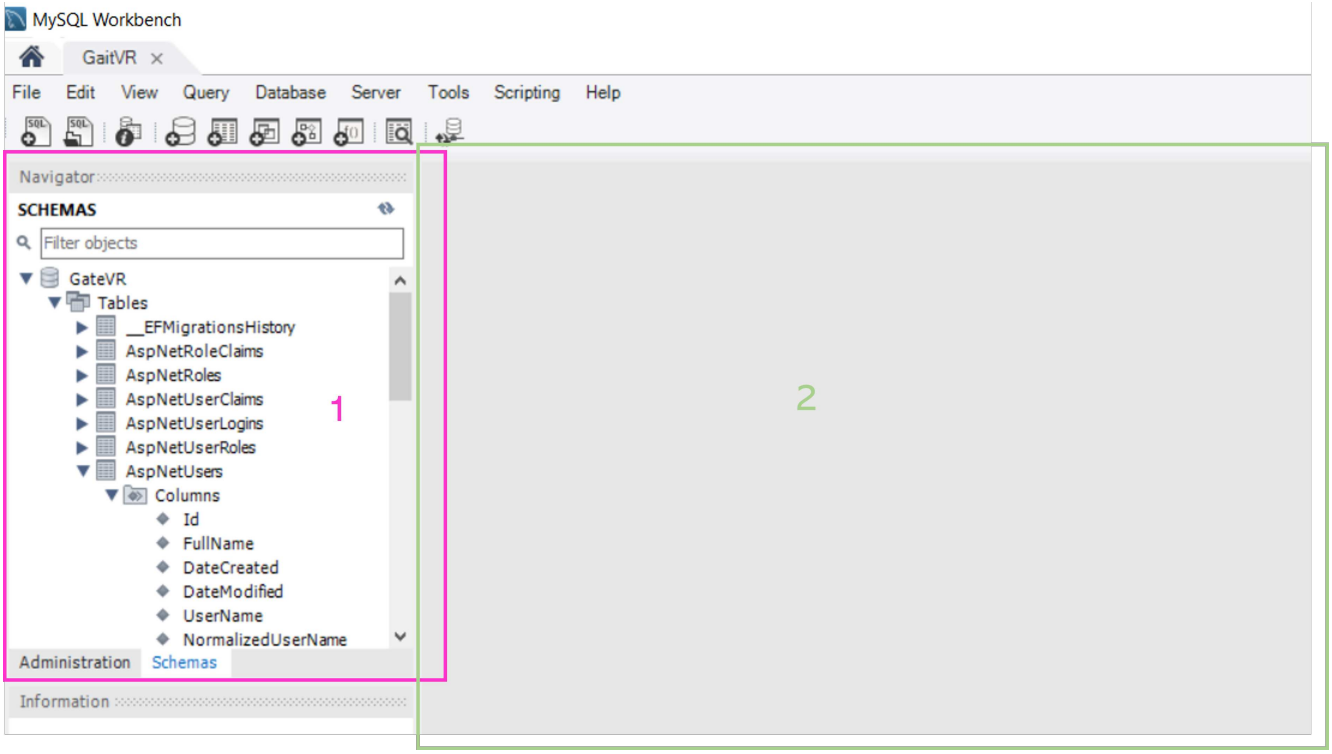


FIGURE 3.30. Workbench Tool Desktop

(1) This is the space that displays all the available databases and also presenting their schema. For this project only one database was created, the one displayed on the picture above. In this space it is possible to create new databases, add new columns, edit entities and values and it is also possible to request the visualization of the first 1000 occurrences in each table of each database.

(2) This is the space available for the user to perform several functions such as viewing the occurrences in each database table; the execution of queries in MySQL code, being possible to perform all kinds of functions such as insert, delete, update and select

The figure 3.31 below shows the final diagram of the database developed.

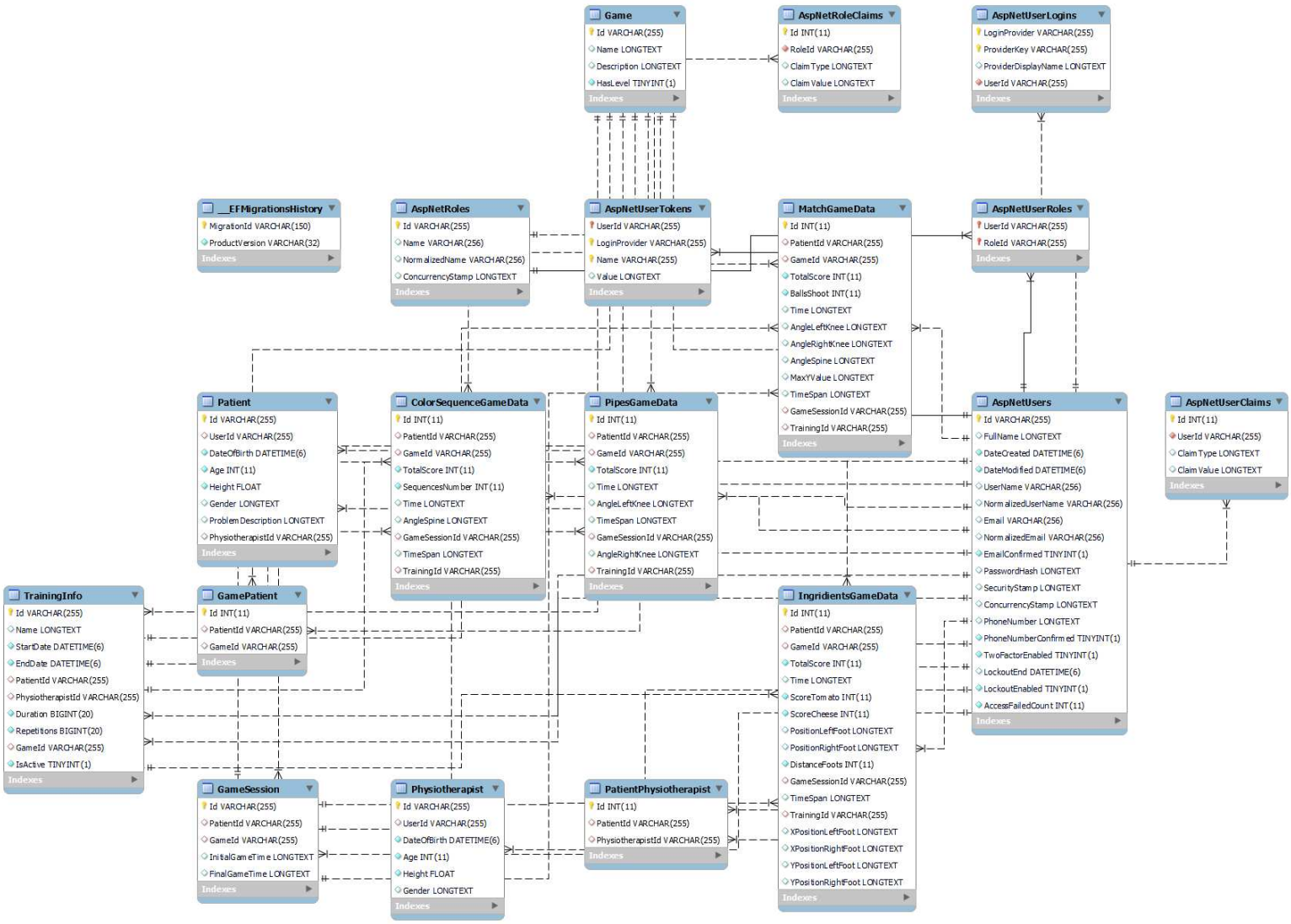


FIGURE 3.31. Database model diagram

This database is composed by 18 tables. 5 of those tables have the ”AspNet” prefix in their names, which means that they were automatically generated through an existing framework available for applications created using ASP .Net Core Language, called Identity. Identity is a

service API consisting of a framework which allows these tables to be automatically created in a flexible manner, in any database we desire to work on.

3.3.2. Database Model

A database model is extremely important for a good organization of the data. A good organization of data results in strong and well structured applications and projects, especially when we talk about big projects like the proposed one in this dissertation.

Gait VR system database was developed with an higher version of the **Entity-Relationship model**, also known as an EER model, that is available in the MySQL Workbench platform, the program used to build and manage this database.

EER models are most known for their incredible features that can divide the data into individual tables. Each table is an entity that is the representative objects of the data in question. All of the tables are linked by an association.

Below are represented all the table names that compose the database along with their descriptions.

- **AspNetUsers:** This table is the main table of the application managing all the users in the application. It is essentially composed by the mosted used fields like FullName, UserName and Email of the users. The primary key is the Id field, always with unique values.

- **AspNetRoles:** This table mainly stores the names of the existing roles in the application that can then be assigned to the users. It's constituted by its main field named Name. The primary key is the Id, which is always an auto-generated and unique value.

- **AspNetUserRoles:** This table relates the values of two tables, the AspNetUsers table and the AspNetRoles table and stores the data of the ids of each side. Is composed by the two main fiels of UserId and RoleId. The primary key is the Id field, always with unique values.

- **AspNetUserClaims:** Table with a foreign key from the AspUsers table where it gets the ids associated to the users. It is composed by the fields UserId, ClaimType, ClaimValue. The primary key is the Id, which is an auto-generated and unique value.

- **AspNetRoleClaims:** Table with a foreign key from the AspRoles table where it gets the ids associated to the existing roles. It is composed by the fields UserId, ClaimType, ClaimValue. The primary key is the Id, which is an auto-generated and unique value.

- **AspNetUserLogins:** Table with a foreign key from the AspUsers table where it gets the ids associated to the users and saves the sessions from when users log into the application.

- **Patient:** Stores the data from the patients type users.It is in this table that columns are stored regarding the patients' personal information that can be made available in the application for health professionals to access. The table contains the foreign keys (UserId, PhysiotherapistId) that matches the AspNetUsers table where all the users are stored.Fields such as DateOfBith, Age, Height, Gender and Problem Description are present in this table.The primary key is the Id, which is an auto-generated and unique value.

- **Physiotherapist:** Stores the data from the Physiotherapists type users.It's on this table that the personal information of each health professional will be stored. The table contains the foreig key (UserId) that matches the AspNetUsers table where all the users are stored. Fields such as DateOfBirth, Age, Height and Gender are present in this table. The primary key is the Id, which is an auto-generated and unique value.

- **PatientPhysiotherapist:** Table that relates users of type patient with users of type physiotherapist. This table is composed by 2 foreign keys (PatientId and PhysiotherapistId) that matches Patient and Physiotherapist tables.The primary key is the Id, which is an auto-generated and unique value.

- **Game:** Table that stores the data from the serious games available in the application. Fields such as Name, Description and HasLevel are present in this table.The primary key is the Id, which is an auto-generated and unique value.

- **GamePatient:** Table that relates the games ids with the patients type users ids. This table contains 2 foreign keys (PatientId and GameId) that macthes two tables, AspNetUsers and Game respectively. The primary key is the Id, which is an auto-generated and unique value.

- **TrainingInfo:** Table that stores the data from the patients trainings. This table is composed by three foreign Keys (PatientId and PhysiotherapistId) that matches AspNetUsers table, in order to give information, to which patient that training belongs and which physiotherapist prescribed it, respectively, and the last foreign key (GameId) that matches the Game table and serves to give information about the serious game that is part of/included in that training. Fields such as Name, StartDate, EndDate,Duration, Repetitions and IsActive are present in this table. The primary key is the Id, which is an auto-generated and unique value.

- **GameSession:** Table that stores information about game sessions played from the application. Each time a game is played, this table will store data about that session, data like, a primary key (Id) that will be automatically generated and will always have a unique value, two foreign keys, the first one (PatientId) that matches the AspNetUsers table in order to have information about which user is playing in the application, and the second one (GameId) that matches the Game table in order to have information

about which game is being played. Fields such as InitialGameTime and FinalGameTime are present in this table.

- **ColorSequenceGameData:** Table that stores the data extracted from the Color Sequence Game. This table is composed by four foreign keys, such as PatientId that matches the AspNetUsers table, in order to know to which patient the extracted data belongs;GameId that matches the Game Table, GameSessionId, that matches the GameSession table, and finally TrainingId that matches the TrainingInfo table. Fields such as TotalScore, SequencesNumber, Time, AngleSpine and TimeSpan are presented in this table. The primary key is the Id, which is an auto-generated and unique value.

- **PipesGameData:** Table that stores the data extracted from the Pipes Game. This table is composed by four foreign keys, such as PatientId that matches the AspNetUsers table, in order to know to which patient the extracted data belongs;GameId that matches the Game Table, GameSessionId, that matches the GameSession table, and finally TrainingId that matches the TrainingInfo table. Fields such as TotalScore, Time, AngleLeftKnee, AngleRightKnee and TimeSpan are presented in this table. The primary key is the Id, which is an auto-generated and unique value.

- **MatchGameData:** Table that stores the data extracted from the Match Game. This table is composed by four foreign keys, such as PatientId that matches the AspNetUsers table, in order to know to which patient the extracted data belongs;GameId that matches the Game Table, GameSessionId, that matches the GameSession table, and finally TrainingId that matches the TrainingInfo table. Fields such as TotalScore,BallsShoot, Time, AngleLeftKnee, AngleRightKnee, AngleSpine, MaxYValue and TimeSpan are presented in this table. The primary key is the Id, which is an auto-generated and unique value.

- **IngridientsGameData:** Table that stores the data extracted from the Ingridients Game. This table is composed by four foreign keys, such as PatientId that matches the AspNetUsers table, in order to know to which patient the extracted data belongs;GameId that matches the Game Table, GameSessionId, that matches the GameSession table, and finally TrainingId that matches the TrainingInfo table. Fields such as TotalScore, Time, ScoreTomato, ScoreCheese, PositionLeftFoot, PositionRightFoot, DistanceFoots, xPositionLeftFoot, yPositionLeftFoot, xPositionRightFoot ,yPositionRightFootAngleLeftKnee and TimeSpan are presented in this table. The primary key is the Id, which is an auto-generated and unique value.

CHAPTER 4

Web Application

4.1. Overview

This chapter's aim is to present in detail the web application developed to provide support to physiotherapists during a patient's rehabilitation process, which will ultimately serve as the main application of this system. The application developed was designed as a support and helping application for patients who require it during their Gait rehabilitation processes. As soon as the application started to be built, the idea was to make the same application with 3 different versions, the first one was for the administrator type user, the second version for the Patient type user and the third one for a Physiotherapist type user. However, due to the complexity of the system, it was decided that Patients would not have access to the main web Application, only to the games platform application. In the following sections it will be explained in greater detail the process of developing the web application, what were the biggest challenges, the motivations, the design behind everything and all the implementations parts.

4.2. Back End Software and Implementation

Today there are several applications that can support various types of languages, can achieve great results in terms of performance and integration and can meet a large set of requirements that makes them very advantageous over other applications, it was for these reasons that the choice of software indicated to use as a Back end software was such a difficult task to make. After a lot of research and consideration of several programming languages I already know, the decision was to use **ASP .NET Core** as a backend software for the web application.

ASP .NET CORE Advantageous Features
Fast and great performance with latest Version (.NET 5)
Is a **cross-platform** which means that it is adaptable to various types of operating systems such as windows, linux, allowing multiple communications between various platforms
It is highly recommended for web application development
Is an Open Source Framework
Considered by Cloud Native Group Foundation as one of the fastest open source frameworks to build applications [13], see figure 5.7
Framework possible for develop a complete product (Design, Assemble and deliver)
It supports the installation of multiple library versions on the same platform
In terms of security, it is highly recommended. For example, it provides Identity(which was used in this system) for authentications and token generation

Table 4.2.1: ASP .NET CORE Advantageous Features

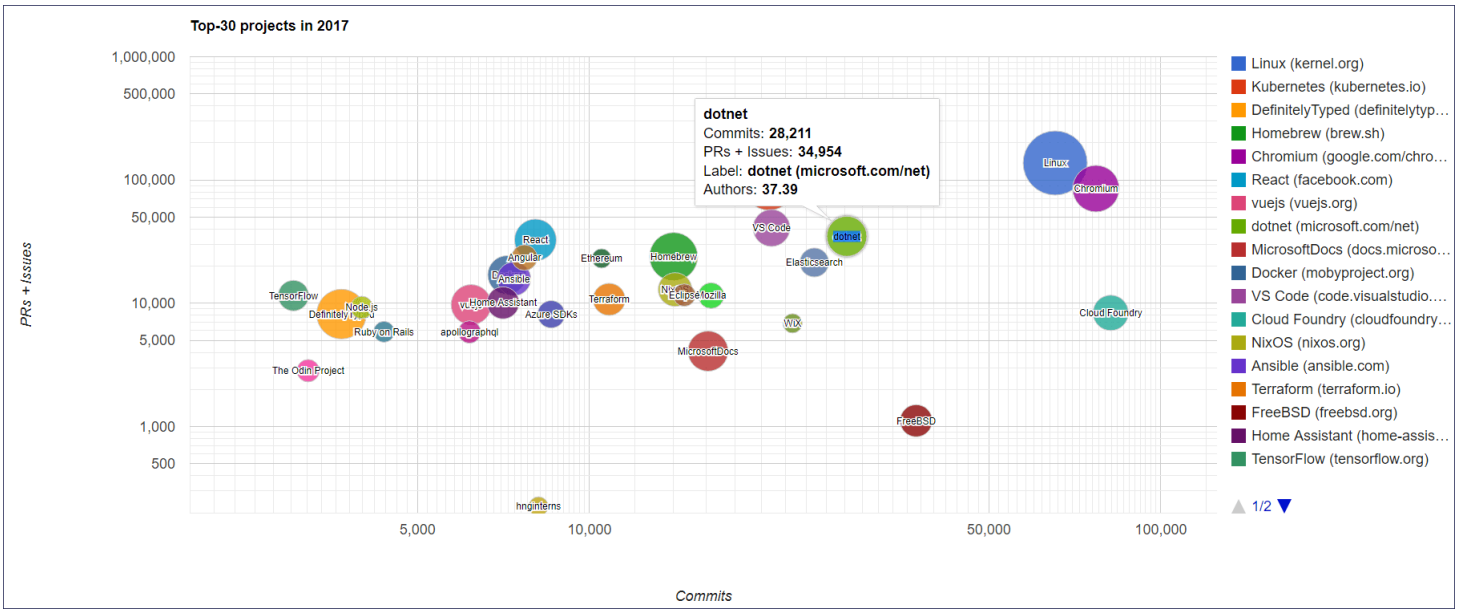


FIGURE 4.1. The 30 highest Velocity open source projects, available at [13], figure from [14]

This part of the project was developed in a platform called Visual Studio 2019, with the appropriate installations done within the application itself, as it's possible to see in the image 4.2 below. As it is possible to visualize, this program has a compartment where it is possible to install all the extensions that will be necessary for the development of the project. The list of all the elements that were installed for the development of Gait VR is placed on the right side of the figure.

