FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

PhysicTV: Motion-based physical rehabilitation games for the GoogleTV

Nuno Matos

U.PORTO

FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

Mestrado Integrado em Engenharia Informática e Computação

Supervisor: Rui Pedro Amaral Rodrigues (PhD)

July 11th, 2013

PhysicTV: Motion-based physical rehabilitation games for the GoogleTV

Nuno Matos

Mestrado Integrado em Engenharia Informática e Computação

Approved in oral examination by the committee:

Chair: António Augusto de Sousa (PhD)

External Examiner: Pedro Miguel do Vale Moreira (PhD)

Supervisor: Rui Pedro Amaral Rodrigues (PhD)

July 11^{th}, 2013

Resumo

As sessões de reabilitação e fisioterapia são imprescindíveis para tratar lesões e readquirir alguns movimentos básicos que, antes da lesão, eram realizados sem limitações. No seu formato tradicional essas sessões decorrem numa clínica ou centro de saúde e envolvem a repetição de movimentos que exercitem a parte do corpo a tratar. Com a constante repetição desses movimentos essas sessões tendem a tornar-se pouco inovadoras e dinâmicas, resultando num desinteresse por parte do paciente que está lesionado e ainda se encontra num ambiente pesado e desencorajador. Estes fatores podem conduzir a um aumento da desmotivação ao longo do processo de reabilitação, levando a que os pacientes apenas queiram terminar a sessão para ir para casa, deixando de ter em conta se o seu processo evolutivo está a ser positivo.

Assim, a inclusão dos jogos eletrónicos desenvolvidos que englobam os movimentos habitualmente utilizados nas sessões de fisioterapia pode ser vista como um fator extra de motivação, permitindo ao paciente encarar o seu processo de reabilitação de uma outra forma e tornando as sessões mais dinâmicas e positivas, que resultará na satisfação do fisioterapeuta e do seu paciente. O desenvolvimento de um sistema, composto por um sensor de movimentos, uma GoogleTV e uma televisão, que suporta esses jogos permitirá também a implementação de um método para capturar os ângulos nos movimentos do utilizador, para que o fisioterapeuta possa dar o seu aval relativamente à evolução do paciente. Assim, o sistema pode funcionar como um complemento à missão do fisioterapeuta de ajudar os pacientes a recuperar de os avaliar.

Para que tudo isto pudesse ser feito, houve um acompanhamento por parte dos fisioterapeutas no levantamento de requisitos a nível de movimentos e medidas para a sua avaliação, para que os jogos fossem posteriormente criados e desenvolvidos para serem utilizados em contexto profissional tal como a fase final de testes comprovou.

Abstract

Rehabilitation and physiotherapy sessions are essential to treat injuries and regain some basic movements that were performed without limitations before the injury. Traditionally those sessions take place in a clinic or health center and involve repeating movements that exercise the part of the body under treatment. The constant repetition of these movements tend to make the sessions less innovative and dynamic, which leads to the loss of interest of the patient who is injured, and in addition is in a heavy and discouraging environment. These factors can lead to an increased demotivation throughout the rehabilitation process causing patients a willingness to finish the session and go home, without having in mind if their evolutionary process is going well.

So, the inclusion of the developed eletronic games that include movements normally used in physical therapy can be seen as an extra factor of motivation, allowing the patient to face his rehabilitation process in a different way and making sessions more dynamic and positive, which leads to the satisfaction of both physiotherapist and patient. The development of a system, composed by a motion sensor, a GoogleTV and a television, that supports these games also allowed the implementation of a method to capture the angles made by the user when performing movements, so the physiotherapist can evaluate the evolution of his patient. Thus, the system can be seen as a complement for the physiotherapist mission of helping the patients recovering and evaluating them.

In order to make all this possible there was an accompaniment of the physiotherapis when making a survey of requirements about movements and their evaluation measures, so the games could be subsequently created and developed to be used in a professional context as the final testing phase proved.

Acknowledgements

In spite of having just one name in the *Author* field this dissertation had a contribution of some people who have the right of being recognized for that.

First I would like to thank Professor Rui Rodrigues for all his comments and suggestions to improve this project. His guidance proved to be very helpful throughout the dissertation and made me see what and where I could do better.

Then, a special thanks to my supervisors at Fraunhofer: João Sousa and Ana Vasconcelos. More than supervisors they were my friends. They accompanied me during this period of almost five months and helped me in everything I needed even when they were busy with other projects.

An honour mention the physiotherapist Alexandra Couto who helped me at the beginning of this dissertation and kept giving me feedback on the project. She has also been tireless in helping during the testing day and was ready to help in whatever I needed and ensuring that there were plenty conditions to perform the tests.

Last, but not the least, I would like to thank to my family and friends for supporting me whenever I needed and for being there not only when things were good but especially when things were not going so well.

Nuno Matos

Contents

List of Figures

LIST OF FIGURES

List of Tables

LIST OF TABLES

Abbreviations

AAL	Ambient Assisted Living
AICOS	Assistive Information and COmmunication Solutions
CRPG	*Centro de Reabilitação Profissional de Gaia*
IREX	Interactive Rehabilitation and EXercise system
ISO	International Organization for Standardization
SUS	System Usability Scale

Chapter 1

Introduction

The rehabilitation of patients, as we know it, involves a recovery process whose duration depends on the severity of the acquired lesion and the ability of the patient's body to recover from the injury. An injury may take many months to heal which can lead to a loss of confidence of the patient to see the recovery taking so long, depending on the psychological profile of the patient [Lew90].

Regarding electronic games, their main goal is to entertain the players by presenting them challenges and goals to achieve. The traditional format of this type of games consists of a device (mouse, keyboard or a controller) that allows the user to play the game on a computer or television screen. The motion-based electronic games are slightly different from the other kind of electronic games because they are played with body movements from the user. This aspect is crucial to include these games within the rehabilitation context.

While moving a part of the body to play the games the patients are at the same time exercising that part of the body. The main goal of including electronic games in the recovery process of a patient is to increase his motivation to face every session [Kat10] and to give him a small distraction while performing the movements.

1.1 Context

The theme of this dissertation is placed in the context of physiotherapy and electronic games and was proposed by *Fraunhofer AICOS* Portugal, a research center located in the city of Porto. The combination of these two subjects can be also considered as a major part of the project because its main goal is the development of electronic games targeted for physical therapy and to be included in rehabilitation sessions in various healthcare centers.

1.2 Goals and Motivation

The purpose of this project's theme is to improve the rehabilitation process in health centers or clinics by combining technological inovations with a set of advantages inherent in including electronic games in this context. Its main goal is the conception and development of a low-cost and motion-based platform that can be used at the patient's home, supports electronic games and allows the user to play them in a television screen.

As mentioned above, the platform will have a technological component which involves the unprecedented integration of two technologies (Asus XtionPRO LIVE and GoogleTV, subsequently described) enabling the full operation of the system and ensuring an innovation side for the project. The interaction with this system is dependent on the movements of the patient and its purpose is to capture and analyze them in a way they can be interpreted by the physiotherapist who will give his judgement about the success of the patient in the sessions and throughout the rehabilitation process.

With a completely dynamic platform and thanks to the inclusion of physiotherapy games, it is expected to change the way the patient faces his sessions and to facilitate the work of the physiotherapist. The development of these games is another goal of the dissertation. It is imperative that the games are targeted to physiotherapy, with a set of movements and rehabilitation metrics that are defined by health professionals. The collaboration with physiotherapists is another of the innovative aspects of this project, because that ongoing communication brought validity to the entire system so it can be used in professional context.

In the end, to evaluate the system, there was a set of tests with physically fit users and rehabilitation patients in order to evaluate the usability and effectiveness of the developed games. The tests with real patients allowed the evaluation of their performance when executing the exercises included in the games and their acceptance of this type of therapy so it can be analyzed and compared with the traditional therapy.

1.3 Contributions

Regarding the contributions, this project aims the development of electronic games to be run on the GoogleTV and completely targeted for physiotherapy. In addition this project also aims to create a low-cost and easy to use platform, consisting of several technological components, so the patients can play the games and perform physiotherapy exercises in the confort of their home.

1.4 Dissertation Structure

Besides this introduction chapter, the dissertation contains other five chapters.

Chapter 2 describes this theme's state of the art by presenting some projects and related work and outlines the characteristics of the devices that will make this project. Chapter 3 gives an overview of the project, outlining its architecture, enumerating the advantages and summarizing interviews with physiotherapist professionals for requirements elicitation.

Chapter 4 explains the details of the implementation such as the client-server architecture, the system's operation, the information and messages that are exchanged, among other aspects. Chapter 5 shows the results obtained from the tests as well as the evaluation of the system and its impact in the tested environment.

Lastly, Chapter 6 presents a brief discussion of the previous chapters and the project in general, the main conclusions of the work particularly about the fulfillment of the objectives and suggestions for future work and a reflection on the contribution of this project. There are also included the bibliographic references used as a basis for the developed project and the appendix section containing, in greater detail, some additional information regarding the project, such as an interview made in the initial phase of the project, the questionnaire performed after the tests and some prototype and testing data.

Chapter 2

State of the Art

This chapter contains an analysis of the existing concepts and projects that are related to the context of this dissertation. First, in Section 2.1 there will be a list of projects with the same goal of this dissertation, that is, to help patients to improve not only their physical condition but also their experience during rehabilitation sessions.