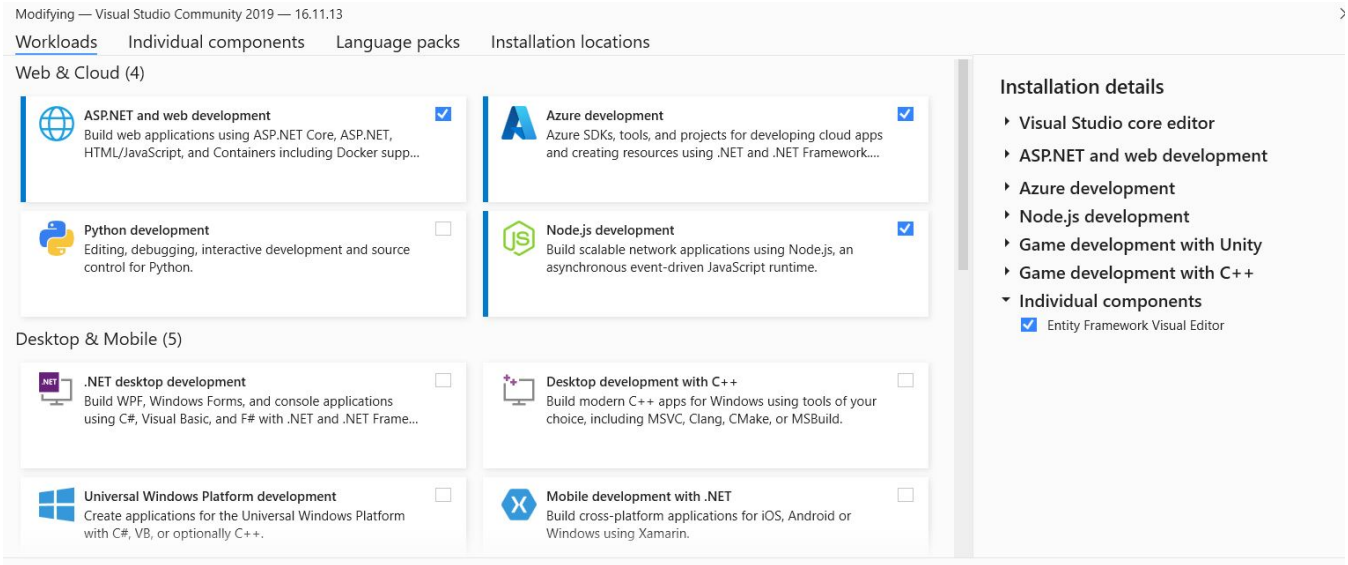


FIGURE 4.2. Visual Studio 2019 installations for this project

The first step in developing the back end software, was to make the connection to the database.This connection goes through two essential files in the project, these files are the appsettings.json and the startup.cs.

FIGURE 4.3. Connection String

- **startup.cs**: File where all the connections are defined. Fetches from the file appsettinggs.json the connection string required to establish the connection to the database that will be used in the project and then defines the type of database that will be applied, in this case MySql was used, as can be seen in the last line of the image (UseMySql statement).
- **appsettings.json**: File where the connecton strings are defined. There can be several formats of connection strings, but in general all have to contain, the name of the dabase, the IP and Port server and the authentication data (Username and Password).

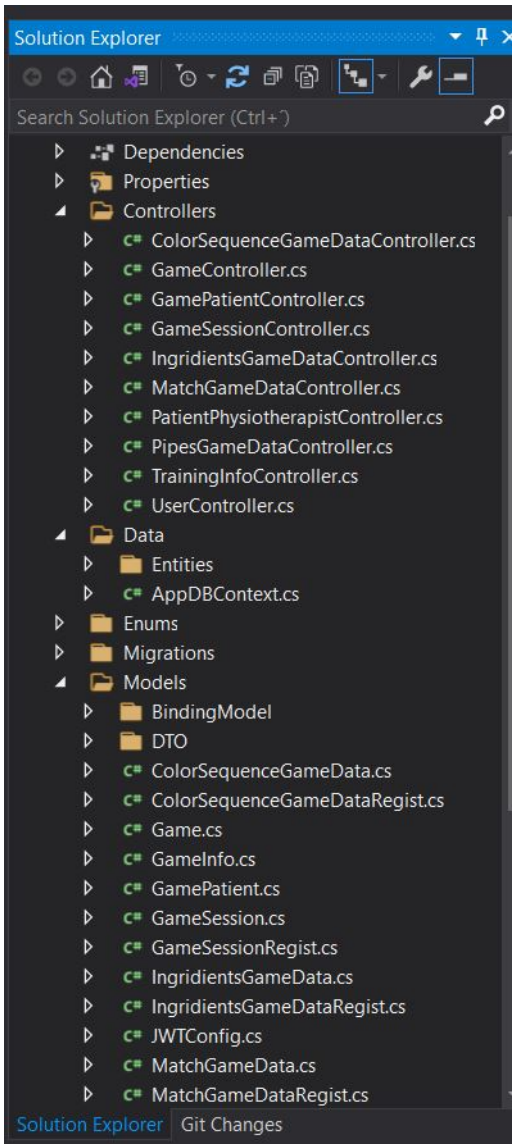


FIGURE 4.4. Visual Studio Solution Explorer

The image above shows the solution explorer in Visual Studio from the Back End part of the system. It was divided into 4 main folders, the Controllers folder, where all the controller are located, the Data folder that contains one main file called AppDBContext.cs, the Enums folder and the Models Folder.

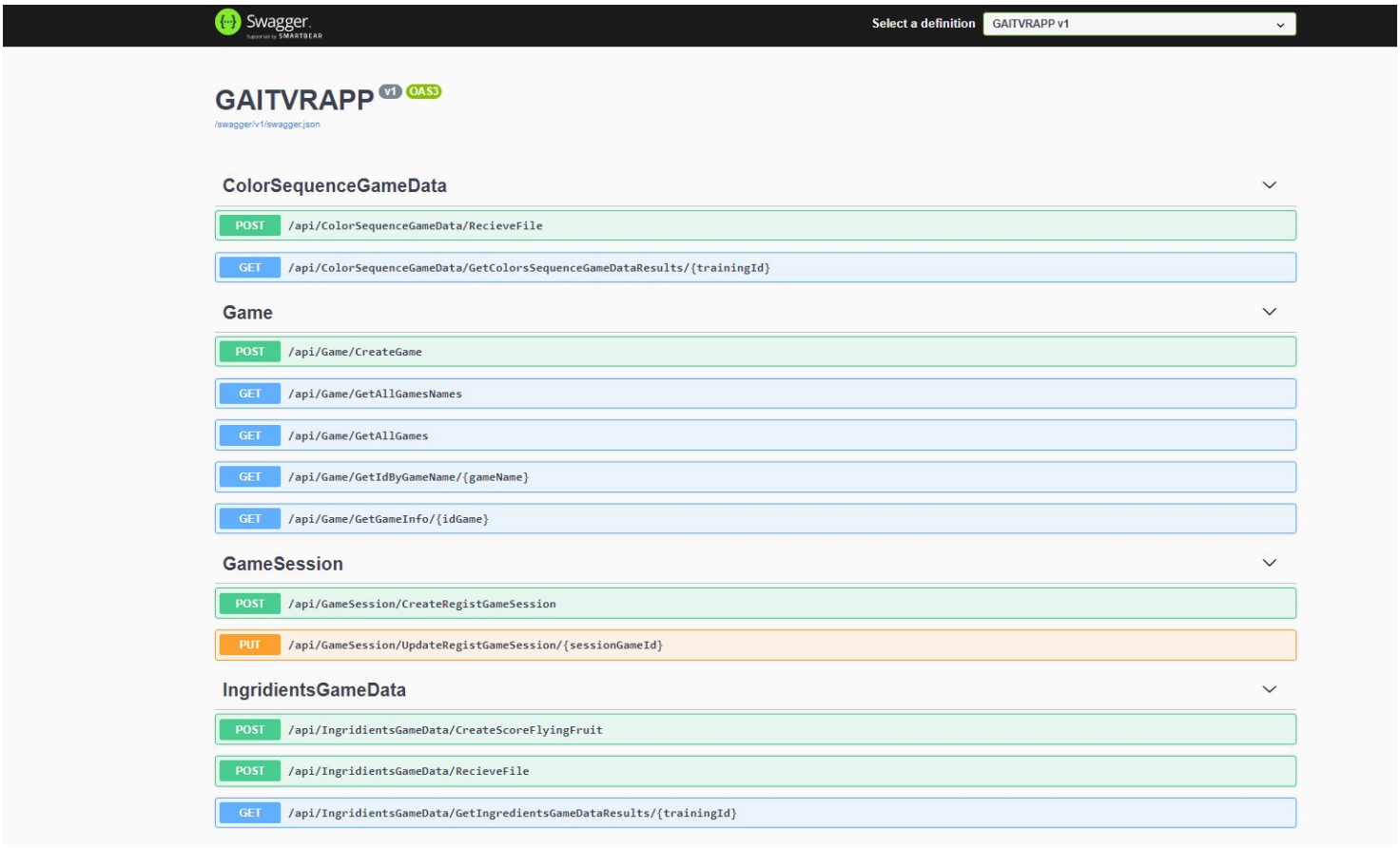


FIGURE 4.5. Swagger Application

Swagger is an open API application used as a documentation tool in this project. This application is launched automatically by visual studio when there is a request to run the project solution. The image 4.6 above, shows the page that is displayed. The page is divided in the number of sections equal to the controllers that exist in the project.In here it's possible to execute tests to every operation providing the various parameters necessary for the execution of the same.

4.3. Front End Software and Implementation

The selection of a framework for the development of the front end software for this Web application project was an almost immediate choice. From the beginning, it was considered that the two most important factors to consider for the web application were to be intuitive to use and to have a user-friendly design.

- **The hard task of building a user-friendly design**: The design is one of the most important aspects in a system because it represents how it can be seen by outside people, clients, the placeholders, it can represents the quality of the product. So, in order to develop an appropriate design various points were considered, such as:

  (1) Choosing an appropriate colour palette

  (2) Using a pattern in order to keep the web application organised and coherent

The front end software chosen for the development of the application was the Angular Js framework precisely because it is a javascript library framework that has so many advantages as shown in the table 4.3.1 below, and which is compatible with the backend software chosen for the development of this application.

Advantageous Features of choosing Angular Framework
Framework that can handle the complex requests that customers expect
It's a framework that is constantly updated in relation to modern designs and common standarts
Provides the developer with a variety of helpful tools
It is compatible with a giant variety of technologies and libraries such as ng-bootstrap and Angular Material (both used in this application)
Uses TypeScript Language, a language that has several advantages
Uses RxJS (Reactive Extensions for JavaScript) a reactive programming language
It is compatible with ASP .Net Core
It has a component-based architecture
Presents a Cross-Platform development
Presents a high speed and performance

Table 4.3.1: Angular Advantageous Features based on [18]

4.3.1. Bootstrap and Angular Material

There are several libraries and frameworks that have been developed and improved over the years in order to allow applications to meet all the conditions to be close to "perfect", bug-free, well-functioning, fast, flexible, and user-focused.

Among the best known and most used frameworks and libraries worldwide are CSS frameworks such as :

- Bootstrap
- Foundation
- Semantic UI
- Skeleton

In the image below are represented two know applications build with the two most used frameworks, bootstrap and Foundation. The Vogue [57] website was built using **bootstrap** and the **Foundation** framework was also used to built a very popular application, Facebook [58].

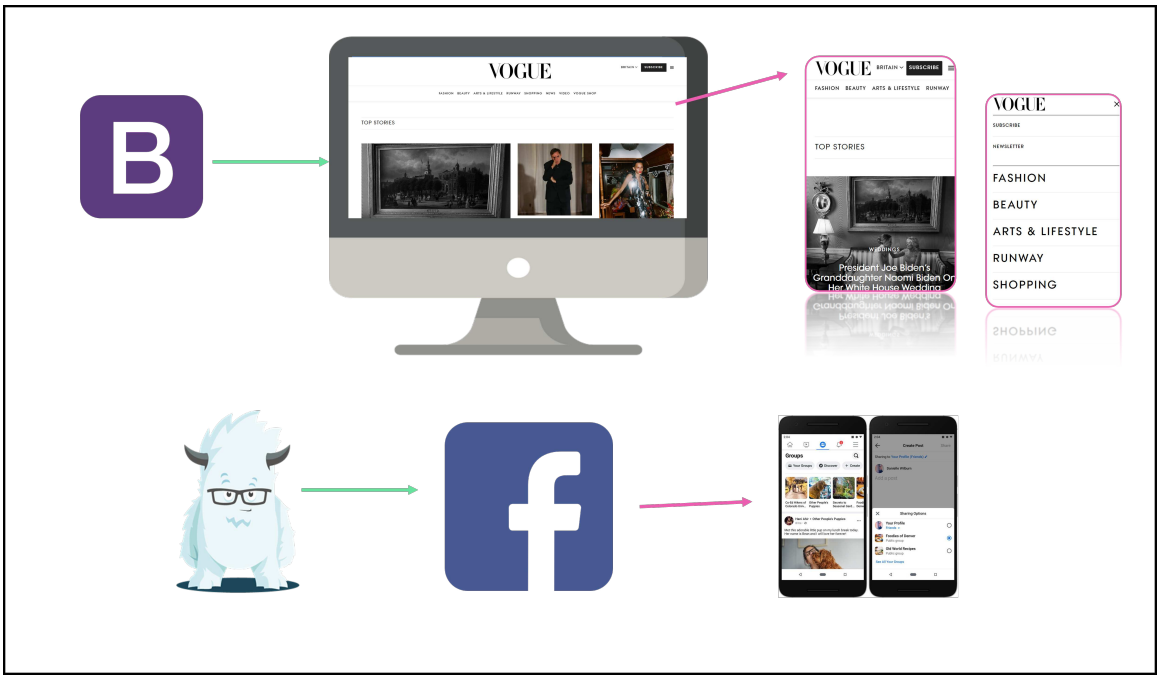


FIGURE 4.6. Bootstrap and Foundations applications

Besides foundation also being a very good framework, it ends up being more complex than bootstrap and since the focus of this project is not on the complexity and the design of the application, but in a simpler design focused on the main user that will be the physiotherapist user, among other many possible reasons, the choice I felt was the right one to use for the development of this project was Bootstrap.

Bootstrap [59] is an open source code library that can be easily used with angular framework in such an easy way and was one of the choices in the front end development for the application.

Besides being a great ally of the main angular framework it is also the most voted framework according to StackShare [60]. It represents a powerfull tool to the responsiveness of a web application, it presents consistency and provides to developers with a lot of UI tools and components to use, helping a lot with the creativity of the developer, completing all the requirements thought out for this project.

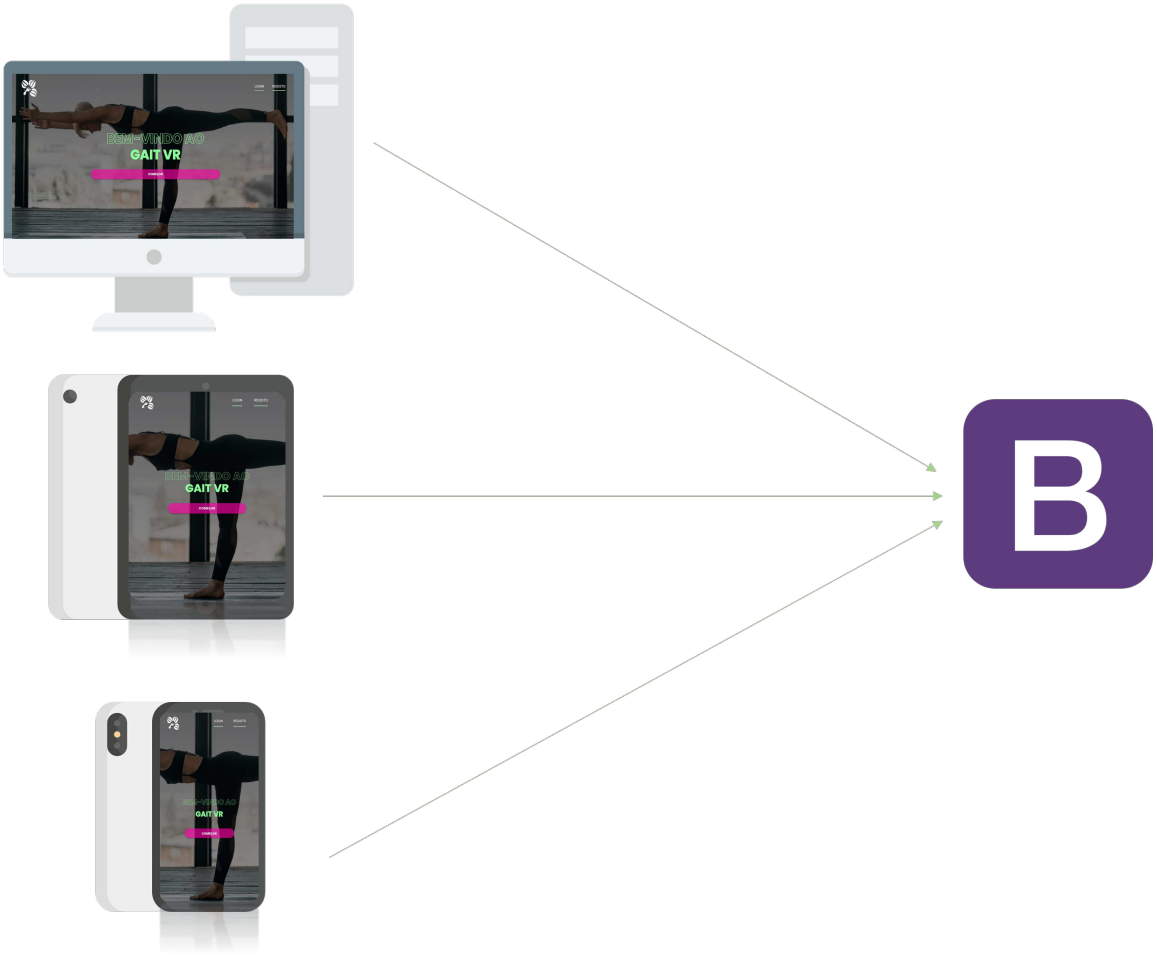


FIGURE 4.7. Responsive with Bootstrap

Angular Material [61] was the other choice made for the development of the front end part of the application. This is already an User Interface (UI) component of the framework and it helps applications to upgrade their quality with an amount of new widgets ready to be used. All the buttons and fields used in this application are part of angular material.

4.3.2. Structure

The web application can be used by two types of users.

(1) Physiotherapists

(2) Administrators

The main purpose for which it was designed was to establish a connection between the physiotherapist and the results of his patients during their rehabilitation processes.

In order to demonstrate the functionalities that a physiotherapist can perform in the web application in a generalized and uncomplicated way it was used a flowchart diagram shown by figure 4.8.

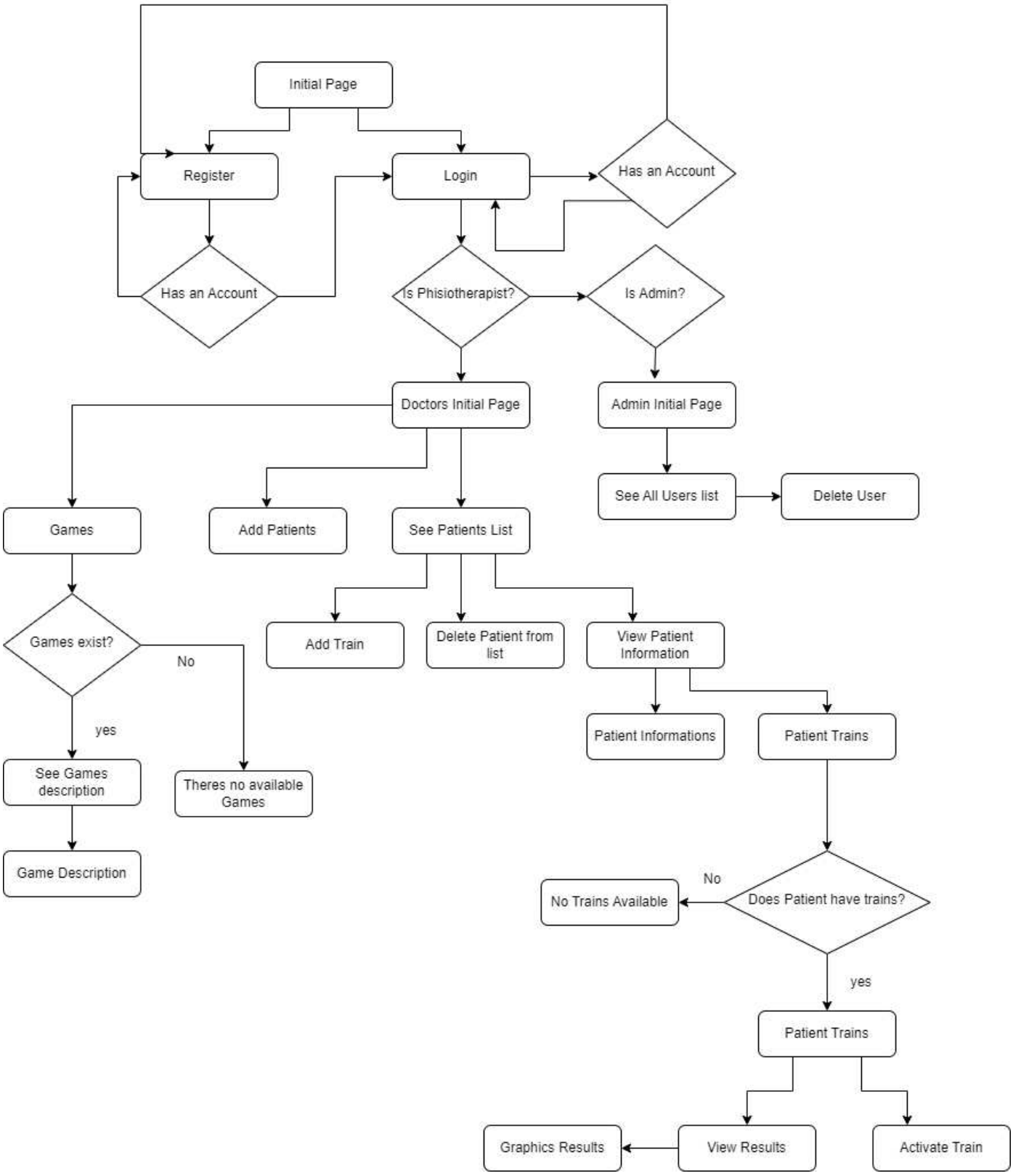


FIGURE 4.8. Flow Chart representing Web Application Functionalities

The application is launched with the main page represented by the following image. On the image it' s possible to identify three main elements:

(1) First, the header in the superior part of the screen constituted by the application logo (on the left side) and the two references to the login and registration page (both on the right side).

(2) Second, the name of the application, accompanied by a welcome message to the user.

(3) Lastly, a start button, which takes the user directly to the authentication page of the application, assuming he already has an account created.

FIGURE 4.9. Gait VR Application Initial Page

The following image represents the authentication page where the user can login to enter inside the application. To make a sucessful authentication, the user needs to fill in the corresponding fields data such as his email and the password chosen by him when he first registered himself.

For security reasons and for user visibility reasons, the button that allows you to successfully enter the application is only active when the fields are correctly filled in.

Regarding the efficiency and quality of the application's usability, the logo is present in the application, which serves as a button if the user wishes to return to the application's initial page.

On this page the user is also given the option to register on the application if he doesn't have an account yet, redirecting him immediately to the registration page.

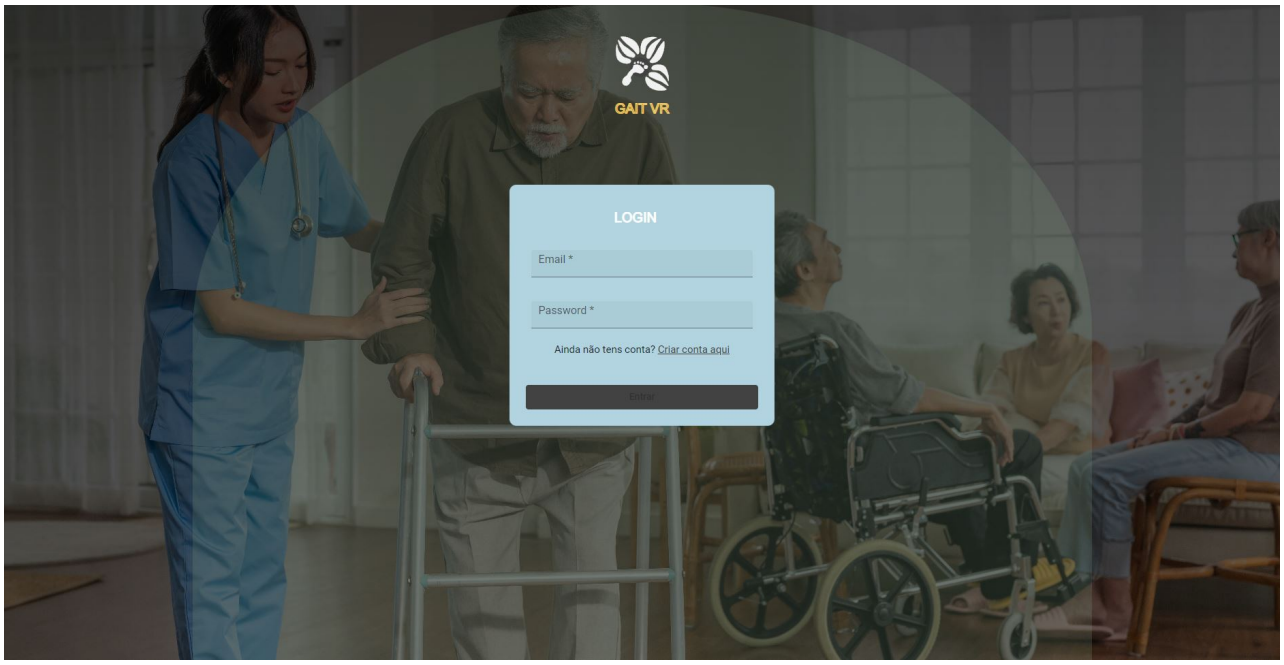


FIGURE 4.10. Gait VR Application Authentication Page

The following image represents the register page where the user can register himself by creating an account, to firstly enter inside the application.

In order to make the process simpler, the data required for a user to authenticate on the application is their full name, email and password.

Also, like in the authentication page, mentioned above, for security reasons and user visibility reasons, the button that allows the users to successfully create an account and then enter in the application, is only active when the fields are correctly filled in.

On this page users are also given the option to go to authentication page to make the login as they already have an account created in the application. As soon as the account is successfully created a message appears in the middle of the screen, advising the user that his account was successfully created, redirecting him to the login page where he can authenticate himself, using the data with which he registered, which will allow him to enter the application for the first time.

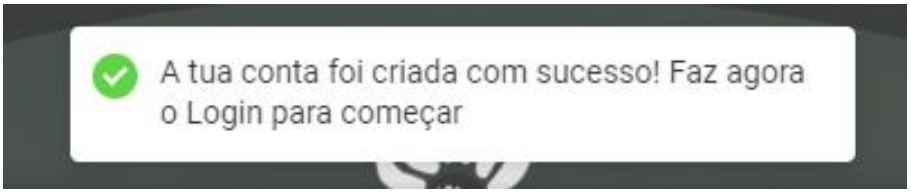


FIGURE 4.11. Success message when user register himself in the Application, made with [15]

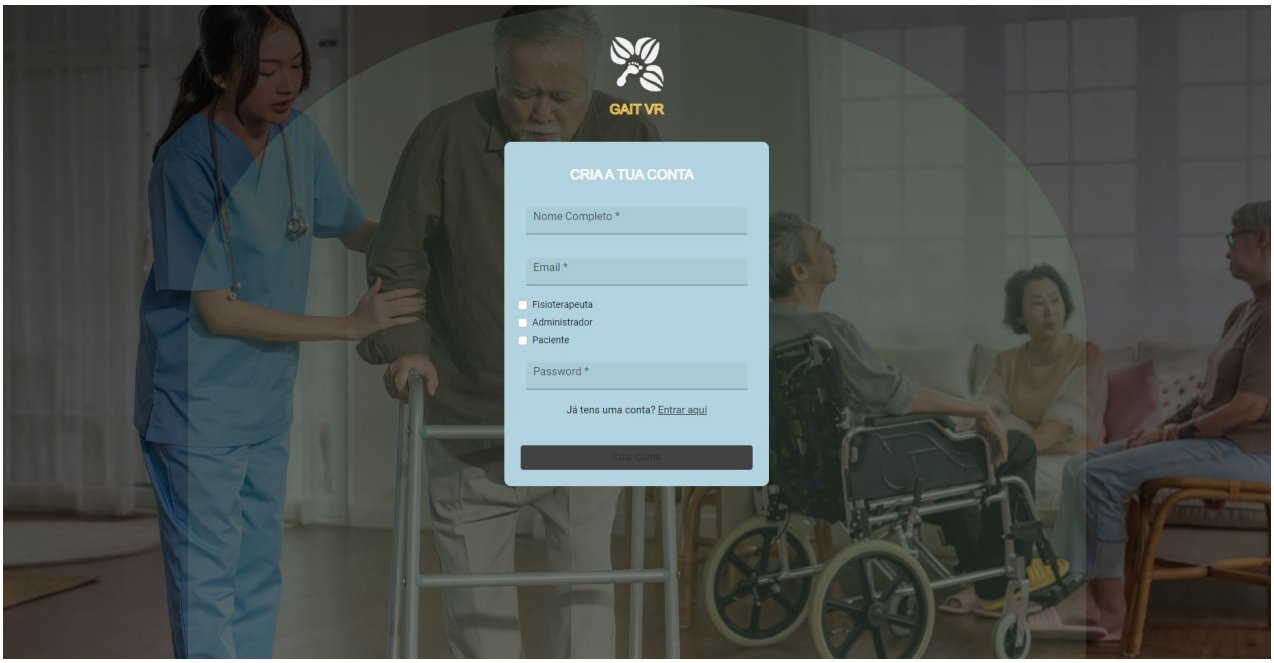


FIGURE 4.12. Gait VR Application Register Page

The next image 4.13 represents the home page of the physiotherapist users in the application. On this page it is possible for physiotherapists to add users of the patient type to their patient list, which is shown just below in a table representation.

In that table, it is possible to view patients' information in a more detailed way, as well as to create new training sessions for them and finally to delete them from their "patient list". The delete functionality will only remove the foreign key relationship between the patients and the physical therapists in the database, and this patient will no longer belong to that physical therapist's patient list.

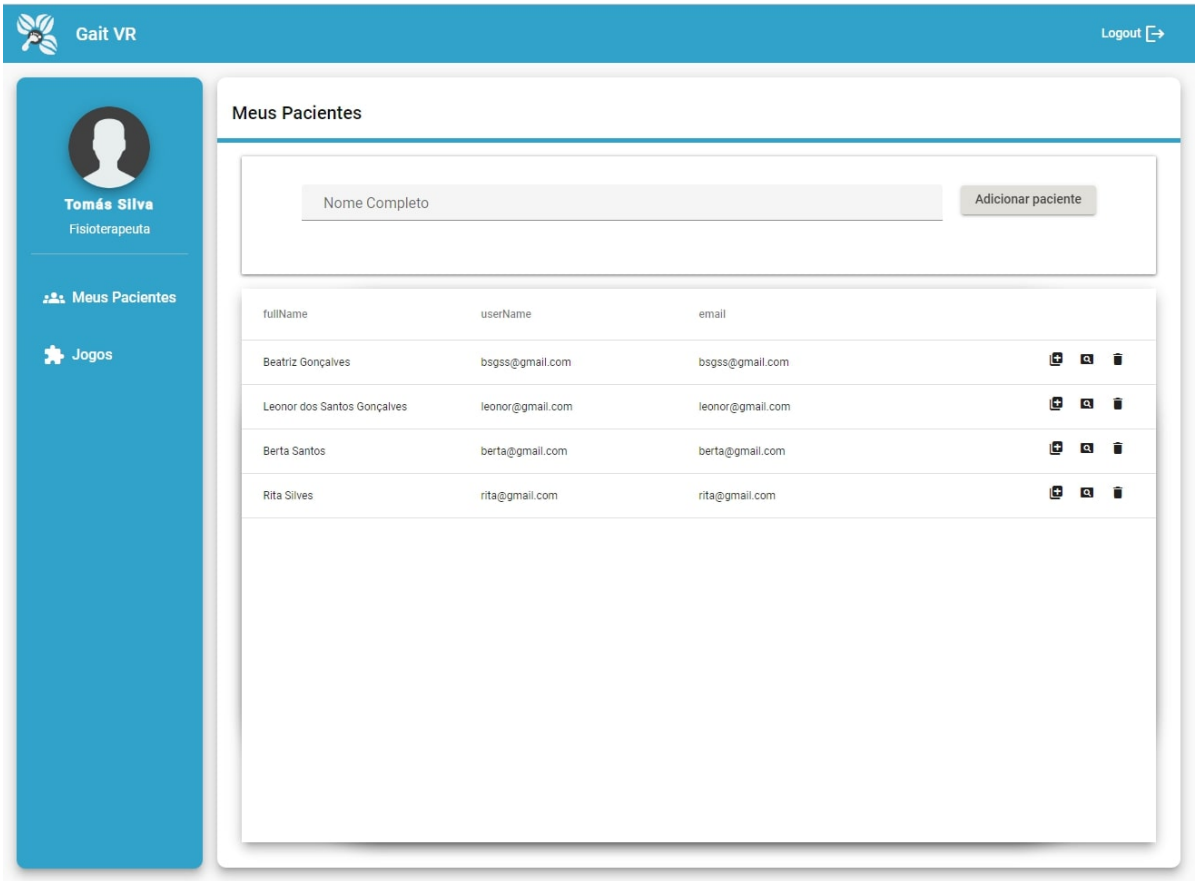


FIGURE 4.13. Gait VR Application Physiotherapist Home Page

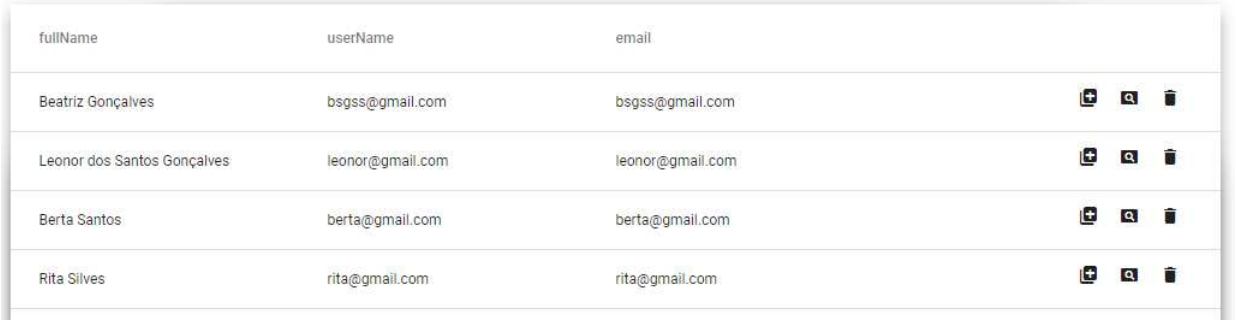


FIGURE 4.14. Gait VR Application Physiotherapist Home Page - Detailed Table Zoom

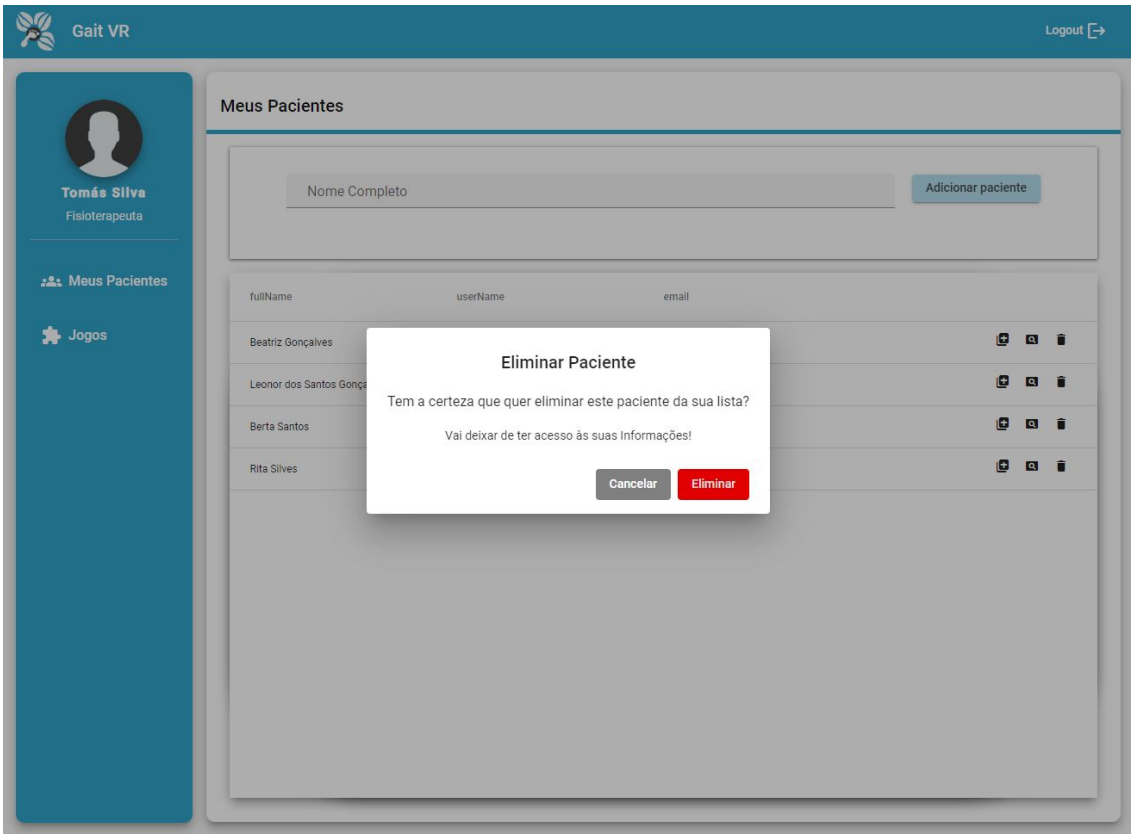


FIGURE 4.15. Gait VR Application Delete functionality

The image 4.16 that follows, represents a screen where it is only possible to navigate there through the side navigation menu that is present throughout the application.