Then, Section 2.2 presents a brief description of the technologies that are part of this project, mostly about their characteristics, as well as a comparison with other possible alternatives. Finally, in Section 2.3 there will be an analysis of the global opinion about the inclusion of electronic games in rehabilitation processes.

2.1 Similar Platforms and Projects

2.1.1 VirtualRehab

VirtualRehab is a platform created by VirtualWare in association with the *Fundación de Esclerosis Múltiple Eugenia Epalza* (Eugenia Epalza Multiple Sclerosis Foundation) [Vir13a], developed for PC and implying the use of Kinect, a Microsoft product. It was created to be used in a context of physiotherapy and physical injuries rehabilitation and due to its nature and goals it is the most similar project to this dissertation. Through the Kinect, it is possible to perform specialized exercises, by allowing the capture of movements and simulating a 3D environment which can improve the user experience. These exercises have as a main goal the future rehabilitation of the patients, focusing particularly on the balance, coordination, weakness, fatigue and spasticity.

This product has benefits for the physiotherapist by providing graphics that represent the rehabilitation progress of the patients, customizable therapy sessions given the patients' state and/or injury grade, analysis and monitorization of the patients movements, patients' personal information management, among other features. The aspects of motivation and challenge as well as the usability and availability for any injury represent the greatest advantages of the system. Technologically the possibility of remote control and online access to the system is highlighted, which enables the clinic to always have an access point for this platform, allowing any qualified health

Figure 2.1: User performing a VirtualRehab exercise [Vir13b]

professional to access and use its features. Besides, it is a reliable and safe system by requiring an user name and password.

The real world establishment of this platform is already considerable, taking into account that some clinics such as Multiple Sclerosis Association from Madrid and Albacete have already acquired it. Any institution or clinic that wants to use this platform has to purchase a license that implies a monthly payment of 2,5 euros for patient and a minimum of 100 patients.

The existing exercises should not be too complex nor hard to perform. One of these exercises for this product consists in intercepting a ball that goes in a random direction and should be captured by the patient using the movement of the arms or legs, as it is possible to see in the Figure 2.1.

2.1.2 Kinerehab

This project is a Kinect-based platform that aims to help the therapists working with students in public schools [YJC11]. It uses the Microsoft Kinect to track the user's joints and movements and uses the obtained data to evaluate whether their condition has improved or not, if they need more therapy sessions or more exercises, etc. The interface of Kinerehab was created in order to be attractive, so it enhances students' interest and motivation to face physiotherapy sessions, but also useful for the therapist as the system records some details regarding students and their progress over time.

The project itself takes advantage of the inclusion of Kinect in its architeture to change the routine of students in the sessions, i.e., the main objective of Kinerehab is not to develop games specifically for the movement sensors of Kinect but to record the performance of the students when doing regular physical exercises like lifting both arms to the front, among others.

Figure 2.2: Nintendo Wii remote controller (Wiimote) [WR]

2.1.3 WiiHabilitation

The *WiiHabilitation* represents a NintendoWii concept completely targeted for rehabilitation. Although it does not consist in an independent product and specifically developed for the mentioned purpose, the fact that it uses the existing games enables the inclusion of this platform in a list of projects related to the physiotherapy context [Red11b, STKRR09]. Despite requiring user movements that can be applied to a rehabilitation context the NintendoWii games are meant to entertain the users.

Although the system allows a type of interaction partially similar to Kinect, that is, through a small device the user movements are captured and allow him to interact with the system, there are two main differences between this device and the Microsoft's: the first one is the fact that the user has to hold one or two controllers (Figure 2.2) in his hands while performing the movements, as opposed to Kinect, where the motion capture is performed only by the natural movements of the body, and the second one is that the Kinect can track the whole body of the user while this device can only track the user's arms.

So, the main goal of WiiHabilitation is to take the existing games in the actual market and use them to rehabilitation purposes [AAB10]. Each game, with its levels and objectives, focuses in a particular part of the body or a more global aspect, such as the balance or the reaction speed. The two most famous and with greater adherence in the market are WiiSports and WiiFit.

WiiSports

As the name implies, this game simulates a variety of sports, like boxing, bowling or tennis. These games are easy to understand and with the necessary movements to perform the exercises, the patient can improve his precision, arm strength, timing, among other aspects [Red11c]. However, the only feature that can distinguish the different injury states is the dificulty level of the exercises, that is, there are three different levels that can be chosen but in a professional rehabilitation context may not be enough to differentiate patients who have similar injuries but are in different recovery phases. This aspect should be taken into account by the physiotherapist knowing that a simple change of level may represent a huge difference in the patients' success to perform movements and consequent recovery.

WiiFit

This game contains a set of aerobic and yoga movements and some mini-games, which make the WiiFit suitable for the patients' recovery. These movements, when applied in a context of professional rehabilitation, enable a muscular, motor coordination, timing and notion of space improvement and should be supervised by the physiotherapists. The WiiFit can also function as a small database for the patients, because the results in every game are stored in each profile and they can be verified anytime allowing a very reliable analysis on the evolution of the patients over time [Red11a, SWEBB09].

2.1.4 IREX

IREX is an interactive virtual reality exercises system, developed by GestureTek, allowing a therapy and rehabilitation focused in some parts of the body. There is a set of mini-games that require movements and exercises to improve the ability to rotate, balance, timing, among other aspects, allowing the physiotherapist to evaluate the performance and evolution of his patient [Gesa].

One of the characteristics of the system that makes it successful is the fact of making the rehabilitation process more motivating and less monotonous for the patient. On the one hand it is similar to other existing platforms, on the other hand it is different in the way of interacting with the system and performing exercises. While the interaction with Kinect and NintendoWii is made through a small device and the simulated environments are shown on the television screen, the IREX demands the presence of a green panel, placed behind the user, from which the existing system camera rebuilds the scenarios (Figure 2.3) so that the patient can achieve the goals of a specific game or level [WT12, BMC^{+}09]. If the therapist wants to focus on a particular area of the patient's body he can use an object with a distinct color (for example, a red glove for the right hand or a red hat for the head) on the area of the body to treat [WK09].

So, knowing the technological characteristics of the system, the IREX is more suitable for permanent installations, that is, it is not easy to carry from room to room in a clinic and that is a disadvantage comparing with similar technologies.

2.1.5 Immersive Therapy Suite

Also developed by GestureTek, the Immersive Therapy Suite is a small and portable system that is normally used in hospitals and physiotherapy clinics because it can be carried by the healthcare professionals through halls and rooms of patients with reduced mobility [Gesb]. It is composed of a small television that exhibits the simulated environment and by a camera that captures the user movements.

In spite of being small (Figure 2.4), it contains a considerable amount of exercises and movements that can motivate the patient and allow the physiotherapist to get his feedback of the sessions

Figure 2.3: IREX environment [Vin10]

and the performance of their patients. Thanks to the flexibility of the GestureTek's software, this system is also suitable for patients with lower mobility allowing them to get positive results in the performance of exercises.

Within all the existing games for this system there are present some sports, mini-games, music creation and replication games, simulation of relaxing environments, among others. This wide range of possibilities given to the physiotherapists keeps the session dynamic and the patients motivated and challenged.

2.2 Devices

This section contains a description of the devices of PhysicTV as well as a comparison between them and some alternatives.

2.2.1 GoogleTV

GoogleTV (Figure 2.5a) is a small box that allows the use and exploitation, on a television, of the services provided by Google, such as music or video visualization on Youtube or the access to the market of applications and programs, known as Google Play. This device also allows the installation of programs and applications for Android. However, depending on its processing capacity the installed applications may have some problems when running and some of their features limited.

The integration of this device is simple (Figure 2.5a) and allows the user to control its functionalities from the television controller or a mobile phone. There is still another technology variant that consists on the full integration of the system in a television (Figure 2.5b), that is, dropping the small box but keeping all the features and controlling possibilities. These two possibilities exist taking into account the two prototypes developed by Google [Goo13].

This project will use the first alternative where the small box is plugged in a television and is connected to a laptop. The games are installed and run in the GoogleTV as a normal application and do not require any changes in the settings of the device.

Figure 2.4: Immersive Therapy Suite device [Tek]

2.2.2 Motion Capture Devices

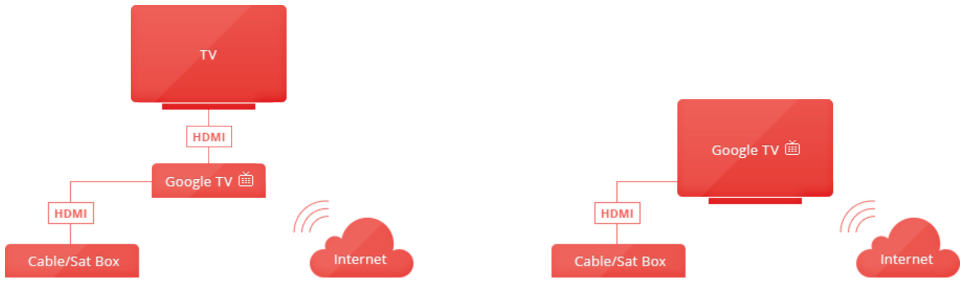
Of all the motion capture devices available in the market there were two specific that were chosen for this project: Kinect and Asus XtionPRO LIVE. The criteria considered were the price, usability and support offered as a development platform. This section describes some of their characteristics and specifications.