The main purpose of this page is only to allow the physiotherapist to have access to the information and main description of each existing game. This way, it becomes easier to know what is the best to prescribe to each of his patients.

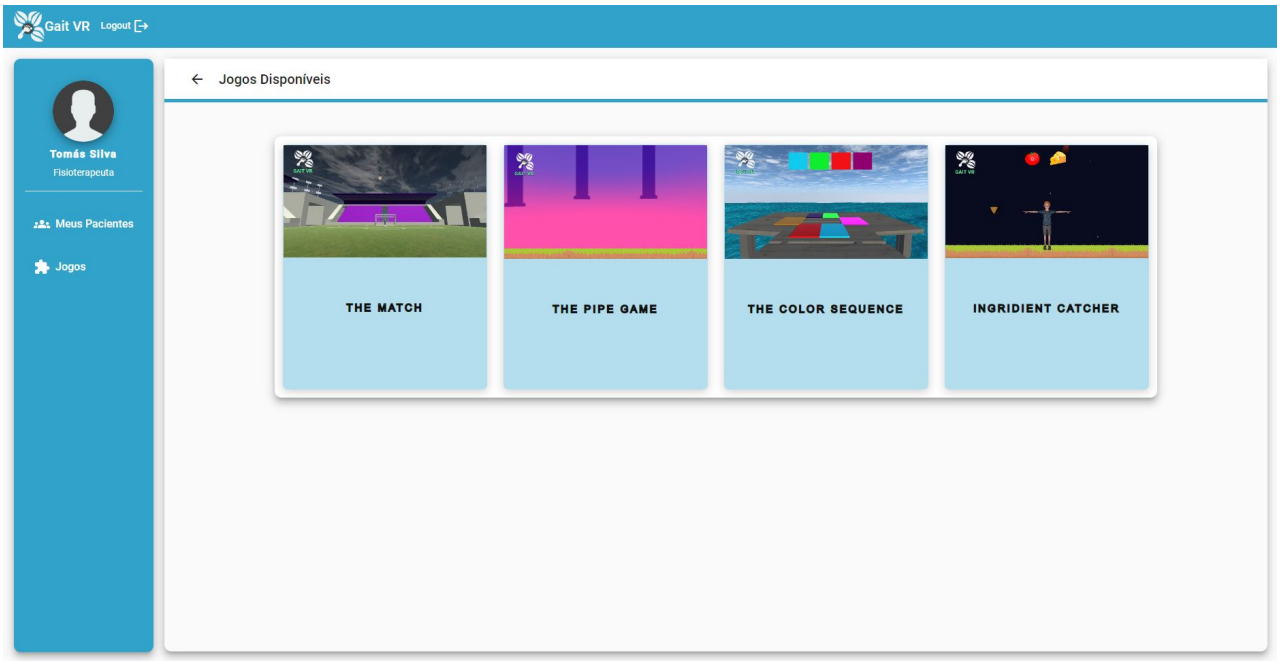


FIGURE 4.16. Gait VR Application Available Games Page

As it is possible to see in the image below, each card represents a game. The physiotherapist user can click on each one individually in order to have more detailed information about each existing game. When he clicks on the card, a dialog will appear like the one shown in the picture, with a short description about the game.

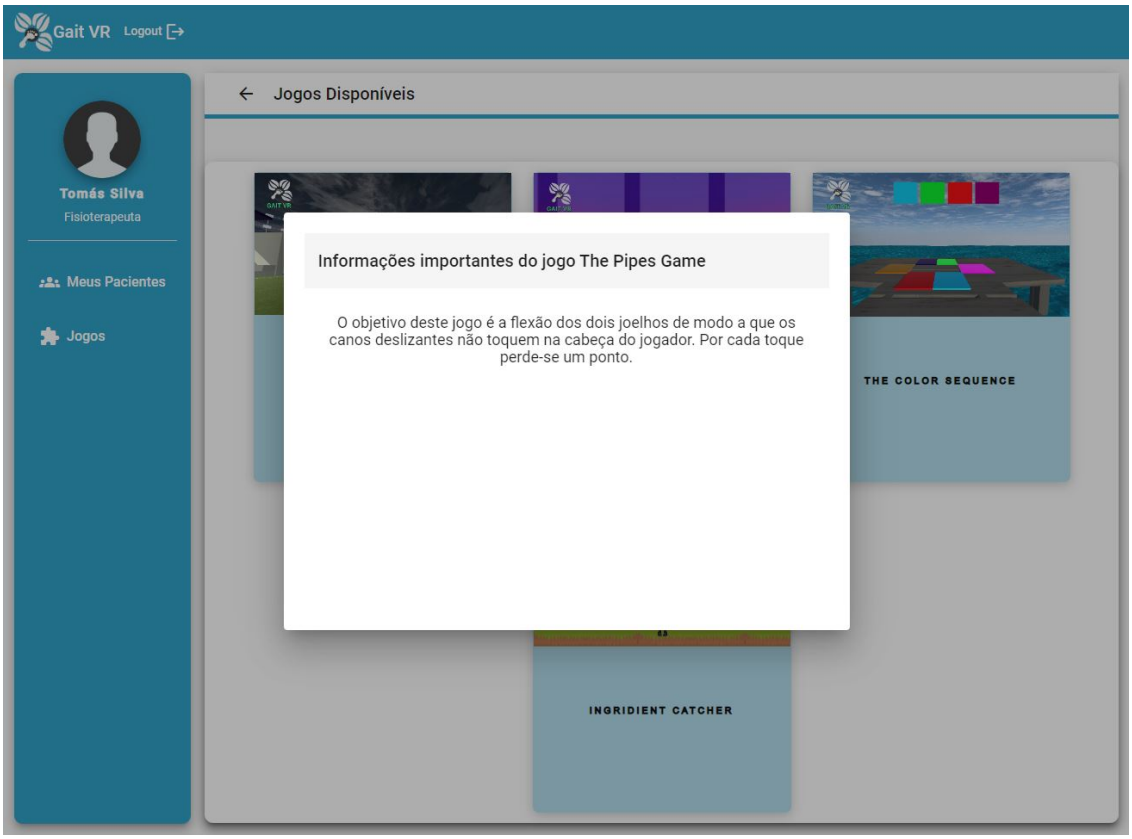


FIGURE 4.17. Clickable cards with game information representation

On the home page of the application there was a table where it was possible for the user to experience 3 main functionalities, one to delete a patient from his list of patients, the other to view the information of each patient, and for this reason and in order to be able to illustratively explain the use case, the following images are related to the functionality of visualizing the patient information.

The image 4.18 below shows the main screen where all the information is gathered. This information displays both the patient's personal information at the top of the screen, as well as their training information.

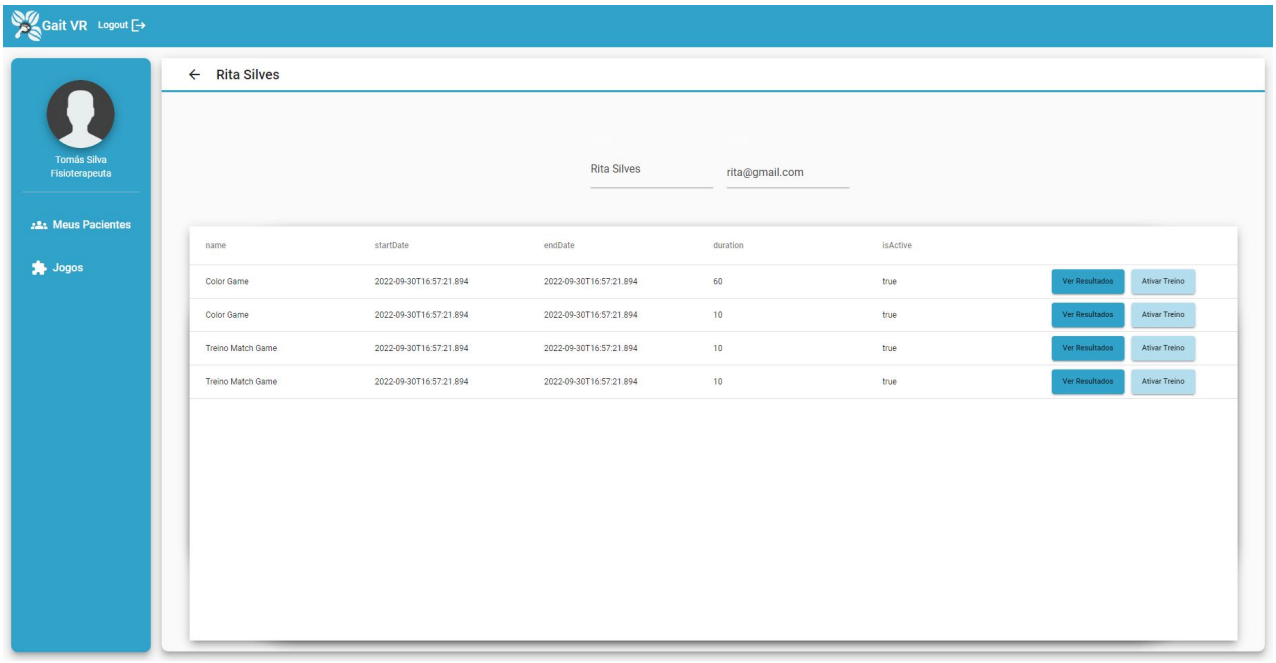


FIGURE 4.18. Gait VR Application - Patients information Screen

The physiotherapist also has the option of visualising the results of each training session. By clicking on the button in the table represented in figure 4.18 he will be automatically redirected to the results of that specific training. Some examples of tables with results are represented by the following images.

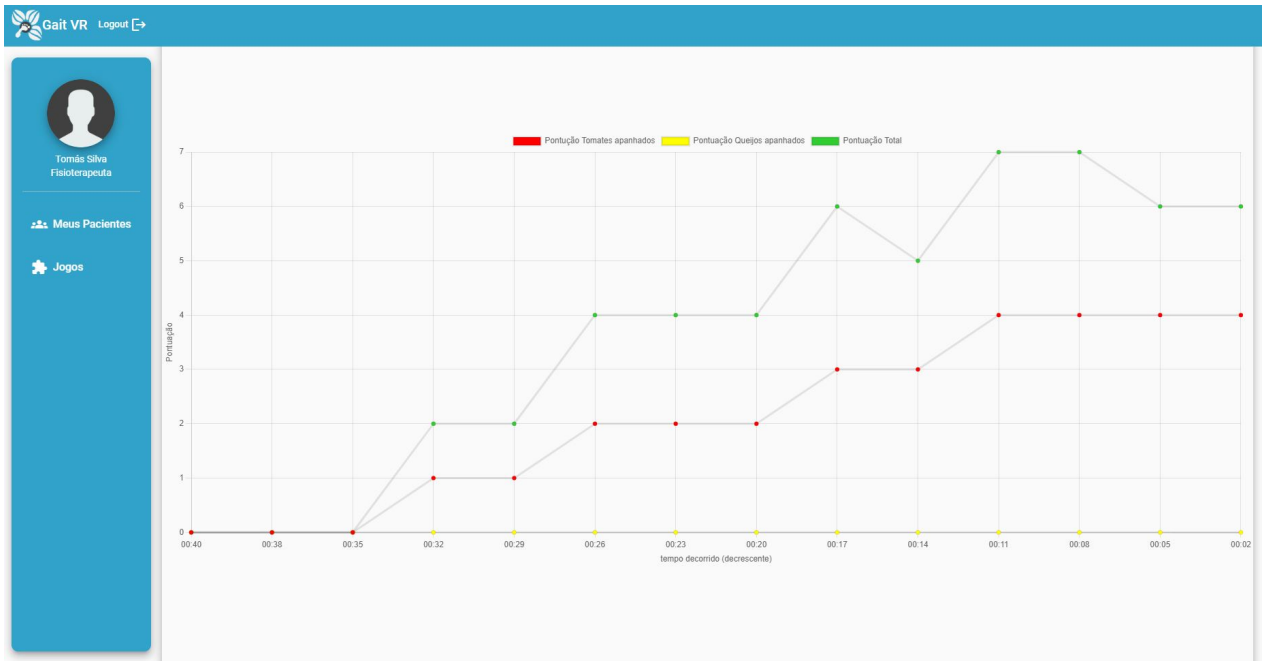


FIGURE 4.19. Gait VR Application - Results Screen 1

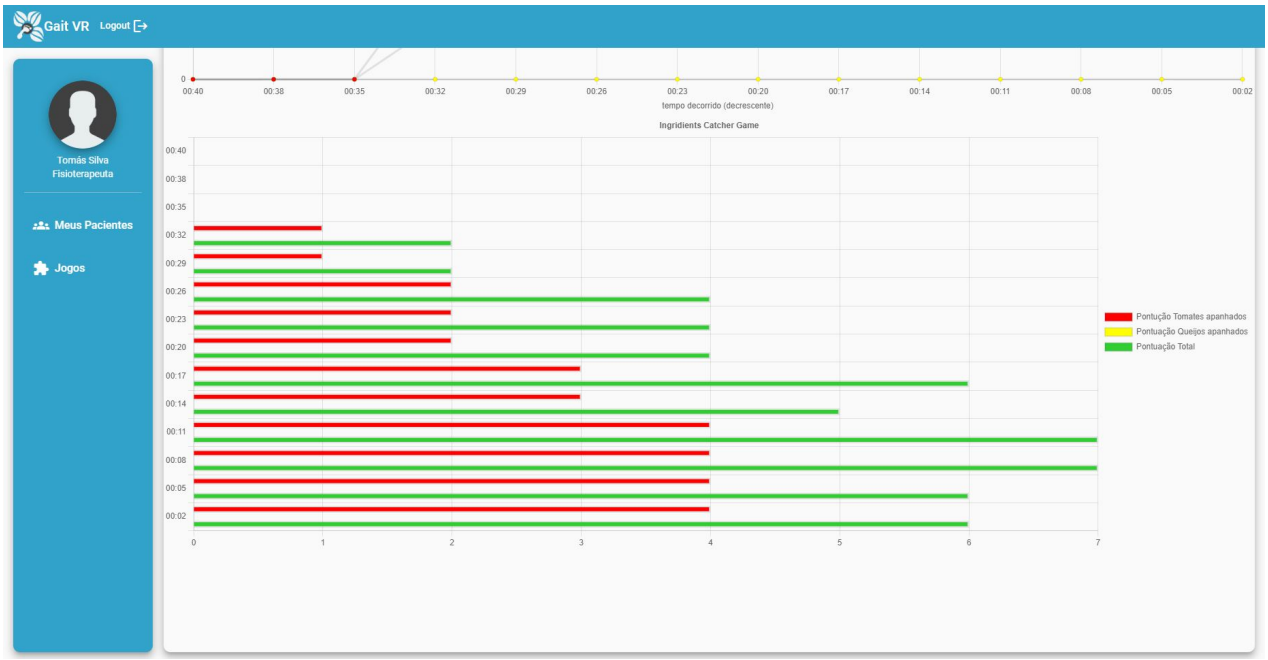


FIGURE 4.20. Gait VR Application - Results Screen 2

FIGURE 4.21. Gait VR Application - Results Screen 3

The third functionality that can be found on the main screen illustrated in the Figure 4.14 above, is the functionality to create training sessions for patients. The physiotherapist has to fill a form with the correct information for each field. Each training consists of a training's name, the start and end date of that prescribed training, the name of the responsible physiotherapist and patient (fields that are automatically filled), the number of repetitions which means the amount of repetitions the patient has to do for the workout to be complete, the duration of the train (that is going to be the time corresponding to the playing game time) the name of the game, because

each train can only be composed by one train at a time, and finally the field isActive that gives information if the train is active or not. If the train is active means that the patient can have access to it in the game Application, if the train is not active two things can happen: Either the train is not ready to be implemented, or the training has already been completed by the patient and goes from active to non-active.

As soon as the fields are all filled , the training is successfully created and the user is directed back to the home page.

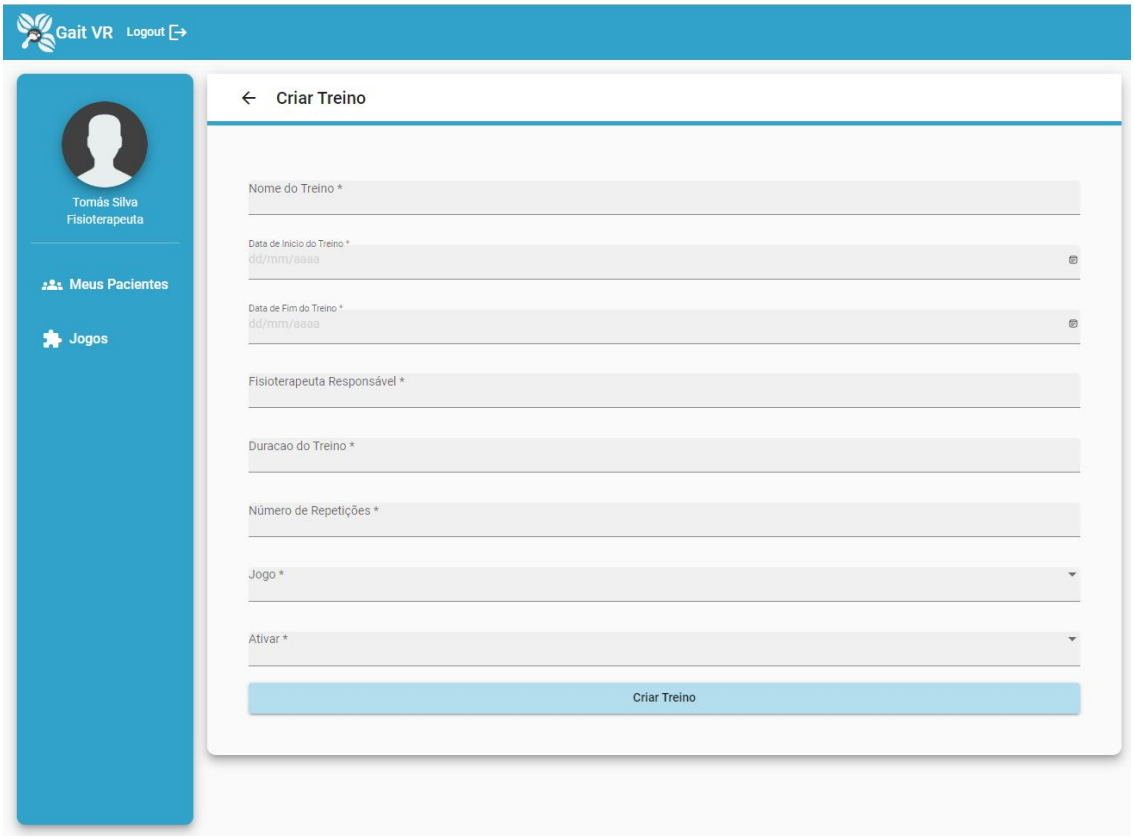


FIGURE 4.22. Gait VR Application - Create training Screen

CHAPTER 5

Results and Discussion

5.1. Overview

This chapter is dedicated to the tests and experimental results that have been conducted on the Gait VR system, during its validation. All the tests were performed according to some important ethical considerations that will be better discussed in the following section. According to the Covid 19 pandemic situation that we are still experiencing, and for all the necessary practices and care that has to be taken, the number of participants originally planned had to be reduced.