Kinect

Kinect is a device developed by Microsoft that, through its sensors (RGB camera and Depth sensor), has the goal of capturing the movements of the user. That capture can be made by the device until a distance of four meters [Mic12] and allows the interaction between the user and the system without using a controller, a keyboard or another auxiliary device. There are two platforms that support the Kinect: Xbox 360 and Windows (Figure 2.6).

Figure 2.6: Kinect for Windows [gdg]

When this technology was launched it had a huge impact in the market, by exponentially increasing sales in favor of Microsoft [Mic11]. So, taking in account the increasing number of users, people became more familiar with the technology and its functionalities. Thus, given the nature of the Kinect and the movements necessary for its usage, it has been considered useful and adequate to include it in the field of health, more specifically, in the area of rehabilitation and physiotherapy. By requiring users to constantly move their bodies, this device implies physical exercise, specially in sports' simulating games. Given this context, the use of Kinect is still viable because although there are no games with rehabilitation exercises or specialized movements, any game could simulate a rehabilitation session, according to the responsible healthcare professional's preferences [VFML04].



(a) GoogleTV with a small box (b) GoogleTV integrated

Figure 2.5: GoogleTV models [Goo13]

Asus XtionPRO LIVE

XtionPRO LIVE is a product of Asus and works as a motion sensor with a basis technology similar to Kinect. The device connects to a computer and is immediately operational and also gives a very good software development solution. This device is small and portable (Figure 2.7), only used in indoor environments, has a depth sensor and a range between 0.8 and 3.5 meters [Asu13].

2.3 Global Acceptance

Like the technological aspect, the human aspect is also very important for a project in this context because its success is dependent of the physiotherapist acceptance and the adaptation of the patients. Globally, the inclusion of technologies in the therapeutical process is well accepted but there are some healthcare professionals against that idea [SWY+11] and, for patients, there are examples of people who did not respond well to performing these exercises, either by not understanding the interaction with the technology or by not liking to take the sessions in this way [GSM+09].

However, the satisfaction and the results are generally positive [BMC+09, LCS+11a, Pap09, GSM+09] and with the increase of technological evolutions, it is predictable that the implementation of these games into the physiotherapy will grow and they will become more influent over time, due to the significant improvements occuring in this field.

Figure 2.7: Asus XtionPRO LIVE [Asu13]

Chapter 3

Overview of the Solution

In the scope of this project, physiotherapy and rehabilitation, there are some problems that this project aims to solve. Starting with the mobility aspect, is relevant to say that usually people under physiotherapy sessions may have their mobility reduced and, consequently, great dificulties in moving to the clinic to perform their sessions with the healthcare professional.

Another aspect that can represent a problem is the cost associated with the physiotherapy. A possible solution for the mobility issue could be the change of place of the rehabilitation sessions: from the clinic to the patient's home. However, that solution would result in an increased cost and, given the actual economic reality, that consequence would become unsustainable for the majority of people in need of physiotherapy [BMC+09].

Finally, the last problem to consider is the motivational aspect. In addition to the injury itself, the patient still has to face a recovery process, very long sometimes, where the exercises are usually very repetitive and boring [STKRR09]. All these factors cause the patient to feel discouraged during the whole process and could lead to the unexistance of significant improvements and positive evolution [VFML04]. It affects the patient but the physiotherapist has also his work hampered by dealing with patients unwilling to perform the exercises.

Considering the characteristics of some of the existing projects in this context and the related problems, the development phase of this project started with the definition of a viable solution. The first step was to determine the target audience of PhysicTV and to do this we chose to define personas in order to help filter out potential users and thus get some more specific details. The details of the profile of the defined personas were added after a first contact with professional therapists that helped to clarify which aspects should be considered in the context of this project. Once defined the personas, the development of the architecture of the system could start by establishing a good communication protocol and then start developing the electronic games.

This chapter gives an overview of the project, about its architecture, functioning and advantages and also about the predicted evaluation methods for the system, finishing with a brief summary of the requirements established in the interview made to two healthcare professionals from the *Centro de Reabilitação Profissional de Gaia* (CRPG).

3.1 Personas

When it comes to designing and gathering all the requirements for the game development, one of the main aspects to consider is the target audience of the game and their physical and psychological profile so that the game can have a valid use. Since one of the characteristics of the physiotherapy is the large of number of injuries that can be treated, trying to cover all of them would result in a more complex project and in an infinite definition of movements considering the freedom of the physiotherapist when creating those movements. So, it is important to limit that range of movements by specifying a set of movements to be included in the game and a group of injuries or physical limitations the game will try to deal with.

This section serves to introduce the concept of personas. A persona is a technique used in the human-computer interaction that works as a model of an user trying to define which are his goals when using the system [Blo02, CLS08]. Firstly introduced by Cooper [Coo99, Coo08], the personas were created not to represent one user nor a group of users but to include the goals and motivations of a potential user by creating a brief description of a fictional user [Blo02] and were based not only on user studies but also on the experience of the designers [CLS08, Ant08].

3.1.1 Characteristics

Although it is not about real people, a persona should have human related details such as a name, age, picture, and other personal details to be as close to reality as possible because they will represent them during the entire process of design, and should be always defined by its goals. By being a design tool a persona is unique for the domain and the context it was created and considering its influence in the game design definition, each persona has a different status: primary, if the persona must be satisfied and can not be satisfied with another user interface, secondary, supplemental, served and negative. All projects have to have at least one primary persona because it needs a specific interface and the design definition revolves around it, i.e., if a project has two or more primary personas then it also should have two or more designs, each one specifically created for a different persona [Blo02].

3.1.2 Advantages

The process of creating personas allows the designer to have a better perspective of the requirements and the specifications when creating a system by focusing on users and their made up details. The details of each persona give a better notion of the target audience so it is possible to improve the ability to make assumptions and to help establishing to whom those decisions were made, i.e., it helps to determine if a design is being created for a type of users or not [PG03].

3.1.3 Risks

One of the main risks associated to the creation of personas is the great challenge of successfully create one that can be exactly representative of a certain type of users. Since a persona will guide the decision making about some design aspects and will be used as a filter regarding the users to whom the game is directed, there can also occur an overuse of the created personas when a simpler solution would be changing some of them [PG03].

3.1.4 Jack

In this project Jack is the primary persona because he is a potential rehabilitation patient to use the application. His story is described below.

Jack

Background

Jack is a 35 year old man who likes to be with his friends and to go to the gym. Unfortunately, he had an accident at his workplace while trying to move a printer and now he has trouble moving his right arm. Since his work involves a lot of interaction with the computer he was afraid of not being able to work properly and that his boss could fire him, but when he went to talk to him he got full support and the permission to work with the possible pace.

Goals and Motivations

In addition to the goal of simply being 100% fit, Jack wants to thank his boss by getting to the normal work rate as soon as possible. Besides, he also wants to get back to the gym and be able to restart his plan of exercises. Since he is a very active person and likes to be challenged, Jack does not want to fall in the usual boredom of physiotherapy exercises and would like to do something different and more innovative.

3.1.5 Susan

In this project Susan is a secondary persona because she is not the main target of PhysicTV. She is a physiotherapist who treats several upper-body injuried patients and her details are described below.

Susan

Background

Susan is a 48 year old physiotherapist woman who works in the same healthcare center for over 20 years. In addition to treating patients, Susan has also directed some student internships which shows her importance in the clinic. She considers herself an open-minded person who likes to apply new rehabilitation techniques and is receptive to suggestions.

Goals and Motivations

With a lot of technological innovations happening in the field of rehabilitation Susan is willing to try to include something new in the sessions with her patients. Thus, Susana is looking for a system that helps her in the management of the details of her patients and that includes games for them to play.

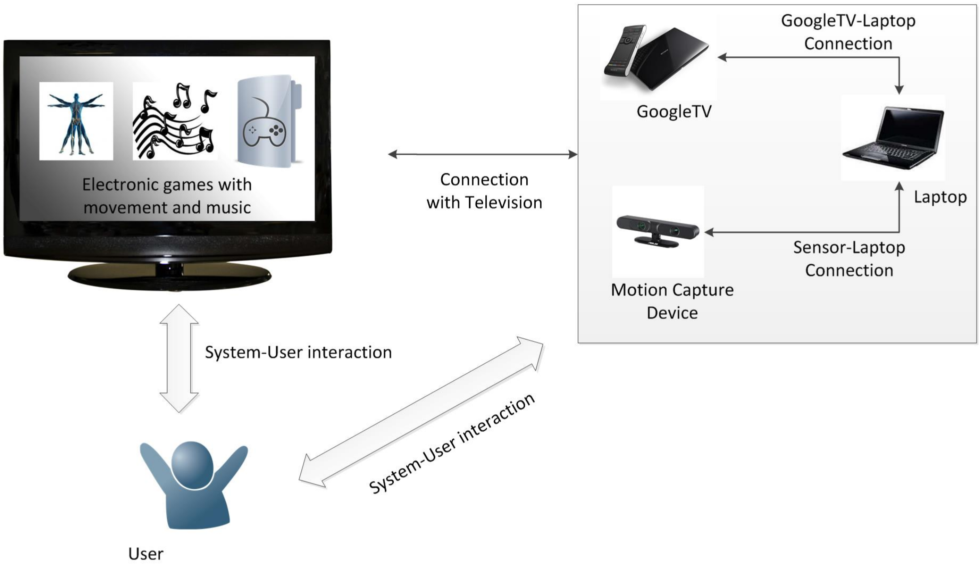


Figure 3.1: PhysicTV

3.2 PhysicTV

PhysicTV[1], consists in a platform, illustrated in the Figure 3.1, composed by two main devices, targeted for the physiotherapy and supporting electronic games developed for being used in rehabilitation sessions. This platform should be used by physiotherapists when supervising the sessions with their patients, but it can also be used in the patients' home, by being easily transported and assembled.

3.2.1 Advantages and Innovations

As previously mentioned, there are three main issues associated to physiotherapy and rehabilitation that this dissertation will try to tackle. By being able to be used at the patients' home, the mobility problem can be effectively countered. The registry of performances in every session keeps the execution of the exercises medically valid and supervised by the physiotherapist even if they are being performed from the patients' domicile [STKRR09].

Financially this solution could become more economic in medium/long term. The acquisition of the Asus XtionPRO LIVE and GoogleTV is relatively affordable and since they can be used during a long period of time, there is a cost only at the beginning. Finally, the motivation aspect, already discussed, is the better solved issue because, either at home or at the clinic, the patients' obligation is to perform a set of exercises and including a game, a challenge or a goal can function as a catalyst for the recovery process by making the patient more motivated to improve his previous performances, ending up to get improve faster or at least make the process less irksome [VFML04, Pap09].

[1] *Physic* (related with the physical aspect) + TV (related with the technological aspect)

One of the main innovations of the project is the fact of the platform is fully targeted for physiotherapy and can be used at patients' home. Technologically, the GoogleTV is recent, does not have many associated projects and has several features that can improve the entire system. Besides, the refered integration with the XtionPRO LIVE consists perhaps in the most innovative technological aspect since that combination is completely new in professional projects.

3.2.2 Requirements Elicitation

The games, to be applied in professional context, had to have some characteristics and features that usually are considered very important or even essential [FTC+08, LCH04, RH07, Pap09] and the movements, to be present in the games, had to have some requirements and specifications, validated by a healthcare professional. So, in order to get an opinion about those requirements, the development of these games and their insertion in the physiotherapy context, an interview was conducted with two healthcare professionals from CPRG. This interview, which can be fully consulted in Appendix A, came not only for the previously mentioned purposes but also to try to understand how the patients would receive that integration, considering their profile and the type of exercises usually performed in the sessions of that specific clinic.

The interview was divided in three main parts: target, physiotherapy sessions and performed exercises. The first one was to define a common profile for the patients so there could be drawn a line of exercise. Ferom the interview it was possible to realize that even there is not just one type of patient, this center treats patients with ages rounding 40 years and with acquired injuries, like in a work accident. About the psychological profile of the patients, i.e., if they would react well to the inclusion of this platform on their sessions, the therapists were unanimous in agreeing that a system that includes physiotherapeutic rehabilitation games would have a very positive impact.

The focus in the physiotherapy sessions consisted in trying to understand which methodology healthcare professionals used in that center. Questions like if the definition of the exercises was dependent on the patient or if there was any kind of defined model, if there are any differences between the exercises from patient to patient and a question about the approach used by the physiotherapists. After asking these questions it was possible to understand that there is a customization for the exercises depending on the patient and his injury's actual stage and the motivational method consists on trying to get the maximum of the patients' performance by previously making a study about each one's potential, that is, if they consider that the patient is able to reach a certain level during the session, they will try to encourage him to reach that goal. This customization gives more freedom and diversity when creating dynamic exercises but makes the task of creating a model to be applied to a group of patients a lot harder.

Finally, regarding the performed exercises, the interview was used to get some information about which exercises could be performed independent and autonomously, that is, without the supervision of the physiotherapist, some information about the parameters to evaluate while performing the exercises and it was also used to know if there is any example of a group of exercises that could be included on this platform and if they were based on any bibliographic reference. It was concluded that light and repetitive movements can be performed autonomously and the main parameter to be considered is the range of the motion because when treating patients with paresis and lack of functionality of the members, that parameter has a big importance for the evaluation of the performance of the patient. They suggested that the exercises to include in the system should be simple, easily understandable and should envolve uniform movements, an appealing scenario and may include musical elements. About the bibliographic references, the interviewed physiotherapists emphasized the use of the internet instead of relying on books.

Globally, the interview was positive because it allowed to get in touch with qualified healthcare professionals who gave very useful advices about the subject and also enabled an effective approach to a very real context of physiotherapy and rehabilitation which was very helpful to add quality to this project.

3.2.3 Architecture

As we can see in the Figure 3.1, the architecture of PhysicTV is very simple to understand. The user, interacts with the system through arm movements that are captured and tracked by the movement sensor of the XtionPRO LIVE. The server, running in the laptop, can handle the obtained data from the sensor through the connection of the device with the laptop. The laptop also provides a communication bridge between the sensor and the GoogleTV who works as a client in this system.

Initially, the communication between the server and the client was supposed to be made directly by connecting the XtionPRO LIVE device on the GoogleTV, but soon it proved to be an impossible task because those two devices were incompatible and the system would not function properly. The solution could be the inclusion of a small computer in the system that would only work as a communication channel but due the high processing power required by the platfrom features this second solution also became impracticable. So, to avoid loss of performance and/or functionalities and to ensure the proper functioning of the system we used a laptop to connect the XtionPRO LIVE and to communicate with the GoogleTV.

The GoogleTV, connected to a television, runs the electronic games that are played by the user by standing in front of the XtionPRO LIVE at a distance between 0.8 and 3.5 meters and by making, as previously mentioned, arm movements. The interaction with the global interface of the games, such as menus or game definitions, is made through the GoogleTV remote.

3.2.4 Proposed Game Requirements

One of the main goals of this dissertation was the development of electronic games that could be run by the GoogleTV and could be performed by arm movements allowing patients to exercise. So, in order to have some guideline for the design and structuring of those games, one of the goals of the interview made with healthcare professionals from CRPG was to understand some global concepts about the movements usually made in their sessions. The interview, that is detailed in Section 3.2.2, allowed us to obtain some requirements for the development of the electronic games:

- **Movements easily understandable** — The movements do not have to be too simple in order to be easily understandable. The most essential aspect is that the patient can quickly understand what he has to do and how he has to do it, so he can successfully perform the exercise. The movement complexity may depend on the physical condition of the patient;
- **Dynamic** — One of the main issues of physiotherapy is that the exercises can be very repetitive and boring. So, these games try to give some dynamic to the exercises and will allow some variation comparing with the usual performed movements in rehabilitation sessions;
- **Appealing scenarios** — What usually captivates the users when trying a game is the visual aspect. Although this issue is not the main focus, in this context it is important that the games are embedded in appealing scenarios that have to please all the patients considering the difference in their ages;
- **Musical effects** — Besides the visual aspect, the music and sounds that usually exist in a game also help to improve the user experience. So, it can be very advantageous for the sessions to have different sounds for certain moments of the game such as, success or insuccess of a movement, running out of time, among others.

These four items were always taken into account as basic items throughout the development phase of the game thereby maintaining the structure and functioning of the games almost equal.

Chapter 4

Implementation of PhysicTV

With constant technological advances occuring every day the field of rehabilitation has also been improved with the inclusion of games [SCB, DCC$^+$12, LCS$^+$11b, LKM$^+$12], auxiliary devices [CPM$^+$06, LCH04], innovative techniques [KDZN12], etc. and it is expected to keep improving through the next years [RB10].

Thus, taking advantage of all the opportunities for development that are currently available to those who want to create software to assist the physical therapists, we developed a solution that was simple but at the same time would add something different. This project comes up with this goal and after a description and characterization mainly about the global system in the previous chapter, this chapter highlights and details the various existing functionalities, system operation, the implementation details, among other things.

Considering the architecture scheme present in Figure 3.1, sections below describe clearly both right (Figure 4.1) and left sides. The first illustrates the components of the system and the interaction between the various technologies, aspects that are described in this section. Note that in this image the motion sensor is already specified, a decision explained later. The second is relative to the component of games, showing three general characteristics: they are electronic games that involve movement of the user and contain appealing sounds.

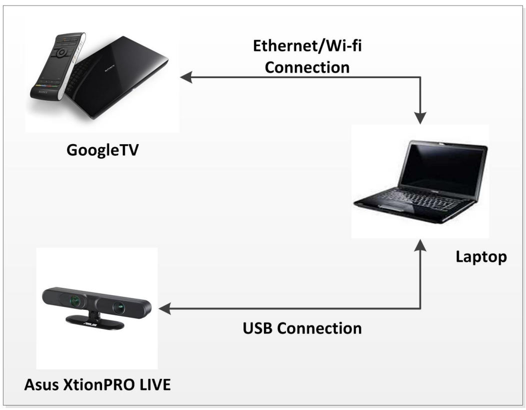


Figure 4.1: Device integration

4.1 Server

This section explains the operation of the server. The first two subsections explain two of the decisions made for the later development of the server, explained in the third subsection.

4.1.1 Kinect vs Asus XtionPRO LIVE

As refered in the chapter of the State of the Art (Chapter 2), the number of options for motion capture devices to include in this project were reduced to these two. This dissertation was meant to be composed by two main technologies: Kinect and GoogleTV. Initially, the development of the system was being made with the Kinect not only for the user tracking but also for the interaction with several features of the platform. However, the libraries that were being used were not up to the date which led to a change in the system architecture by switching the Kinect device with an Asus XtionPRO LIVE device. The update of those libraries, described furthermore in this report, was essential to prevent future problems when reusing the code because there were some changes in some functions and a few of them were even deprecated, and that could lead to the complete destruction of the system.