From this section of results, several conclusions can be drawn regarding gait rehabilitation and the influence that the system proposed in this master's thesis may have on the efficiency of the treatments.

In order to better understand and to provide some organization, this chapter will be divided into 3 subsections. The first one will discuss the ethical considerations necessary for conducting this type of research work, the second one will discuss the participants who took part in the tests performed on this system and finally the third section will discuss all the results and the analysis of the extracted data.

5.2. Ethical Considerations on Research works

When tests are conducted for any research work, a set of rules must always be considered, those rules are known as ethical considerations.

Below are represented some established standards by Bryman and Bell in [62], that I thought being really important taking into account the system developed.

- Participants chosen to participate in the study should not be forced or persuaded to do anything they do not want to do, that's why it's necessary to have an informed consent form for them to sign.
- Before the tests begin, the participant should be given an informed form about what will happen.
- The privacy of the participants is a very important factor that has to be kept under protection always.
- Always ensures for the respect with all participants, which means not using offensive language.

- Anonymization of all participants must be ensured, and only necessary general data such as age, gender etc. can be shared

5.3. Participants

The validation of the Gait VR system, the system proposed in this dissertation work, was carried out with the presence of 7 participants aged between 22 and 60 years old. Four healthy persons with no gait limitations, and three persons who presented an anomaly that affects their movement and gait.

- **Patient 1 - Age 25 - Gender: Female - Body Mass Index (BMI): Normal**

  Healthy patient without any type of gait condition

- **Patient 2 - Age 60 - Gender: Male - BMI: Normal**

  Healthy patient without any type of gait condition

- **Patient 3 - Age 27 - Gender: Male - BMI: Normal**

  Healthy patient without any type of gait condition

- **Patient 4 - Age 26 - Gender: Male - BMI: Normal**

  Healthy patient without any type of gait condition

- **Patient 5 - Age 22 - Gender: Female - BMI: Normal**

  young patient with a hip deviation of approximately 11 millimeters, a condition that makes the right leg longer than the left leg.

- **Patient 6 - Age 58 - Gender: Female - BMI: Overweight** A patient who presents problems with his right leg due to a birth defect. Uses a walking stick to support himself so he doesn't fall off. Did Physiotherapy a long time ago.

- **Patient 7 - Age 23 - Gender: Female - BMI: Normal**

  Young patient who had an operation on both knees to put the kneecaps in the right place. The patient is currently undergoing physical therapy.

5.4. Results and Data Analysis

The development of the system required various devices such as an expensive camera and a computer with specific features to ensure that everything together worked successfully. Due to the difficulty of transporting these materials to other places, all the tests in the ambit of this dissertation were carried out at ISCTE-IUL university.

With the main goal of being able to draw efficient conclusions and make comparisons between the participants involved in testing this system, the 4 serious games were played divided among the seven participants. The games that each participant with problems played were chosen carefully to ensure that there would be no injuries and damage.

5.4.1. First test Session: The Pipes Game - Patient 6 - Duration: 2,5 minutes (150 seconds)

The first test session was carried out with Patient 6. This patient has a condition in his left leg, using a cane to balance herself and not fall. Due to various operations she has already had, her left leg is in irons within the skin to keep it stable.

The game chosen for this patient was the Pipes game.

Name Game	Description	Duration
The Pipes Game	It was told to the patient that she had to stand in front of the camera and try to bend her knees every time the pipes passes by through her body	2,5 minute (150 seconds)

Table 5.4.1: Test Session Patient 6 informations

Below are presented some of the results extracted.

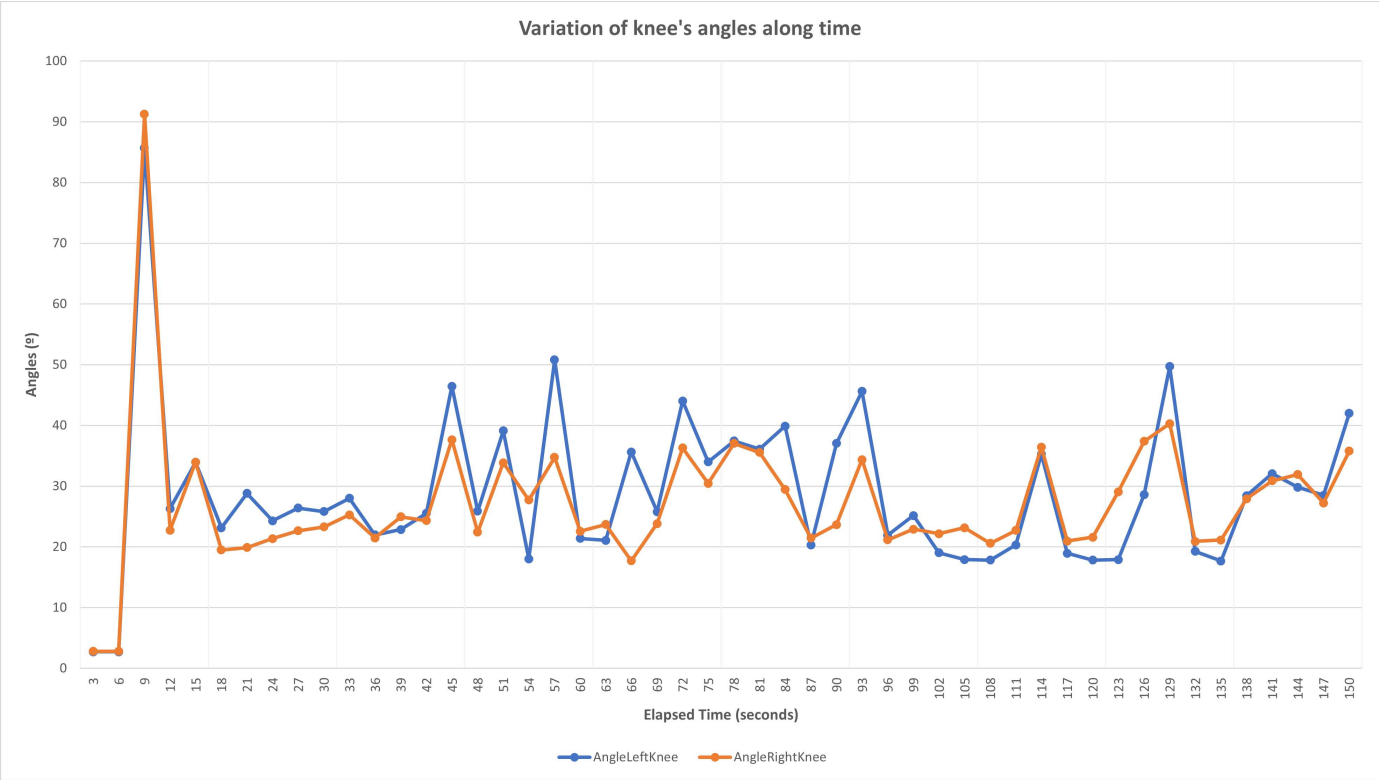


FIGURE 5.1. Extracted data from the Pipes Game

The graphic above represents the behavior of the left and right knee angles during the entire playing time (counted down).

During this game, the patient had to bend both knees at the same time to attempt to pass through the pipes that are appearing in different positions (heights) without touching them. By direct visualization of this graph it is possible to notice that there is still a significant difference in some moments of the game between the angles made by the left and right knees. If the leg angles were completely straight making a 90° angle with the ground that the feet are standing on then the angle made by the knees would be approximately 0°5.2. However, it's a really good thing that they are not like that because our body needs to have flexibility in order to make the gait movement that allows us to walk.

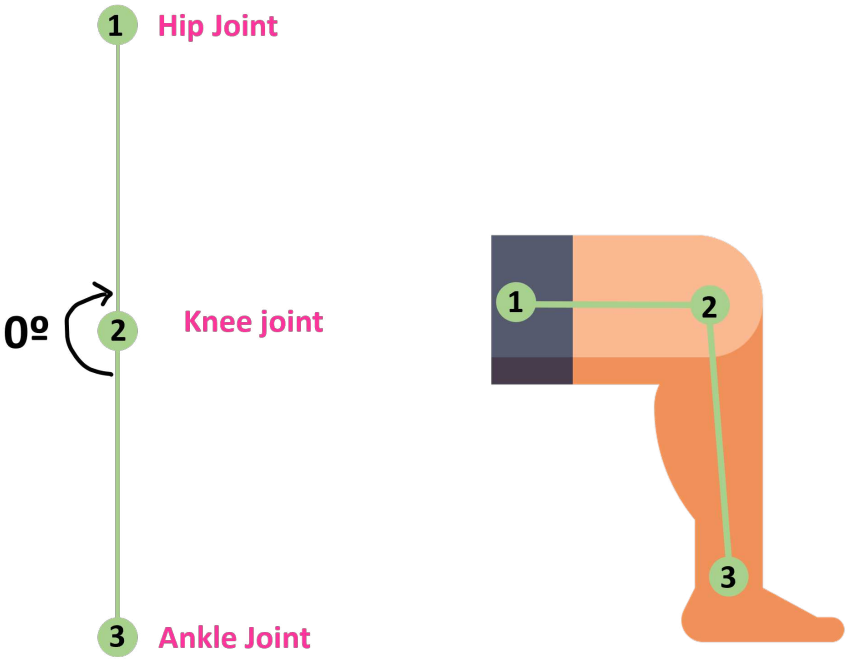


FIGURE 5.2. Explanation of measuring knee angles

Usually when a person is resting, standing with both feet on the ground with relaxed knees, the angle made is designated by the Q angle and can be variable according to the gender of the person. According to [63], there is an average of 21,47 degrees during the stance phase of the gait pattern.In the female gender the average of knee angles is approximately 22 degrees and in the male gender the average can change to 18 degrees. The Right knee values presented on the graphic 5.1, presented values along time lower than the Left knees values and those values seems to be very present in the 20º and 30º range, which means that the patient in question did not bend the knee much during the course of the game, but tried it and was almost always close to the average knee angle of the resting position, due to his physical condition.

In the figure 5.3 below you can see a graph that represents the average values of the knee angles variation during the 150 seconds of the game play.

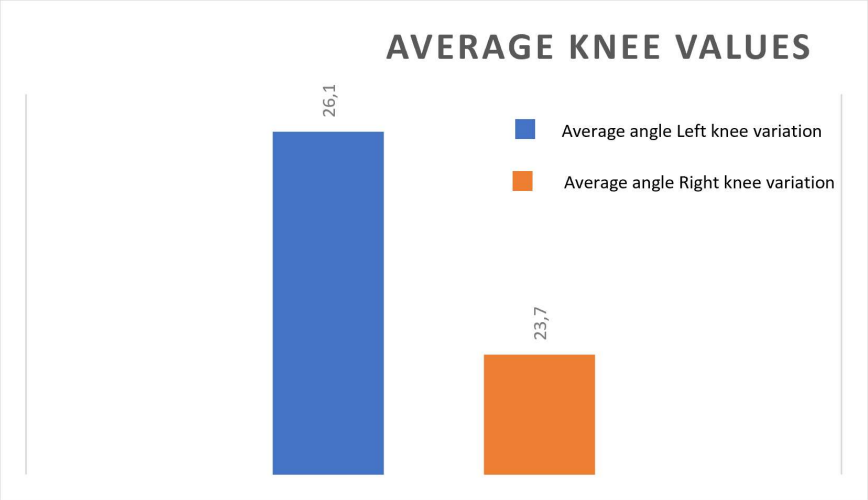


FIGURE 5.3. Angle Knees Average chart

Maximum angle value recorded on the left knee	**Maximum angle value recorded on the right knee**
85,6 °	91,2 °

Table 5.4.2: Maximum angles records

One of the most important parameters to measure in gait rehabilitation is speed, and this value can be measured and calculated using the following graphic that represents the total score and how it varied over the playing time. Using this values the physiotherapist can make comparisons and come to useful and quite interesting conclusions.

The following graph represented by image 5.4 concerns the total number of points scored by the patient who performed this test throughout the game, which is also represented in the same.

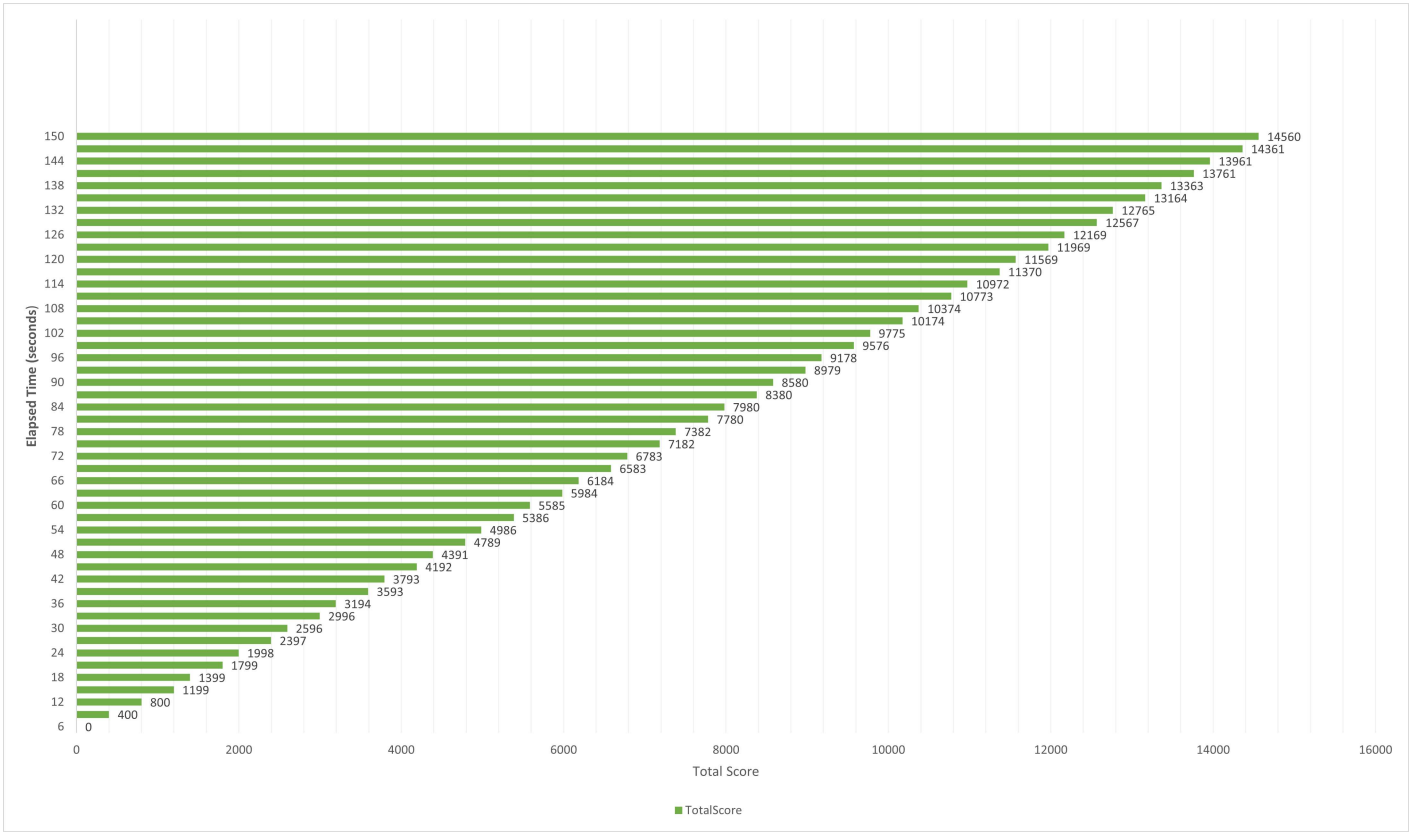


FIGURE 5.4. Total Score chart

5.4.2. Comparison of results between healthy patient and patient with problems

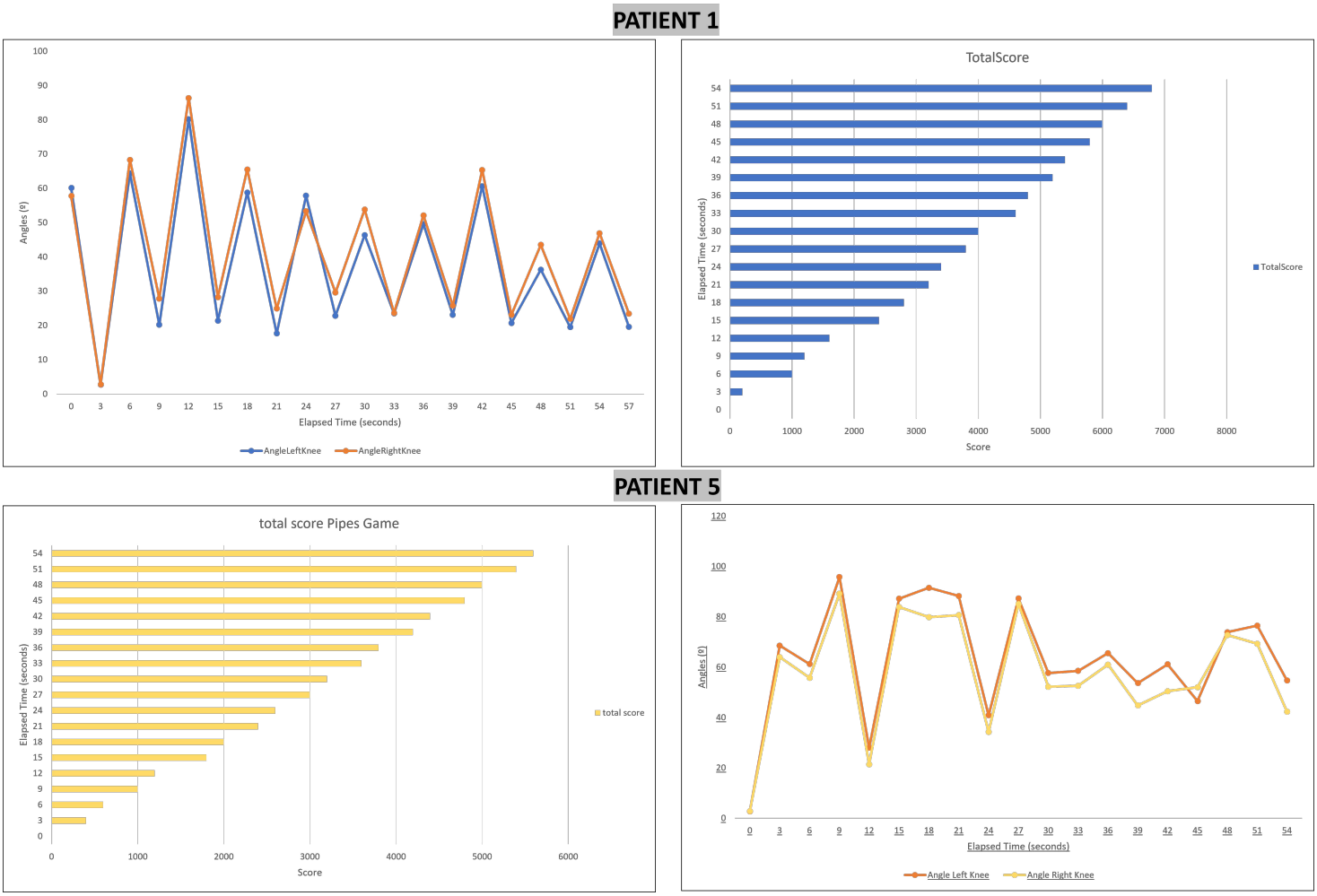


FIGURE 5.5. Comparison of results between patient without problems and patient with problems - Graphics

Patient 1 has no gait problems while patient 5 has a condition where his pelvis is dislocated. Comparing the two results of the serious game The Pipes Game with a playing time of approximately 1 minute = 60 seconds, we can see some differences, especially regarding the variation of angles.