Thus, it was decided that a small regression in the project was better than a big regression in an advanced phase of the project. Besides that change in the used software, the change made in the hardware proved to be very successful because the Asus device is cheaper, smaller, easier to move and gives a very good platform of software development for the programmer. In spite of having less features and usage scenarios than the Kinect device, the XtionPRO LIVE has met every requirement and helped achieving the originally proposed objectives in addition to provide a very quick rebuilding of the system when the previously mentioned changes occured.

4.1.2 Libraries

The only library used throughout the development of the server was the Nite library. This library was used because it works as a bridge between the development platform and the Asus XtionPRO LIVE sensor allowing the access to the features of the device. Thanks to this library it is possible to use several functions and have access to some sensor parameters, including some information about the tracked user, their data, status, etc. The most used classes were:

- **NiTE** — Initializes the sensor;
- **UserTracker** — Used to allow the sensor to start tracking the users;
- **UserData** — Allows the access to all the user information;
- **SkeletonJoint** — Allows the access to the skeleton joints and some values about them. There are 15 possible joints to track (Figure 4.2);
- **SkeletonState** — Used to obtain the user's skeleton status:

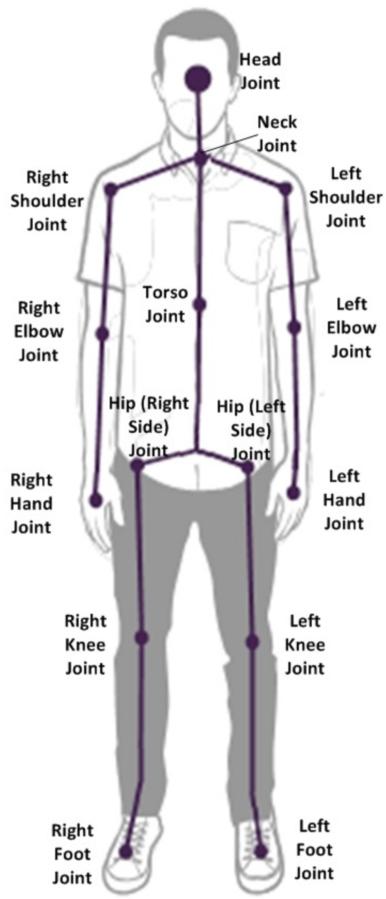


Figure 4.2: Tracked skeleton joints (Adapted from [Mic13])

  - *Calibrating* — The sensor is calibrating the skeleton of the tracked user;
  - *Tracking* — The sensor is tracking the user allowing the server to get his data;
  - *None* — The sensor can not calibrate nor track the user or there is no one in front of the device.

- **Status** — Enumeration of all the status given by the sensor (*OK*, *ERROR* and *BadUserID*);
- **UserTrackerFrameRef** — Used to access the information about the frames captured by the sensor.

4.1.3 Detailed Implementation

This project's server was developed using the language C++, runs on the laptop that is present in the architecture and has a major role considering the operation of the system. As we could see in Figure 4.1, the sensor connects directly to the laptop via an USB cable.

The server is always running, so once started it never stops running and can keep accepting new clients and exchange information with them. There is a port number value defined in the code of the server that is used when the user starts the server. It uses that port number to start the communicator (described in Section 4.3) which will function with the purpose of communicating with the clients and then it also initializes the variables responsible for connecting the Asus XtionPRO LIVE with the laptop:

```
UserTracker userTracker
UserTrackerFrameRef userTrackerFrame
userTracker.create()
```

Starting with the *userTracker.create()* to create an object responsible for tracking the users who will stand in front of the sensor. If the object is successfully created then it returns a *STATUS_OK* and advances by setting a smoothing factor to a high value, but lower than 1, in order to keep viable the usage of the system when tracking the user. If it is unsuccessfully created, usually caused by the sensor being unplugged or badly plugged to the laptop, the server will keep calling the function until it returns the success status.

Then, the server enters this cycle:

```
while(true){
    ...
    userTracker.readFrame(\&userTrackerFrame)
    ...
}
```

In this cycle the server keeps calling the *readFrame* function to ensure that the sensor is reading all the frames. If so, the servers updates the list of users tracked by the sensor by calling:

```
    userTrackerFrame.getUsers()
```

Since the communicator is already started a client can be connected to the server but not being tracked by the XtionPRO LIVE, if that list of users is empty the server puts all its clients waiting until the sensor starts tracking an user. If the list of users is not empty the server starts to go through the list of clients to see what is requested by each one and prepares all the information to send to him. For example, if a client requests two users to be tracked and the list of users of the server has only one user, the server informs that there is one user missing and does not send any information to the client. On the other hand, if a client wants one user to be tracked and the server is tracking three users, it will only send the data about the user closer to the sensor. So, when the server is ready to send information about an user to the client, it updates the state of that user by calling:

```
    updateUserState(user,userTrackerFrame.getTimestamp())
```

In this function the first argument is an user of the list of users and the second is the timestamp of the frame. By updating the user state, the server knows if the user is visible, new or tracked and it can now face three distinct situations:

- The user is new;
- The user is visible and is not being tracked;
- The user is visible and is being tracked.

For the first two, the users calls the function

```
userTracker.startSkeletonTracking(user.getId())
```

to force the sensor to start tracking the user and change his state so in the next iteration the server could finally send the data to the client. For the last one, the server checks what is requested by the client and starts processing that information. First it checks if the client wants the left or the right hand of the user to be tracked and sees which is the confidence value for that joint by calling

```
user.getSkeleton().getJoint(joint).getPositionConfidence()
```

where the joint is either the right hand or left hand. The confidence value, from 0 to 1, of the position of a specific joint is given by the XtionPRO LIVE and corresponds to the amount of certainty that the device has to be correctly identifying the joint all over the skeleton. If the value of the confidence is less than 0.6, the server restarts the tracking for that user by calling

```
userTracker.stopSkeletonTracking(user.getId())
userTracker.startSkeletonTracking(user.getId())
```

but if the value is equal or greater than 0.6 the server checks which function is called by the client, filters the requested information of all the data obtained from the XtionPRO LIVE and sends that information to him. This process is repeated for every client that is connected to the server and is active, that is, requesting data.

4.2 Client

After describing the server and its operation, it is now detailed the client component. There are two main aspects associated to the client in this project: the implementation itself and the interface created to interact with the system. In this section these two aspects are described in order to understand how the client was developed.

4.2.1 Detailed Implementation

In Figure 4.1, it was possible to verify that the client component exists by connecting directly the GoogleTV to the laptop via an ethernet cable or via a wireless conection. During the development phase of this project the prefered solution was to use an ethernet cable, however, the alternative solution where both the laptop and the GoogleTV are wirelessly connected to the same router, also allows a viable interaction between these two components and a good quality of communication between the server and client.

In this project, the client component of the system was developed in Java as a normal Android application with an interface and some menus and runs on the GoogleTV. There is also used the OrmLite library to support the application's database, allowing the storage of patient's details and sessions, because it is a library easy to use and does not involve a very complex development. In the scope of this project, the client has two main purposes: to allow the user to play the games by connecting to the server and as a database of patients for the physiotherapist to use. The first thing to configure is the IP and Port that will allow a connection to the server. This configuration can be made in the code or in a proper page in the program interface, which will be full detailed in Section 4.2.2.

After configuring the connection parameters, whenever a client wants to play one of the games, it must define which game wants to play, which side (left or right) of the upper-body and angles (described in the Section 4.3.4) it wants to be tracked, how long the game should last and in what level of difficulty it starts and ends. The first three settings will be used when communicating and exchanging information with the server in order to define which information and data the clients requests to the server. As soon as the client starts a game, these three settings form a combination that defines which function it wants to be used in the game and remain unchangeable until a new game is started. Along with that, the client connects to the server and after being confirmed as added it requests the server what has been defined in that combination of settings. This connection is made within a background thread that is started along with the game and allows the performance of background operations, and is also closed at the same time the game ends. This thread is responsible for starting the game, updating the cursor coordinates, updating the difficulty level of the game, checking if the goals of the game are completed and inform the main class about that, starting the chronometer and communicating with the clients.

There are two ways of playing the existing games: as a patient or as an independent user. The first way requires the user to load a patient profile and then start a new session so the data and values can be recorded when the game ends. If the therapist thinks the patient was not ready when the game began or the patient did not understand the game's rules he can just repeat the session withouth saving the results or even exit the session. If the user is playing the game as an independent user then there is no recording of any values. Either way, the game operation and the communication process with the server are identical.

4.2.2 Interface

Beside the games, this application also has an interface for the user so he can navigate between menus and define some settings. This interface can be divided in two distinct contexts: physiotherapist and patient. Since the main goal of this project is to give the patients the chance to play games while exercising the only interface they use is the game itself. However, there are several pages composing the application that are helpful for the physiotherapist to manage his patients details, history of sessions, evolution, etc.

In order to do that, this application has a main menu where the physiotherapist can choose to add a patient to the database, load an existing patient, simply play a game without being within a patient profile and redefine the network settings. To add a patient, his name and age are mandatory fields but the physiotherapist can only include some details he finds useful when consulting that patient's profile. The process of loading a patient is very simple: the physiotherapist just needs to enter the *Load Patient* page, select the patient he wants and press 'Enter' on the remote control. Then the application enters the patient profile, composed by five separators, where his personal details can be consulted and edited and both his session history and evolution can be consulted by the physiotherapist.

Figure 4.3: Patient's graph

To consult the patient's evolution the physiotherapist must indicate the system how many of the last sessions of the patient he wants to include in the evaluation graph. If the physiotherapist leaves that field empty or requests a higher number than the available number of sessions of that patient, the system will return a graph of all registered sessions the patient has ever made within his profile. Otherwise the system will return a graph with the number of sessions the therapist requested.

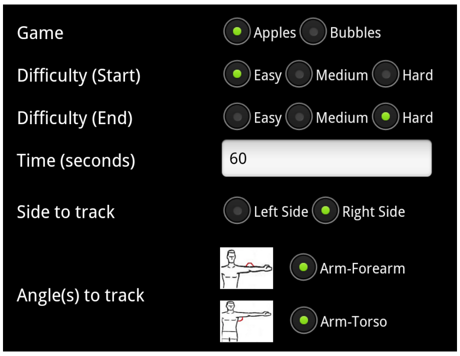


Figure 4.4: Game settings

The graph menu has three separators (Figure 4.3, with the original dimension in Appendix C): one for each angle and one for the game goal (depending on the game of each session, this value can be relative to the number of bubbles caught or apples dragged). In each one of these separators the graph contains a 'x' axis with the date of each session and a 'y' axis with the value of the arm-forearm angle, the arm-torso angle or the game goal value, depending on which separator is selected. In the separators of the angles, the graph also has two lines (for the average and maximum angles obtained in each session) and for the separator of the game goal the graph only has one line.

Finally, it is also in the patient profile where the physiotherapist configures a new session for his patient. In that separator, the physiotherapist chooses the game to be played, the difficulty of the game, how long it will last, which side and which angles will be tracked (Figure 4.4).

When the session ends, the details of the game are displayed on the screen and the therapist can choose to repeat the session with or without saving the results or exit also with or without saving the results (Figure 4.5). If he chooses to save the session it will be added to the patient's history with the date and hour of the session.

Figure 4.5: Session details

The button *Game Menu* in the main menu allows the user to play the game without being on a session. The game configuration process is the same but there is no record of the game details because there is not a session in progress. The last button of the main menu opens the network configuration page where are two fields, one for the IP and the other for the Port, used to connect to the server, which means that the value of the IP and the Port of the server must be replicated in the client so a connection can be made.

4.2.3 Games

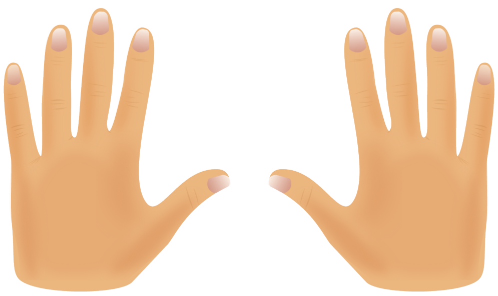
This section lists and details all the system components that are associated with the developed games, such as, the difficulty or duration of them. There is also a brief description of the two games themselves and their rules and operation.

Cursor

The cursor is used to indicate the user where is his hand on the screen so he can know where he has to move it to reach the object. As a matter of convenience and ease of calculations the cursor is always considered as a circle in every process of the operation of the games although it is represented by a bitmap as we can see in Figure 4.6. Its (x,y) coordinates keep changing in every iteration due to the sensitivity of the tracking by the sensor, that captures the slighest change of those coordinate values. Then, the server sends the new coordinates to the client who uses it to update the position of the cursor so the user can at any time know the position of his on the screen without having his game performance affected.

Duration

The duration of the game is defined in seconds and the default value is 60 seconds. Whenever the server tells the client that the user's hand is being tracked the chronometer starts and the game ends when it reaches the defined value.



(a) Left hand cursor (b) Right hand cursor

Figure 4.6: Hand cursors

Difficulty

When defining the game settings, the user must define both initial and ending difficulties, that is, in which difficulty the game must start and end. The difficulty may be the same troughout the game or may increase during the game but can not decrease during the game, that is, if the game starts in the hardest level it must end in that level. Increasing the level of difficulty depends on the defined duration of the game, because each level lasts the same time, calculated by:

$$DifficultyDuration: \quad Dif = \frac{TotalGameDuration}{EndingDifficulty - BeginningDifficulty + 1} \tag{4.1}$$

For example, if the user chooses to begin the game in the Easy level and end it in the Hard level in a game with a duration of 30 seconds we will have:

$$DifficultyDuration: \quad Dif = \frac{30}{2-0+1} = \frac{30}{3} = 10 \tag{4.2}$$

So in this example the game will change its difficulty level in every 10 seconds.

The difficulty level also influences the range of the screen where the game is played. Considering the goals of the game, the object or objects appear in a certain area of the screen and have a certain size and these aspects depend on the actual level of difficulty. The formulas of the size of the objects and the screen width and height ranges are:

$$ObjectSize: objectSize = 100 - 25 * CurrentDifficulty \tag{4.3}$$

$$ScreenRangeX: rangeX = \frac{(3 - CurrentDifficulty) * ScreenWidth - ScreenWidth}{6} \tag{4.4}$$

$$ScreenRangeY: rangeY = \frac{(3 - CurrentDifficulty) * ScreenHeight - ScreenHeight}{9} \tag{4.5}$$

The value of the CurrentDifficulty varies between 0 (Easy) and 2 (Hard) and as we can see, the higher the difficulty gets the smaller the objects are and the lower the range is. These two ranges are used in the final formula of the minimum and maximum values of the set (x,y) of the objects to appear in the television screen. The formulas for those values are:

$$MinimumX: \quad minX = rangeX + objectSize \tag{4.6}$$

$$MaximumX: \quad maxX = ScreenWidth - objectSize - rangeX \tag{4.7}$$

$$MinimumY: \quad minY = rangeY + objectSize \tag{4.8}$$

$$MaximumY: \quad maxY = ScreenHeight - objectSize - rangeY \tag{4.9}$$

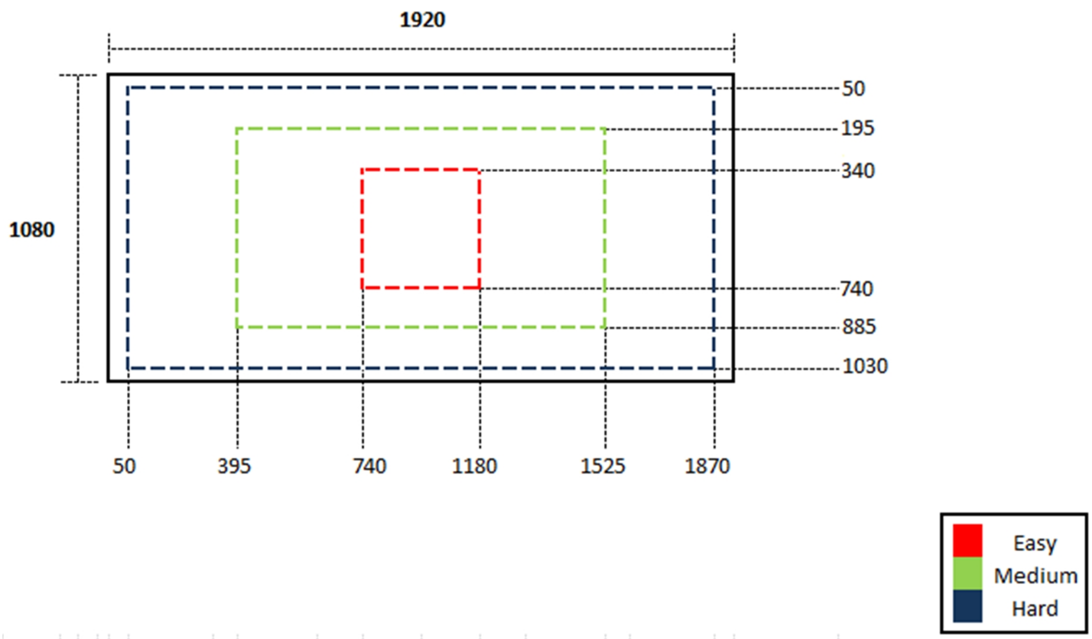


Figure 4.7: Game area for each level (1920x1080 dimensions)

The values of ScreenWidth and ScreenHeight are constant but the rangeX, rangeY and objectSize keep changing which causes the size of the game area on the screen to change too. In Figure 4.7, there is a picture of a television with 1920x1080 dimensions that simulates the various playing areas, for both games, considering the current difficulty.

Chasing Bubbles Game

The goal of this game is to reach the bubbles that keep appearing in random places on the television screen. Whenever a new bubble appears, the user must move his hand, consequently moving the cursor, and then try to touch the object so a new bubble can appear. The game saves and updates the number of bubbles already caught to give the user an idea of how his performance is going. The interface of the game can be seen in Figure 4.8.

The operation of the game starts when the user starts the game. The first bubble is already on the screen to be caught by the user even if he is not being tracked yet. After connecting to the server and sending what he wants to be tracked, the server sends the first tracked coordinates (x,y) and the cursor starts moving. Then, for each iteration, the client locally verifies if the cursor is touching the bubble by running the algorithm below.