Although patients do not perform the gait and walking function, in this game, they perform very important motions and movements, which, if not functioning correctly, may indicate problems and condition the gait function.

The patients stand still in the same place and do the squatting position throughout the course of the game. The movement of knee flexion is a movement that is always present when we practice the action of walking, it is present in the initial and final phases of the gait cycle, where it is necessary to give the balance that the body needs to start the walking process, and it's present when it is necessary to have the impulse of movement to ensure that when the patient finishes taking a step, or when the patient reaches the end of one of the phases of the gait cycle, the body can maintain its balance and do not fall.

During the training session of patient 1 the angles of both knees vary together, which shows that the patient in question has a flexibility within the normal range for someone who does not have problems that affect these joints, while in the training session of patient 5, it can already be seen that it was not so linear, showing some differences.

5.4.3. Second test Session: The Match Game - Patient 2 - Duration: 1,5 minutes (90 seconds)

The second test Session was carried out with Patient 2. This patient doesn't present any gait anomaly. Time was chosen as it is a considered average where the player can enjoy the game and at the same time not get too tired. This time can be changed to a lower one if the player is a patient with different conditions than the one who performed this test session, in this case, a player with lower limb problems.

The serious game chosen for this patient was the Match game.

Name Game	Description	Duration
The Match Game	The patient was told that he had to be positioned in front of the camera but with his back to it. The patient has to kick the ball that appears at his feet and try to hit the moving goal	1,5 minutes (90 seconds)

Table 5.4.3: Test Session Patient 2 informations

This is the only game in which the patient is positioned in front of the camera but facing away from it. In order to make it easier for the patient to perform the tests, a projector was used to project the games on the wall as shown in the following figure 5.6. The participant is standing in front of the camera for an average distance of 2 meters. The following photograph was taken with the consent of the patient 2 in question, a healthy participant.

FIGURE 5.6. Participant performing tests to the Match Game

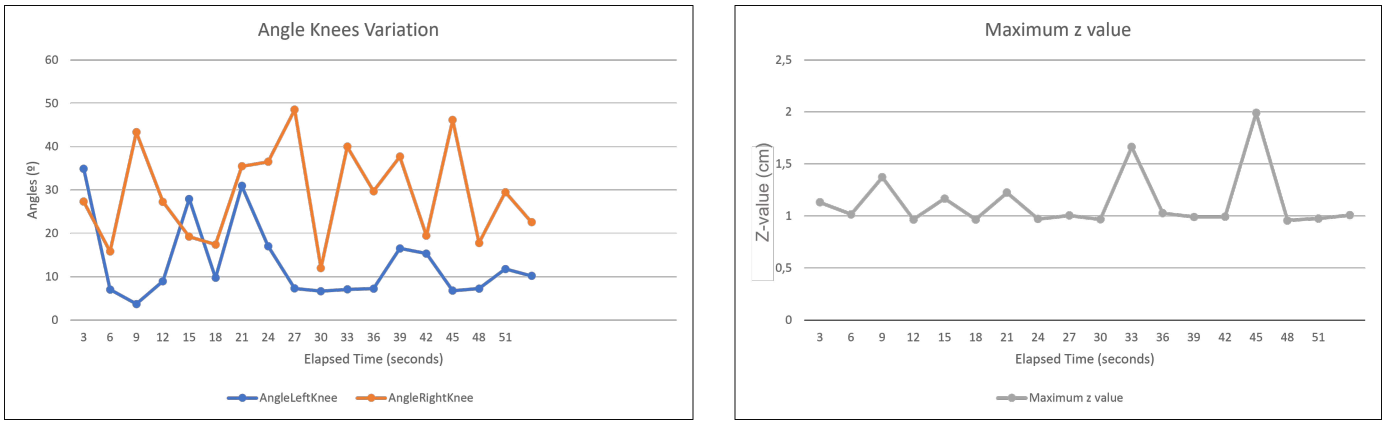


FIGURE 5.7. Graphic results for the Match Game

From this game it is possible to extract various types of results such as the variation of knee angles while the patient kicks the ball. It is also possible to extract the maximum position reached by the patient's foot every three seconds, and the total score made during the game time.

The number of balls the patient shoots towards the goal is directly related to the total score of the game and gives information about the speed of his leg movement.

It was considered that the maximum value of z is a value that can be quite useful for physical therapists to draw conclusions and make comparisons over time, however, it can be dangerous if

a patient obtains high values because they run the risk of falling due to the fact that when the ball is kicked, the player is supported by only one foot, and his body could lose its balance. Due to these reasons, these tests for this game were only carried out on people considered without gait problems, but a possible adaptation so that it is less dangerous for a person with more serious conditions playing this game will be considered in the future work chapter.

all the developed serious games for this system were considered for and evaluated in these tests, however only a few were analyzed in this report due to the vast information they present.

5.5. Usability Questionnaire

In order to complement the tests performed on the application, a usability test was also developed and answered by all participants after doing their tests. To carry out this questionnaire, Nielson's heuristic evaluation [64] was taken into account, which are used by experts in usability and application design. These heuristics are short simple usability questions that help to identify and solve big problems.

the ten most important general principles for developing an application are:

(1) **System visibility**:The system must be built in such a way that it always keeps the users informed about what is happening. For this case, dialogs with relevant information were always used before the user tries to perform any functionality. The buttons try to be explanatory. In the game application we have a game HUD where it gives the user the necessary information such as his name in order to know that he is in his session, the game time, the points he is accumulating, etc. The objective of this point is that the user never finds himself lost, without exit in the application.

(2) **Relation between the system and the real world**:All the language used in the system should be familiar to the user and never be terms that the user has never heard of, such as computer terms. The system, both the Unity game application and the web application are all in one language only, which is Portuguese and tries to use familiar, real world terms.

(3) **User control and freedom in the application**:The user should never anywhere in the system be trapped with no way out. This means that on every screen of the system there should be a button that allows the user to go back to the previous page, or even to any other page

(4) **Consistency and standardization**:This heuristic means essentially that the system must be consistent in its functionality and language. Everything should be clear to the user and there should be no questions, otherwise this heuristic will fail.

(5) **Error prevention**:When there is an error in the application, making that error message appear is a good practice because then the user can know that something is wrong.

However, this heuristic is about error prevention, which means that the system must be designed to always avoid errors.

(6) **Recognition instead of remembrance**:There is a pattern of knowledge and common practices that users are used to seeing even in everyday life and in other applications. I'm not talking about information by text, I'm talking about information translated from colors, translated from signs and icons. This heuristic addresses the fact that a user recognizes things just by looking and not having to think about what information that part of the application is trying to convey. For example, in the web application we have several examples of this heuristic, such as the functionality that a user can delete a patient from his/her patient list. The delete functionality is a dangerous functionality that sometimes happens by mistake, yet that is what we are trying to avoid. When a user decides to delete a patient, a dialog appears telling him what he is going to do, along with a red button where he will actually do the deletion. The color red is a good practice because it gives an immediate alert feeling without the user having to think, he just recognized the information.

(7) **Flexibility and efficiency of use**:It is necessary to have shortcuts in the application that increase the speed and efficiency of the system

(8) **Aesthetic and minimalist design**:The system should not contain information that is unnecessary or rarely used by the user, otherwise its efficiency of use will decrease. Only essential and simple things.

(9) **Support for users to recognize, diagnose and recover from errors**:The error and information messages that appear in the application should be simple, in language commonly used by users, and if possible accompanied by a solution.

(10) **Help and documentation**:A system that includes documentation, although simple, is necessary because it helps the user find what he is looking for in a much simpler way.(user manual that will be available in attachment)

Below are some relevant answers given by the patients who participated in the system tests. The questionnaire was developed and completed by all participants on google forms. [65]

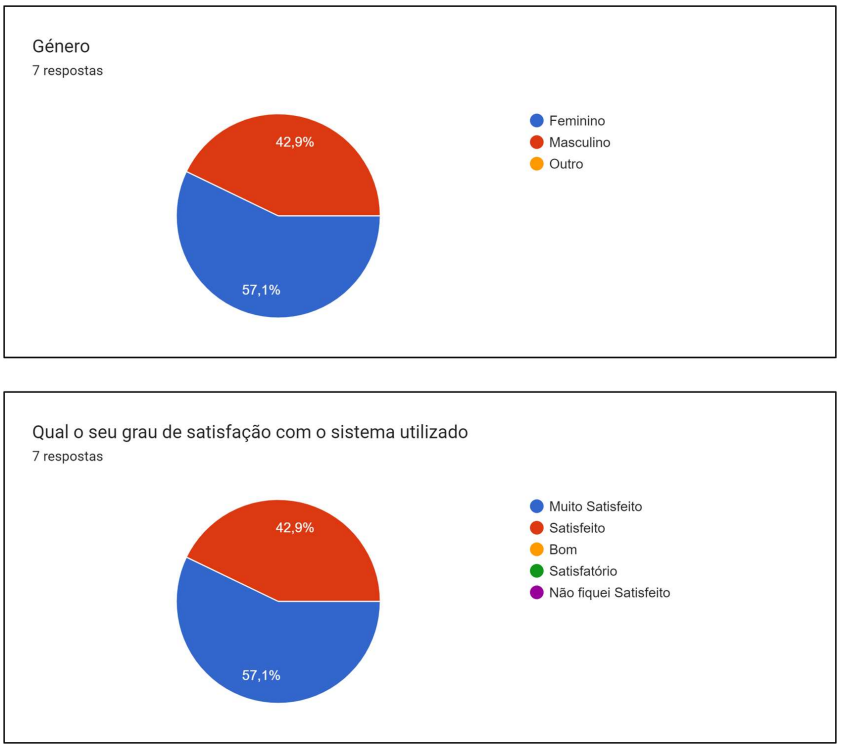


FIGURE 5.8. Gender and satisfaction level of volunteers in system tests

The figure 5.8 above shows the results of two questions in the questionnaire regarding the gender of the person answering and their level of satisfaction. The answers regarding the satisfaction level were in general very positive, with only respondents finding the system between good and very good.

Another of the questions asked in the questionnaire was the question represented in the following image that asks what was for the participants the most positive aspect in the system. The answers as can be seen were varied, from that it is an original system, with a well organized and well done layout, that it can be very interesting and a help in increasing the motivation of people in the rehabilitation process, to that it can be a great help in the rehabilitation process.

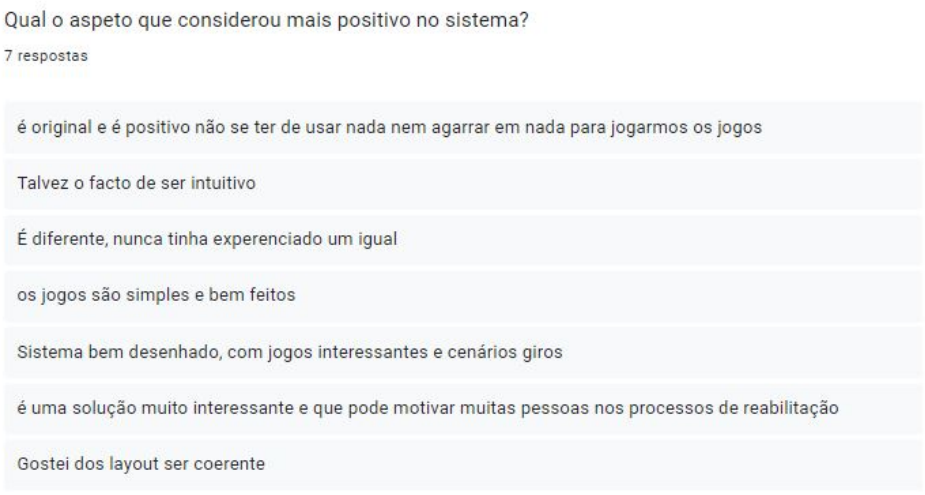


FIGURE 5.9. Positive aspects of the system, responses from participants in the system tests

Just as in the previous question we have information about the positive aspects of the system, an even more important question is the negative aspects of the system, in which some answers were also obtained. Among the negative aspects presented are the high cost of the system, that is, the cost of having the azure kinect camera, which costs between 200€ and 300€, Having an initial countdown in every game, and the mirroring characteristic of the Azure Kinect camera. These answers will help a lot to improve the functionality and usability of the system and will be considered in the next chapter of future work.

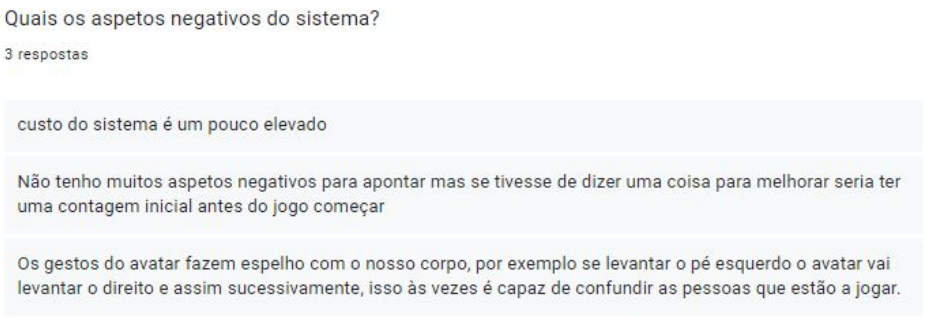


FIGURE 5.10. Negative aspects of the system, responses from participants in the system tests

The figure 5.11 below represent statistics regarding how well the application and the games work, whether they are original, intuitive, creative, boring, flexible and easy to play. The participants gave a score from 1 to 10 depending on what they thought and many varieties of answers were obtained. In general, the results were quite positive due to the fact that most participants answered scores between seven and ten on the positive characteristics and a score of one on the negative characteristic, which was whether the system had been boring.

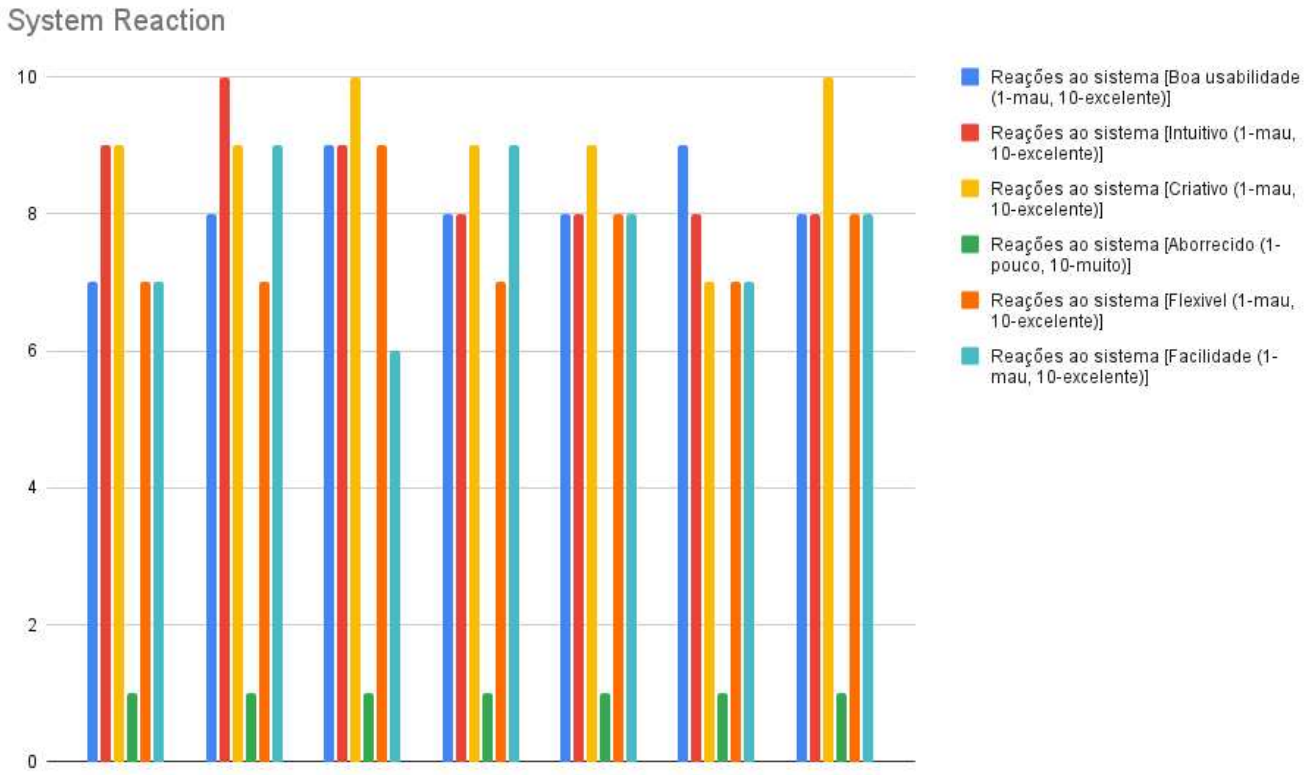


FIGURE 5.11. Statistics regarding how well the application and the games work

	Good Usability	Intuictive	Creative	Boring	Flexible	Easy
Patient 1	7	9	9	1	7	7
Patient 2	8	10	9	1	7	9
Patient 3	9	9	10	1	9	6
Patient 4	8	8	9	1	7	9
Patient 5	8	8	9	1	8	8
Patient 6	9	8	7	1	7	7
Patient 7	8	8	10	1	8	8

FIGURE 5.12. Table Statistics regarding how well the application and the games work

Finally the participants were asked to give suggestions on how the application could be improved and quite a few were given. These suggestions will also be considered in the next chapter of future work.

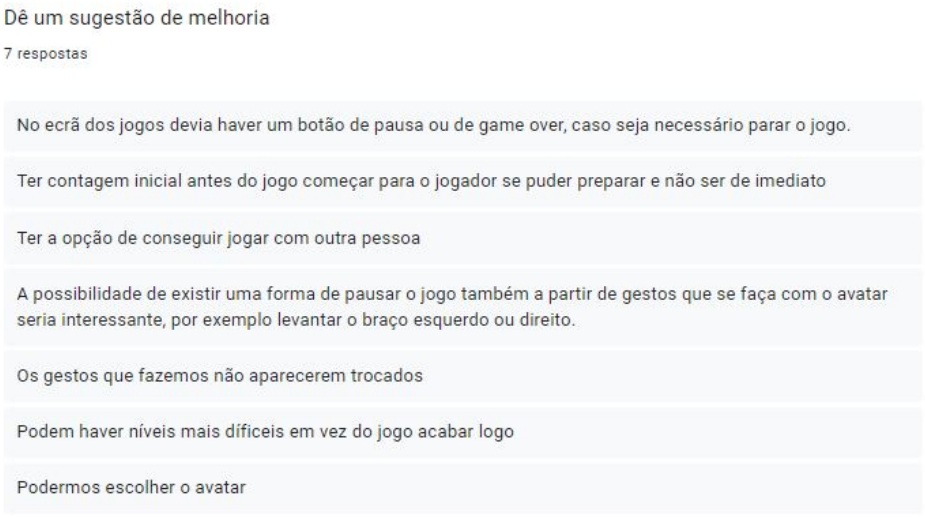


FIGURE 5.13. Suggestions for improvement of the system

CHAPTER 6

Conclusions and Future Work

6.1. Conclusions

Throughout this dissertation work, a system was developed named Gait VR. This system was developed with the main purpose of supporting health professionals specialized in the area of physiotherapy and rehabilitation in a more effective way and with higher quality, so that it becomes possible to regularize the monitoring of patients and extract important data that can make a big difference for the future of the patients treatments in Gait rehabilitation. The system itself was developed to be composed of 2 features, a game application that will allow patients to play the four serious games and consequently perform their training sessions prescribed by their physiotherapists and a web application that will allow the physiotherapists to visualize the training session results and to manage their patients personal information.

It was quite a long project that was initiated with a deep research work in order to try to understand what were the most revealing aspects to be aware about the serious games and how they could increase the motivation of the patients during the whole process of their rehabilitation and how the world of technology could relate so successfully to the world of medicine. The serious games were developed using the Unity 3D software platform and kept in consideration all the research work done previously and the requirements of all kinds of patients, an example of that was their scenarios that were developed in order to be adapted for patients with cerebral palsy condition, using a 2D plane without depth, because they present a lot of difficulties seeing a 3D world depth. The gaming platform also uses the new camera created by Microsoft Azure Kinect, a camera made up of sensors that can, using a tool provided called Body Tracking SDK, detect the various body joints of a person, and can detect up to 6 people at the same time. With this it is possible to extract and obtain data such as the coordinates that represent the position of the patient's feet, the opening distance of his or her legs, the angles made by the knees, and many others. With the concept of the four games together, it will be possible to determine very important obtained parameters for gait rehabilitation such as speed, balance, and even values that can help in cognitive rehabilitation, with The color sequence game.

As a complement to all this work, the development of a web application was also considered, a tool only available to physical therapists, where it will be possible for them to monitor all the work done by their patients and draw faster and more efficient conclusions about the state of your rehabilitation.

As it was possible to observe in the previous chapter, all the results and tests were in general satisfactory in terms of the amount of information that it is possible to gather and analyse.

Whenever a patient plays a game, the information that is extracted is allocated to a MySql database and is subsequently displayed in the web application. The Gait VR system is a system that brings with it strong possibilities for the large amount of help that is being needed in the medical field in the last few years. There has been a large increase in dropouts from rehabilitation because of the time-consuming and sometimes discouraging work involved, but it is hoped that this system can be a solution and a remedy for the motivation of patients in gait rehabilitation.

6.2. Future Work

This chapter is only dedicated to the future work that can be done for the proposed system of this dissertation work. Although this has been a very extensive project, involving deep research work, development of a system consisting of multiple components, there are still many aspects to improve and to take into consideration. Listed below are some of the steps that are either part of the group of improvements, or new features that were not possible to be implemented due to the fact that this project had a limited time and was part of a master's thesis.

- **Implement Azure Kinect voice recognition system** : Azure Kinect camera has a voice recognition system that can be very useful during the patients training sessions, for example if they, for any reason, are playing the game and have to stop the game, the system could be programmed so that when a word is spoken the game is paused.

- **Camera Image mirroring :** The camera used in this project mirrors the images that are shown (that's its natural way of working), which means that when a person stands in front of the camera and lifts for example his right arm, the arm that the person will see being lifted is the left one. For this point to be done there has to be development around an OpenCV and flip the API to mirror the image horizontally, so this will be a point to have in consideration in the future.

- **Applications Authentication**: Simplify user authentication in both applications (web and game) with a QR code system

- **Adaptability of Game application**:At this moment in the game application it is only possible for the players to play with one avatar, but it would be interesting and more dynamic if the application was adapted to the different characteristics of each player, and with that it would be interesting to have several types of avatars that could be chosen by each player at the beginning of the game, such as related to their age or gender.

- **Multi-Language Applications**: The applications of Gait VR system were developed only in one language, the Portuguese language. The system would be accessible to many more people if it had at least the universal language, the English language.

- **Improvement of the serious Games**:

(1) Improve serious games, and make them have difficulty levels.

(2) In the Match game there is a value that is extracted that is de z max value which means the highest height the foot can reach. This value can be very useful for future conclusions, but it is a value that can be dangerous because the patient in question has his foot raised and can raise his foot too high and risk falling. In order to prevent this from happening, it would be interesting to be able to implement in the HUD of the game in question a bar with a pointer that varies in the color range of green, yellow and red and warns the player each time he raises his foot too much.

(3) Create a virtual assistant in Unity software that appear before every game starts. That virtual assistant will have the main objective of explaining the rules of the games to every player.

- Take into account all suggestions given by users who participated in the system tests and who responded to the usability questionnaire.

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Attachments

Appendix A - Certificated

CERTIFICATE OF ATTENDANCE

This is to certify that:

Beatriz dos Santos Gonçalves, Octavian Postolache, José Miguel Dias Pereira

have presented a scientific contribution at

the 12th INTERNATIONAL CONFERENCE AND EXPOSITION ON ELECTRICAL AND POWER ENGINEERING - **EPE 2022**

held in IASI, ROMANIA, October 20 - 22, 2022.

Conference chair,
Prof. Marinel Temneanu
Dean of Electrical Engineering Faculty

Appendix B - Published Article

Gait Rehabilitation in Virtual Reality Serious Game Interactive Scenarios

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***Abstract*—Fall accidents are generally very harmful and can be the consequence of gait impairments, that's why it's very important for a person to have regular checkups if they notice any unusual differences in the way they use to walk. The way a person walks can at times be characterized by a certain anomaly that can compromise their everyday routines and be an enormous risk to their state of health. These types of anomalies are known as Gait disorders. Inside the healthcare areas of physiotherapy and rehabilitation, the growing demand to improve the quality and efficiency of treatments, has led to several experimentations, developments, and implementations of various types of technologies and innovations in the past few years, to allow patients with these types of conditions to reach a faster and more motivating recovery. In this paper is presented a solution designed and implemented to be used for gait based on the concept of 3D serious games. Virtual reality interactive scenarios were considered and implemented using the software platform Unity 3D and the interaction between the user and the VR scenario is carried out by Azure Kinect. Microsoft Azure Kinect SDK is used to extract the body joints tracking. The proposed solution includes a Web application designed for physiotherapists to access the electronic health record of their patients but also to prescribe the training plan supported by the high interactive VR scenarios of the proposed serious game. Based on the joins acquired data different metrics are considered and used to validate the capabilities of proposed system.**

Keywords—gait disorders, physical rehabilitation, Virtual Reality, serious games, Unity 3D, Azure Kinect SDK

I. Introduction

Technologies are growing at an exponential rate, which means that it's almost impossible for anyone to keep up with them in real time.

By looking at multiple and different sectors around the world, not only connected with technology but also related with many other areas as well, we can easily understand that technologies are on the right track to change them, the future, and the world in a highly successful way. For example, in the medical sector, there have been major changes in the quality and effectiveness of patient care and in the evolution and treatment of diseases that some years ago were scarce of cures, presenting nowadays much more advanced treatments that give hope to the patients, which means an important approach to their life quality.

The Gait Cycle is a very important object of study that helps health professionals to diagnose various types of diseases. In normal gait [1], the foot moves forward and backward, side to side, and rotates in circles in a coordinated way. The body goes through all the events described above in an unconscious and natural way, but when something's wrong, the natural way stops being natural.

Over the years, physiotherapy has been the great salvation for the recovery of certain parts of the human body. However, there are a countless number of different approaches to physiotherapy treatment. In Gait rehabilitation, treatment sessions in general are not easy, for patients often have a sense of fear when performing the exercises proposed by the physical therapist for their treatment and, furthermore, rehabilitation sessions could become long and time-consuming processes for patients, that consequently leads to the lack of motivation and to the drop out of their rehabilitation processes. There's a need to recover patients' autonomy and participation in healthcare decision and health self-management [2].

One of the ways found to increase the motivation of patients and consequently reaches higher positives results during treatments, was the implementation of the concept of serious games, a concept that was born with the purpose to meet objectives very apart from the entertainment [3], mainly design to teach, build skills, and change behaviors. They can be used in a lot of different areas like education, business training, medical training, agriculture and so much more, but they're also a growing field in games development and are starting to become a serious sub-field of games studies all their own.

II. Related Work

Serious games use a variety of technologies from virtual reality, sensors, telecommunication technologies to human computer interfaces and cloud services. These technologies provide support for the precise and detailed capture and analysis of complex kinetic and kinematic variables during motor rehabilitation [4]. The process of rehabilitation itself really depends on the frequency and effectiveness of the physical rehabilitation sessions. One successful solution that can serve as a complementary therapy to the rehabilitation methods, is the remote physiotherapy self-training at home [1].

The rehabilitation is expected to progress faster and with better results due to the remote nature of the intervention. The rehabilitation at home requires more time and effort, which may be difficult for some patients to maintain, but it also has the potential to create, enhance and reinforce patient's existing rehabilitation regime and, ultimately, may improve the outcome of the rehabilitation process.

The success of the rehabilitation process also depends on patients' motivation and ability to adhere to the rehabilitation program, which is challenging in the remote setting.

Gait rehabilitation using virtual reality scenarios is a dynamic way of obtaining something more than visual feedback in a simple static state [5], it offers users a sense of

immersiveness, solving some of the spatial and safety problems that can occur during walking practice sessions not to mention the importance of getting quantitative data, like walking kinematics and some other parameters like position, angles, velocity and balance [6,7].

III. System Description

The system proposed in this solution is called Gait VR and was developed with the main purpose of support gait and lower limbs rehabilitation, in patients with different type of motor impairments caused after accidents, natural events (like births) or stroke events.

Bellow, we can have access to a block diagram which serves as a representation of Gait VR system architecture (Fig. 1).

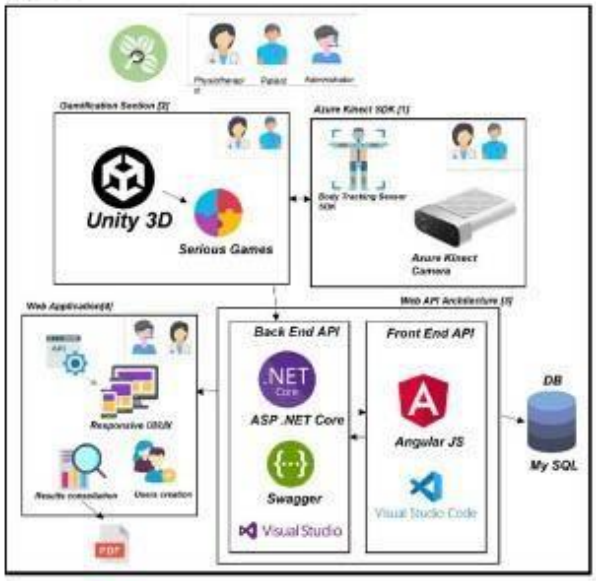

Fig. 1. The Gait VR System Architecture representation.

A. System Architecture

1. **Azure Kinect SDK:** The Azure Kinect (Fig. 2) is a low-cost camera device launched my Microsoft, which can display and collect images, including RGB images, infrared images, and depth images [8].

   The 3D camera provides information that is used by embedded AI algorithm from Microsoft that provide information about 32 joints of a human body, and this is very beneficial because it allows a person to stand in front of the camera and track their entire body, all its joints, its movements, measure the world and local coordinates positions, angles, and so can allow patients to have a more realistic experience, without having to use or being dependent of wearable devices to play the games and to complete their training exercises.

   In this project it was used an open-source library for unity 3D available from Microsoft Azure Kinect called Body Tracking SDK (available in [9]), which allows the detection of the patient joints and the mirroring of his movements to an avatar that will be used to play the developed games.

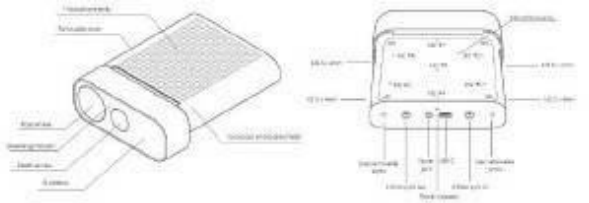

Fig. 2. Azure Kinect SDK device represented in [8].

2. **Gamification Section:** This section of the diagram is the section dedicated to the development of the serious games and the user interface for all the patients. A Unity 3D software interface was developed in order to allow "patient" users to authenticate themselves using their emails and passwords and have access to the training exercises prescribed by their physiotherapists. Users who enter into the current Unity Application will firstly see an authentication page that will direct them straight to their own prescribed training area. This area is represented as a page with clickable elements with the respective name of the active games they will need to play to complete their workouts. Their trainings exercises can be composed by a collection of games, chosen by the physiotherapist, which will work as a complementary support for their physical therapy. There are four serious games in total, each with its own characteristics, and each focused on collecting a range of important metrics that can later be analyzed by health professionals.

   It is important to highlight that the games existing in this system were not only developed thinking about people with gait disorders only, but also about people with neurological issues too, more specifically for people suffering with the cerebral palsy condition.

3. **Web Application Architecture:** Besides the Serious games section and the Azure Kinect Camera, connected to Unity 3D platform that allows the patient to play the games and complete their gait rehabilitation and training exercises, a web application was also developed. This section is the representative one that will build as a whole the final application developed, represented in section 4. This web application is named GaitVR and is intended exclusively for use by healthcare professionals and its principal objective is to be a reinforcement for them to directly access their patients' information, visualize their training data results in graphical representation, and actually make decisions about their health status.

   a. **Back End API:** Application developed with the ASP .Net Core programming language, directly connected to a remote MySQL database, which allows communications between all parts of the application. It also provides access to a very useful and important tool named Swagger that link directly to an https web page where is possible to test all the existing API methods created for the web application.

   b. **Front End API:** Server-side application built with Angular JS open-source framework for developing dynamic web applications [10]. This framework does a connection with the Back-End API and works as a platform for the health professionals to access to visualize all the necessary information

and results according to the trains performed in each session. This application is prepared to be used by two types of user's roles: Physiotherapists who can create/register patients, associate them to his patients list, visualize their results in a graphic type of form, and access to all their private information; and Administrators, the users who can have access to all of the other roles users and can create physiotherapists to start using the application. Patients won't have access to this web application for now.

4. **Web Application:** The junction Web Application between the Front-End development and the Back-End development. This Web application has a responsive design, which means that is ready to be used in the three types of devices: computers, tablets, and phones. It allows to health professionals to create patients type users, associate them with them and create the right training exercises for them. Each training exercise is composed by a set of metrics such as the name of the serious game, description of the game, how long it will be playing, whether it will have repetitions, and whether it is active or not. A patient will only be able to access the training if it is active. The patients will receive that information on Unity 3D platform, where they will perform and complete every training exercise.

IV. The Concept of Serious Games and System Games Description

Serious games are games with a purpose. They're designed to teach, build skills, and change behavior. They're used in education, business training, medical rehabilitation, and so much more. They're also a growing field in games development and are starting to become a serious sub-field of game studies all their own.

Virtual Reality based games [4] are becoming more accessible nowadays. There's no doubt that immersive gaming experiences are fun, but they can also be a great tool for keeping people healthy and engaged in their daily lives. Researchers are exploring the potential uses of virtual reality for treating mental health problems, helping people with disabilities maintain their independence and providing therapeutic experiences for people going through difficult times. The applications for VR are almost endless, and it only makes sense to invest in the technology today while it's still a relatively novel and affordable one.

Considering for this work and this research the physical rehabilitation of the lower limbs, four games were developed in Unity 3D multiplatform game engine:

1. **The Match Game:** The main objective of this game is for the patient to score as many goals as possible in the constantly moving target. To shoot the balls, the patient does not need to be in movement, but it is necessary that his feet and leg to move and apply force in the target direction (forward). The user wins a point every time a ball enters inside the moving target. The total score is defined as soon as the playing time is over.

   This game allows the physical therapist to collect several important metrics that will be significant in making a decision whether the patient is improving or not. The metrics taken from this game will be as follows: Angles formed by both knees (left and right), as the patient will be able to shoot the ball with either foot. It will also measure how fast he shoots the ball, the coordinate position in a 3D world of his feet's and also the maximum height his foot reaches (Fig. 3).