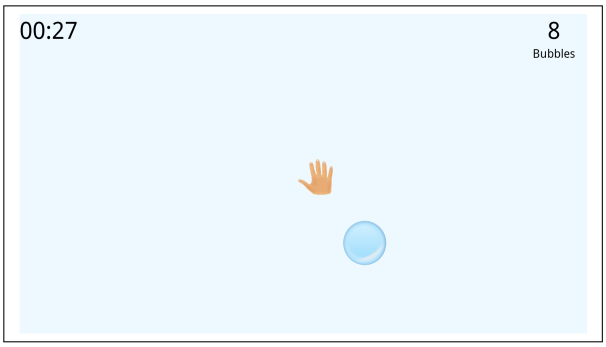


Figure 4.8: Chasing Bubbles interface

distanceX = (circle1X - circle2X)(circle1X - circle2X)*
distanceY = (circle1Y - circle2Y)(circle1Y - circle2Y)*
distance = sqrt(distanceX+distanceY)
radiusSum= radiusCircle1 + radiusCircle2
if *(distance <= radiusSum)* **then**
    return true
else
    return false
end

Algorithm 1: Function to check if two circles overlap.

This algorithm considers both objects as circles and uses basic math by first calculating the distance between the centers of the two circles by squaring the subtraction of both x and y coordinates, then summing it and finally calculating the square root of the result. Then, it gets the sum of the radius of both circles radius and compare it to the distance previously obtained. If the sum of the two radius is greater than the distance between the center it means that the circles don not intersect each other, otherwise the algorithm returns true because one circle can be completely inside the other or they can be overlapping and either of these conditions means that the user reached the bubble. When it happens, the helper class broadcasts an order of *NEW_BUBBLE* to place a new bubble on the screen and to give an audible signal indicating it was successful. The coordinates of the new bubble are calculated by the formulas in 4.6, 4.7, 4.8 and 4.9.

Dragging Apples Game

In this game, the user must pick up an apple and drag it to a basket. The operation of the game is similar to the Chasing Bubbles, because the connection to the server is also made at the beginning of the game where it also starts the background thread. The functions of this class are identical in both games, but in this game there is an extra function related to the goal of the game because while the Chasing Bubbles game only required a touch in the bubble, the Dragging Apples game requires two things that have different operations. First, the user needs to grab the apple and to do that he must move his hand to move the cursor over the apple during roughly one second and a half. While doing this

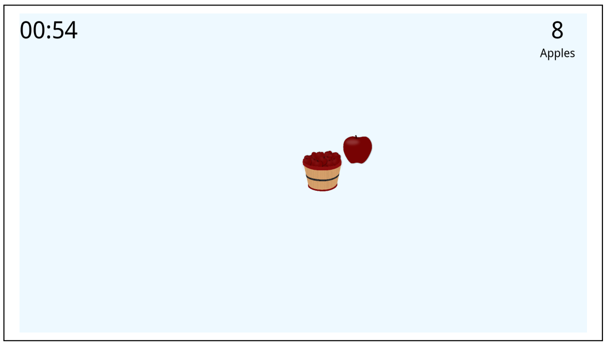


Figure 4.9: Dragging an apple

there is a small timer that appears on the screen indicating if the user has already picked the apple and if his hand is even over it or not (Figure 4.9). Then, while grabbing the apple, the hand movement by the user controls the apple and not the cursor and he needs to drag it to the basket (Figure 4.10). The process of dropping the apple in the basket is simple because the user just needs to touch the basket in any point and not specifically on the top, for example.

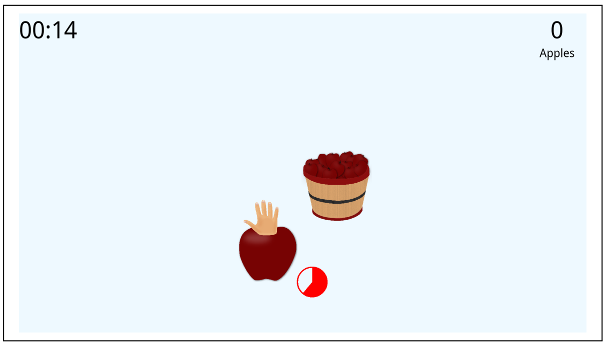


Figure 4.10: Picking an apple

The background thread is, in each iteration, checking both parts of the process. When the game starts, both basket and apple get a set of coordinates (x,y) calculated by the formulas in 4.6, 4.7, 4.8 and 4.9 but while the basket position is the same throughout the game, the apple keeps changing its position when it is dropped in the basket. So, the first thing to verify is if the user is picking the apple. If so, the backgroud thread broadcasts an order for the main class to hide the cursor, so the user can, with his hand, move the apple and not the cursor. Whenever the user gets to drop the apple in the basket, the thread broadcasts an order to unhide the cursor so the user can start to try to grab another apple. Everytime the user achieves that goal, the apple gets a new set of coordinates, always calculated by those four formulas, the number of dropped apples increases and the system gives a sound signal to inform about the success of the task. Since both apple and basket are considered as circles, the algorithm used to verify both tasks (picking and dropping) is the same as the other game's (Algorithm 1).

If the algorithm returns true the background thread gives the already mentioned order of unhiding the hand. In the picking process the two circles considered are the hand cursor and the apple while in the dropping process it considers the apple and the basket. This algorithm is only used once to check if the apple can be dropped in the basket, but when the user is trying to pick the apple the algorithm needs to be called in every iteration during the period of time needed to pick it. The timer is restarted if at any time during that period of 1,5 seconds time the algorithm returns false because it means that the user's hand was not over the apple.

4.2.4 Collectable Parameters

During the games, for each new set of coordinates (x,y) there are also new values for the angles chosen in the game settings. For each angle these values are kept in a list so in the end the application can calculate both the average and the highest of the obtained values. Then, if the game was played during a session and the physiotherapist wants to save it, the system will save the maximum angle and the average angle for each one of the selected by him and associate them to the session so in the future it can be consulted by the therapist. Beside these angle values, the number of bubbles caught or apples dragged, depending on the selected game, is also saved. This list of sessions will allow the creation of a graph about the patient's evolution in each of these parameters (arm-forearm angle, arm-torso angle and game goal) throughout his rehabilitation process.

4.3 Communication Server-Client

In this application the server is always running and accepting new clients that want to connect to it. This section describes how the communication between the server and client happens, the architectural scheme of it, the type of data exchanged, etc.

4.3.1 Operation

Once started, the server opens a communicator that runs on background and is used to accept messages from the clients. Each time a client connects, the server creates a specific channel to exchange messages only with that client, avoiding the message from being delivered to the wrong recipient, and adds him to its list of clients. The server defines a client as an object with the following fields:

- **SocketInfo** — This field contains the id, the port and the address of the communication chanel, so the server knows to whom it must send the information;
- **Function** — When a user sets the definitions for the game it is about to play, he defines a function for the client to inform the server which information it wants to receive;
- **Status** — This field refers to the status of the client helps the user to know if the client is waiting for information or if it has disconnected from the server. The value of the status is usually updated after a client request but can also be changed by the server if there is any kind of error with the sensor;
- **UsersNumber** — Each client has the possibility to define how many users it wants to be tracked by the sensor. This field indicates that number so the server can verify if that condition is fulfilled or not.

The communication happens entirely during the games, because as soon as the game begins, the client is already connected to the server and has already specified what values it wants to get. Throughout the game, the client keeps requesting information and assure the server that it is still connected so the server will not close the previously created channel of communication. Depending on the message received from the client, the server may have to update some values of the fields described above.

4.3.2 Architecture

The scheme of communication between the server and the clients can be seen in the Figure 4.11. As we can see, if a client tries to connect to an inactive server or a server with the communnicator

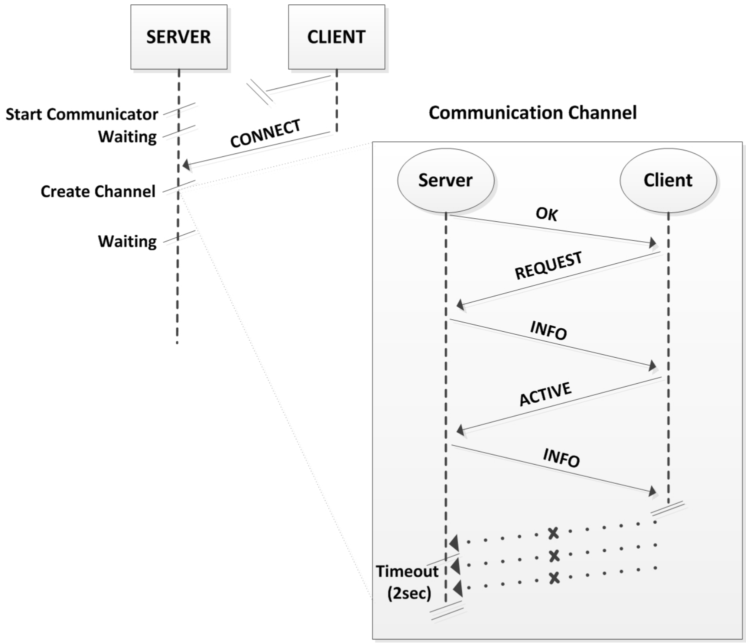


Figure 4.11: Communication scheme

closed nothing will happen, but as soon as the communicator is started any client can connect to the server that is waiting for new connections. The client first sends a *CONNECT* message, detailed in Section 4.3.3, so it can establish an exchange of information with the server. On the other side, the server receives that message and opens the communication channel created for that specific client, but keeps waiting for new clients. The first message sent to the client is an *OK* just to inform that the server is now ready to communicate. Then, after the user defines the game settings, the client sends a *REQUEST* containing the specific type of information it wants to receive from the server. Finally, after the server sends the first message containg the requested data, the exchange of messages is always made in the same way: the client informs that it is still active and waiting for new messages and the server keeps sending the information until the client disconnects.