Fig. 3. The Match Game Interface.

2. **The Color Sequence Game:** This game is composed of four colored planes positioned on the ground. The player has to stand in the middle of them and move his feet following the right sequence that will appear on the screen. The main objective of this game is to follow the color sequence presented on the screen. The patient must then step on all the colored sequences in the correct order to gain points before the playing time is over. This serious game allows the physical therapist to collect several important metrics that will be significant in deciding whether the patient is improving or not. The metrics taken from this game will be as follows: The Positions of the feet, both left and right, the angle that the spine makes with the plane of space in order to measure the balance of the body and the speed determined by the number of points it accumulates and the sequences it finishes. This game is not only a serious game that serves for the rehabilitation of the gait and lower limbs, but also serves for the cognitive rehabilitation of the player since he will have to think how he will complete the sequence of colors, starting from his lower limbs (Fig. 4).

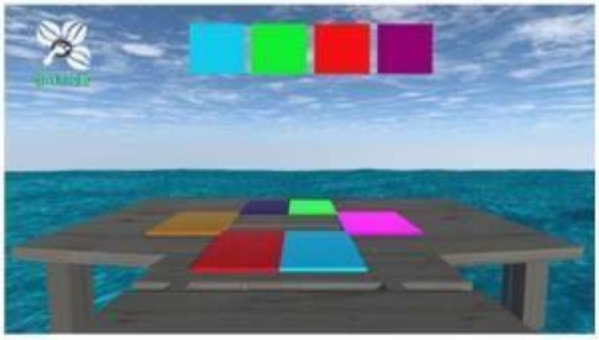

Fig. 4. The Color Sequence Game Interface.

3. **The Pipes Game:** The main objective of this game is for the patient not to let the pipes touch his head. The player will have to stay in the same place and reflect his knees every time the moving pipes are passing by him. The pipes appear at different heights so the user will need to reflect his knees to a greater degree every time that happens. The scenario of this game was created without 3D depth notion to be adaptable for people with cerebral palsy.

This serious game allows the physical therapist to collect important metrics that will be significant in deciding whether the patient is improving or not. The metrics taken from this game will be as follows: The most important metric which is the angle made by each of the player's knees, because they are the most accurate joints for this game. Speed will also be part of the metrics collected and will be measured according to the number of points accumulated by the end of the game (Fig. 5).

Fig. 5. The Pipes Game Interface.

4. **Magic Ingredients:** The main objective of this final game is to catch as many falling ingredients as possible in a constant movement. The user will have to be careful and dodge the bombs that can fall at any moment. He must earn as many points as possible before the game time runs out. The scenario of this game was created without any notion of 3D depth to be adaptable for people with cerebral palsy. This serious game allows the physical therapist to collect several important metrics that will be significant in deciding whether the patient is improving or not. The metrics taken from this game will be as follows: Positions of the feet, the speed that is defined by the amount of ingredients the player catches, the angle of the spine with the space in order to also measure the balance of the body (Fig. 6).

Fig. 6. Magic Ingredients Interface.

V. Web Application

The web application was developed and design as a functional tool to allow healthcare professionals to manage all the information and the results about the physiotherapy training sessions made by their patients. A real representation of the web application is shown in Fig. 7.

Fig. 7. Web application.

The application was developed in the Angular framework, always thinking always thinking about the use of the term user-friendly design. This platform then makes it possible for the health professional to have a space where he can review the entire rehabilitation process of his patients, create new patients, create the trainings for them, see all the information about the available games and visualize the results in the format of a graph in a more efficient way. The graphics were developed with a JavaScript library that allows the creation of dynamic and interactive graphics, called chart.js, where it will be possible to see more approximate values with informative tooltips, and also edit them.

VI. Results and Discussions

In order to test the developed system, preliminary tests were carried out with the principal objective to obtain some results and reach efficient conclusions. The tests were realized with 3 volunteers' participants, aged range between 23-59 years old, 2 females (25 years old and 59 years old) and 1 male (27 years old). The participants played two of the four serious games, in the software platform Unity 3D during approximately 1 minute (60 seconds), and all data were collected and saved in a global database every 3 seconds. The Match Game and The Magic Ingredients Game were tested.

Fig. 8 below displays (in a graphical representation) the behavior of the angles made by the user right and left knees during the playing time established for the test. By direct observation it's easy to see that the biggest variation of values happened in the right-angle knee, which means that the volunteer shot the ball with his right foot during the course of the game. The highest angle reached was a value of 77.5 degrees approximately.

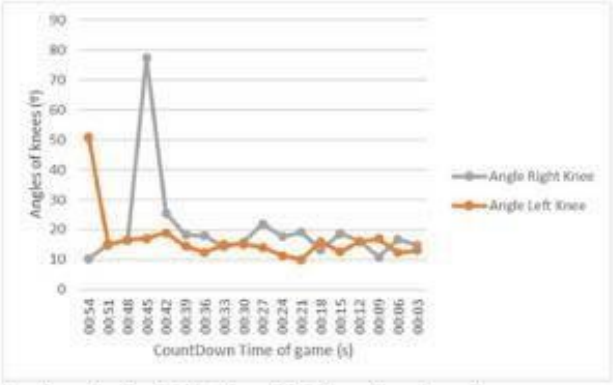

Fig. 8. Angle of both right and left knees along time of game.

Fig. 9 and Fig. 10 represent the height values reached by the player's foot represented also with an interval of every 3 seconds, and the comparison of two metrics of the serious game, the number of balls shot and the total score of the game. The tests conducted based on the Match Game and all the metrics and values extracted, will allow a physiotherapy health professional to acquire information in advance, in order to be able to monitor their patients more thoroughly, allowing for a more trained evaluation, which will enable patients to have a more efficient and faster motor recovery. And this will not only be in this game, but in the other 3 as well. The physiotherapists will be able to obtain not only the knee angles, the positions of the feet, but also metrics that allow them to understand the patient's balance (angle spine), possibly the pressure point of the patient, the speed, positions, flexibility and even values that result from cognitive rehabilitation.

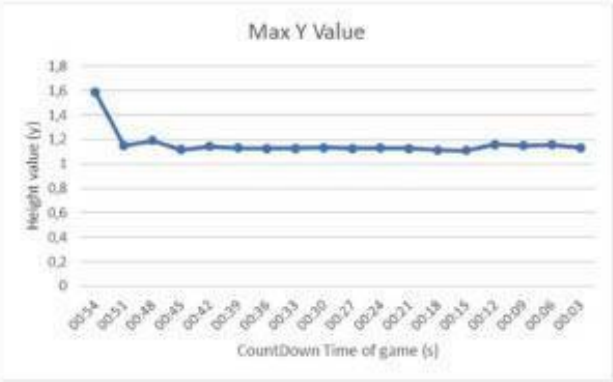

Fig. 9. Y values reached during time of game.

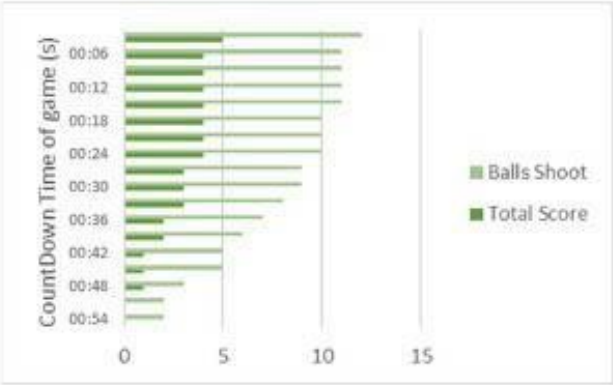

Fig. 10. Comparison of number of balls shot and the total score during time of game.

VII. Conclusions and Future Work

The presented solution has been proven to be a very efficient tool in both motor and cognitive rehabilitation of patients, who have been increasingly in need of help along the years. The proposed solution based on VR serious game give motivation for the users to follow the physical rehabilitation plans that are sometimes be very difficult and time consuming. Several game implementation and the validation with volunteers are reported. Thus, the rehabilitation of the gait and consequently the lower limbs using the developed Unity 3D software and the Azure Kinect as user natural interface prove to be a high accepted solution. Ongoing tests in clinics are carried out and additional metrics will be defined according with clinical feedback. Additionally, a web application was developed for the physical therapist side several tests being performed.

Acknowledgment

This research is supported by Instituto de Telecomunicações and ISCTE-IUL, Lisbon, Portugal.

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Appendix C – Games Scripts

InstaciateBalls.cs (The Match Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
public class InstanciateBalls : MonoBehaviour
{

    public GameObject myPrefab;
    public float ballVelocity;
    private GameObject ball;

    public void Start()
    {
        StartCoroutine(SpawnBalls());
    }

    IEnumerator SpawnBalls()
    {
        Instantiate(myPrefab, new Vector3(0, (float)0.05, 78),
Quaternion.identity);

        yield return new WaitForSeconds(10);
        StartCoroutine(SpawnBalls());

    }


}
```

MoveBaliza.cs (The Match Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class MoveBaliza : MonoBehaviour
{
    public float movementSpeed;
    private bool movingLeft;
    // Start is called before the first frame update
    void Start()
    {
```

```
        movingLeft = true;

    }

    // Update is called once per frame
    void Update()
    {
        if (movingLeft == true)
        {
            transform.position += Vector3.left * Time.deltaTime *
movementSpeed;
            // move left
            if (transform.position.x <= -30) movingLeft = false;
        }
        else
        {
            transform.position += Vector3.right * Time.deltaTime *
movementSpeed;

            if (transform.position.x >= 30) movingLeft = true;
        }


    }
}
```

ShootBall.cs (The Match Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class ShootBall : MonoBehaviour
{
    public GameObject instanciatedObject;
    public Rigidbody m_Rigidbody;
    public int ballVelocity;
    private Vector3 v= new Vector3(0,0,0);
    public float speed;

    private int NumberOfTouchsInBall = 0;
    public AudioSource shootSound;

    public Text namePatient;

    public void Start()
    {
        namePatient.text = PlayerPrefs.GetString("FullName");
```

```
    }


public void OnCollisionEnter(Collision collision)
    {

        if (collision.gameObject.name == "Ball(Clone)")
        {
            Vector3 direction = (collision.transform.position -
transform.position).normalized;
            v += new Vector3(0f, ballVelocity, 0f);

            shootSound.Play();

collision.gameObject.GetComponent<Rigidbody>().AddForce(Vector3.forward *
ballVelocity, ForceMode.Impulse);

            NumberOfTouchsInBall++;

            PlayerPrefs.SetInt("NumberBalls", NumberOfTouchsInBall);
        }
    }

}
```

GameScript.cs (The Color Sequence Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class GameScript : MonoBehaviour
{
    public GameObject square1;
    public GameObject square2;
    public GameObject square3;
    public GameObject square4;

    public Image panel1;
    public Image panel2;
    public Image panel3;
    public Image panel4;
```

```
    public Image rightImag1;
    public Image rightimage2;
    public Image rightimage3;
    public Image rightimage4;

    public AudioSource colorRight;
    public AudioSource sequenceRight;

    public Text points;
    public int totalScore;
    public Text username;



    public List<Color> SquaresList;
    public List<Color> PanelColorList;
    void Start()
    {
        username.text = PlayerPrefs.GetString("FullName");
        totalScore = 0;
        points.text = totalScore.ToString("00");

        SquaresList.Add(square1.GetComponent<Renderer>().material.color);
        SquaresList.Add(square2.GetComponent<Renderer>().material.color);
        SquaresList.Add(square3.GetComponent<Renderer>().material.color);
        SquaresList.Add(square4.GetComponent<Renderer>().material.color);

        panel1 = GameObject.Find("color1").GetComponent<Image>();
        panel2 = GameObject.Find("color2").GetComponent<Image>();
        panel3 = GameObject.Find("color3").GetComponent<Image>();
        panel4 = GameObject.Find("color4").GetComponent<Image>();

        rightImag1 = GameObject.Find("RightImage").GetComponent<Image>();
        rightimage2 =
GameObject.Find("RightImage2").GetComponent<Image>();
        rightimage3 =
GameObject.Find("RightImage3").GetComponent<Image>();
        rightimage4 =
GameObject.Find("RightImage4").GetComponent<Image>();


        rightImag1.color = Color.clear;
        rightimage2.color = Color.clear;
        rightimage3.color = Color.clear;
        rightimage4.color = Color.clear;



        panel1.color = RandomlistColors(SquaresList)[0];
```

```
        panel2.color = RandomlistColors(SquaresList)[1];
        panel3.color = RandomlistColors(SquaresList)[2];
        panel4.color = RandomlistColors(SquaresList)[3];



    }

    public List<Color> RandomlistColors(List<Color> listColors)
    {
        for (int i = 0; i < listColors.Count; i++)
        {
            Color temp = listColors[i];
            int randomIndex = Random.Range(i, listColors.Count);
            listColors[i] = listColors[randomIndex];
            listColors[randomIndex] = temp;
        }
        return listColors;
    }


    public void OnTriggerEnter(Collider other)
    {
        if(other.gameObject.GetComponent<Renderer>().material.color ==
panel1.color)
        {
            colorRight.Play();
            rightImag1.color = Color.white;

        }

        if (other.gameObject.GetComponent<Renderer>().material.color ==
panel2.color)
        {
            colorRight.Play();
            rightimage2.color = Color.white;
        }

        if (other.gameObject.GetComponent<Renderer>().material.color ==
panel3.color)
        {
            colorRight.Play();
            rightimage3.color = Color.white;
        }

        if (other.gameObject.GetComponent<Renderer>().material.color ==
panel4.color)
        {
            colorRight.Play();
```

```
            rightimage4.color = Color.white;
        }

        if(rightImag1.color == Color.white && rightimage2.color ==
Color.white && rightimage3.color == Color.white && rightimage4.color ==
Color.white)
        {

            sequenceRight.Play();
            totalScore++;
            points.text = totalScore.ToString("00");
            PlayerPrefs.SetString("TotalScoreColors",
totalScore.ToString());
            rightImag1.color = Color.clear;
            rightimage2.color = Color.clear;
            rightimage3.color = Color.clear;
            rightimage4.color = Color.clear;
            panel1.color = RandomlistColors(SquaresList)[0];
            panel2.color = RandomlistColors(SquaresList)[1];
            panel3.color = RandomlistColors(SquaresList)[2];
            panel4.color = RandomlistColors(SquaresList)[3];

        }


    }
}
```

ScoreController.cs (Magic Ingredients Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.SceneManagement;
using UnityEngine.UI;

public class ScoreController : MonoBehaviour
{
    [SerializeField] public Text pointsText;
    [SerializeField] public Text cheeseText;
    [SerializeField] public Text TomatoText;
    [SerializeField] public Text NameUser;

    public static int points;
    private int ingredientsCatchTomato;
    private int ingredientsCatchCheese;

    private Spawner spawnerIngridients;
```

```
public AudioSource winPoint;
public AudioSource lostPoint;

private void Start()
{
    NameUser.text = PlayerPrefs.GetString("FullName");
}


public void Update()
{
    pointsText.text = points.ToString();
    cheeseText.text = ingredientsCatchCheese.ToString();
    TomatoText.text = ingredientsCatchTomato.ToString();

    PlayerPrefs.SetString("FinalScore", points.ToString());
    PlayerPrefs.SetInt("ScoreTomato", ingredientsCatchCheese);
    PlayerPrefs.SetInt("ScoreCheese", ingredientsCatchTomato);







}

public void OnTriggerEnter(Collider collision)
{

    if (collision.tag == "Ingridient")
    {
        winPoint.Play();
        Destroy(collision.gameObject);

        points++;
        if (collision.name == "RightTomato(Clone)")
        {
            ingredientsCatchTomato++;
            points++;
        }
        if (collision.name == "cheeseGame(Clone)")
        {
            ingredientsCatchCheese++;
            points++;
        }

    }
```

```
        if (collision.tag == "Bomb")
        {
            lostPoint.Play();
            Destroy(collision.gameObject);

            points--;
        }
    }
}
```

Spawner3d.cs (Magic Ingredients Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class Spawner3d : MonoBehaviour
{
    public GameObject[] ingridients;
    public GameObject bomb;
    public GameObject speed;




    public float x, y;
    // Start is called before the first frame update
    public void Start()
    {
        StartCoroutine(SpawnRandomGameObject());

    }



     IEnumerator SpawnRandomGameObject()
    {
        yield return new WaitForSeconds(Random.Range(3, 4));
        int randomIngridients = Random.Range(0, ingridients.Length);

         if (Random.value <= .6f)
        {
            Instantiate(ingridients[randomIngridients], new
Vector3(Random.Range(-x, x), y, (float)1.0), Quaternion.identity);

        }
```

```
        else
        {

            Instantiate(bomb, new Vector3(Random.Range(-x, x), y, 1),
Quaternion.identity);


        }
        StartCoroutine(SpawnRandomGameObject());
    }


}
```

InstantiatePipes.cs (The Pipes Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class InstantiatePipes : MonoBehaviour
{
    //public float speed;
    public GameObject myPrefab;
    public GameObject myPrefab2;
    public float x,y;
    private GameObject v;
    public GameObject avatar;


    // Start is called before the first frame update
    void Start()
    {
        StartCoroutine(SpawnPipes());
    }


    IEnumerator SpawnPipes()
    {
        Instantiate(myPrefab, new Vector3((float)1.5,
Random.Range(y,(float)4), -1), transform.rotation * Quaternion.Euler(90f,
180f, 0f));

        yield return new WaitForSeconds(Random.Range(2, 3));
        v = Instantiate(myPrefab2, new Vector3(Random.Range((float)-0.5,
2), (float)1.5, -1), transform.rotation * Quaternion.Euler(0f, 0f, 0f));
        Destroy(v, 3);

        StartCoroutine(SpawnPipes());
```

```
    }
}
```

movePipes.cs (The Pipes Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

public class movePipes : MonoBehaviour
{
    public float speed;

    void Update()
    {
      transform.position += Vector3.left * speed * Time.deltaTime;
    }
}
```

scorePipe.cs (The Pipes Game)

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using UnityEngine.UI;

public class scorePipe : MonoBehaviour
{
    [SerializeField] public Text pointsText;
    [SerializeField] public Text userName;
    public AudioSource lostPoint;
    public AudioSource winPoint;
    public GameObject avatar;
    public GameObject pipe;
    public static int points;


    void Update()
    {
        pointsText.text = points.ToString();
        userName.text = PlayerPrefs.GetString("FullName");
    }


    public void OnTriggerEnter(Collider collision)
```

```
    {
        if (collision.tag == "Pipe" )
        {
            lostPoint.Play();
            points--;

        }


        if (collision.tag == "Star")
        {

            winPoint.Play();
            Destroy(collision.gameObject);
            points +=2;
        }

    }
}
```