In the example of the scheme, after a few traded messages, the client disconnects. In this case, the server does not receive a message informing about the disconnection nor an *ACTIVE* one, so it starts a timeout of 2 seconds where it waits for a new message from the client. After these two seconds, it closes the communication channel of that client.

4.3.3 Exchanged Messages

During the communication between the server and the client there are some defined messages so the server and the client can know the information that one requests and the other sends. These defined messages are:

- **CONNECT** — It is the first message sent from the client so it can connect to the server. The message consists of *"CONNECT"*;

- **OK** — After receiving the connect from the client, the server sends it a confirmation to inform that the communication between them can proceed. The *OK* message consists of *"OK|ID|"*. The *ID* is generated by the server and represents the identification of that client;
- **REQUEST** — This message is also sent from the client to the server and contains the specific kind of data the client wishes to receive. The entire message is composed by *"REQUEST|ID|NUMBER_OF_USERS|FUNCTION"* where:
  - *ID* — Identification number of the client, sent from the server;
  - *NUMBER_OF_USERS* — The number of users the client wants to be tracked by the sensor;
  - *FUNCTION* — The combination of information the client wants to receive. The existing functions are detailed in Section 4.3.4.
- **INFO** — As soon as the server knows what information the client wants, it is ready to send it. This message consists of *"ID|CursorX|CursorY|Ang1|Ang2|"*, where:
  - *ID* — Identification number of the client;
  - *CursorX* — Mandatory field. It has the value of the new X coordinate of the cursor;
  - *CursorY* — Mandatory field. It has the value of the new Y coordinate of the cursor;
  - *Ang1* — Optional field. It is present in the message depending on the *REQUEST* message sent from the client;
  - *Ang2* — Optional field. It is present in the message depending on the *REQUEST* message sent from the client
- **ACTIVE** — During the game, the client sends this message to the server to inform it is still connected and waiting for new messages with data. The message is composed by *"ACTIVE|ID|NUMBER_OF_USERS|FUNCTION"*, and its fields are the same as the *REQUEST* message's.

4.3.4 Transmitted Data

Almost all the messages exchanged by the server and the client contain data which can be requested by the client or not. This section describes the type of information that can be requested and sent.

Functions

The user must choose which definitions the game shall have and when he does that, he is creating a combination of several fields of information he wants to get. There are eight different functions in this system:

- **RIGHT_HAND_TRACKING** — The user wants to track his right side and play the games with his right hand;
- **LEFT_HAND_TRACKING** — The user wants to track his left side and play the games his left hand;
- **RIGHT_HAND_WITH_ARM_ANGLE** — The user wants to track his right side and the angle formed by his right arm and his right forearm and wants to play the games with his right hand;
- **LEFT_HAND_WITH_ARM_ANGLE** — The user wants to track his left side and the angle formed by his left arm and his left forearm and wants to play the games with his left hand;
- **RIGHT_HAND_WITH_TORSO_ANGLE** — The user wants to track his right side and the angle formed by his right arm and his torso and wants to play the games with his right hand;
- **LEFT_HAND_WITH_TORSO_ANGLE**— The user wants to track his left side and the angle formed by his left arm and his torso and wants to play the games with his left hand;
- **RIGHT_HAND_WITH_BOTH_ANGLES** — The user wants to track his right side and the two previously mentioned angles and wants to play the games with his right hand;
- **LEFT_HAND_WITH_BOTH_ANGLES** — The user wants to track his left side and the two previously mentioned angles and wants to play the games with his left hand.

Cursor Coordinates

When the communication is established and the games are being played, every message sent from the server has the new coordinates (x,y) from the cursor so the client can update the user's hand position. In order to give the user the opportunity to be able to move within the range of the sensor or even sitting on a chair while playing without affecting the cursor position, the server considers the shoulder of the tracked side the center of the screen and every hand or arm movement is done in relation with that point. The server calculates the distance between the shoulders and simulates a screen made from the mentioned shoulder point. As we can see in Figure 4.12, the simulated screen dimensions are equal and dependent of the distance between the shoulders. First is calculated the difference between the coordinates of the shoulders, then it is applied the value of the difference downwards, upwards and to the side that is being tracked (right

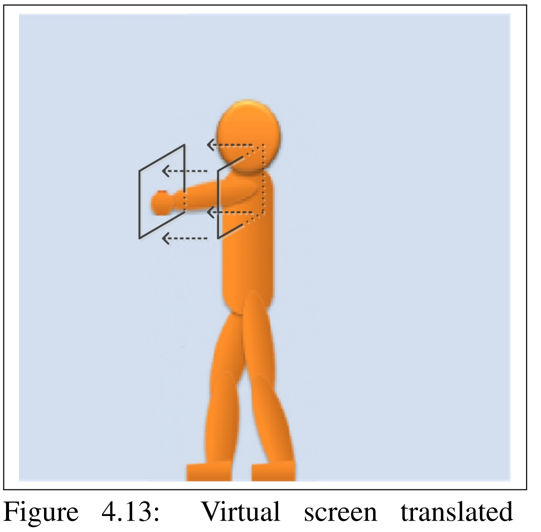


Figure 4.13: Virtual screen translated (Adapted from [Pav11])

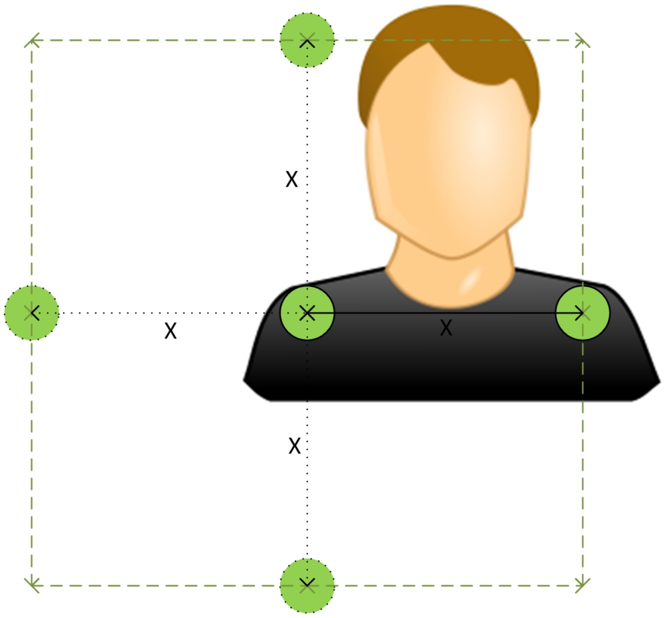


Figure 4.12: Simulated screen (Adapted from [acs07])

side, in the example), creating a simulated screen with equal dimensions that can be applied in depth because when an user is playing the games his arm and hand are standing in front of their shoulder, so there is a virtual depth translation of the simulated screen to give the notion that the hand is actually moving on the screen (Figure 4.13).

Since these dimensions are different of the screen television dimensions, the server uses relation factors by calculating the (x,y) position of the cursor in that simulated screen, in order to get a value between -1 and 1 for both width and height. Then, it includes those values in the message to send to the client which is responsible to apply them to the television screen dimensions. The server gets the values by using these formulas:

$$ShoulderDistance : SD = RightShoulder.X - LeftShoulder.X \tag{4.10}$$

$$TranslationX : TX = RightHand.X - RightShoulder.X \tag{4.11}$$

$$TranslationX : TY = RightHand.Y - RightShoulder.Y \tag{4.12}$$

$$FactorX : FX = \frac{TX}{SD} \tag{4.13}$$

$$FactorY : FY = \frac{TY}{SD} \tag{4.14}$$

These values were calculated for a right hand tracking. The first formula is only used once, in the first time the user is tracked, so it is possible to have a constant reference value to compare in each iteration. Then, it is calculated the translation in both x and y coordinates to finally get the

(a) Arm-Forearm angle (b) Arm-Torso angle

Figure 4.14: Tracked angles

factor values. When the server finishes using these formulas it sends the values to the client which handles them by using these formulas:

$$CursorX : CX = \frac{ScreenWidth}{2} + \frac{ScreenWidth * FX}{2} \quad (4.15)$$

$$CursorY : CY = \frac{ScreenHeight}{2} + \frac{ScreenHeight * FY}{2} \quad (4.16)$$

$$(4.17)$$

The client considers the center of the television as the (0,0) point, so every new set of factors are calculated from that point. Even being a restricted range of values, any small change in the hand position causes the factor values to change so these formulas are called in every iteration and the cursor's position is always changing.

Tracked Angles

In order to help the physiotherapists to evaluate the evolution of the physical condition of their patients during the sessions, this application also captures some data about the patient performance. When configuring the settings to play the game, the physiotherapist can choose which angles of the patient's body he wants to be tracked: none, arm-forearm angle and/or arm-torso. These two angles were chosen to be included in the system because when playing the games and interacting with the system, the arm movement and aperture cause some variation of these angles which allows the physiotherapist to conclude whether his patient is achieving a greater distance when opening and extending his arm, for example. The first tracked angle is the angle made between the arm and the forearm (Figure 4.14a) and the second tracked angle is the angle made between the torso and the arm (Figure 4.14b).

The server is responsible for calculating the values of the angles if requested by the user and, therefore, by the client. For the angle between the shoulder and the elbow, there are two vectors with the differences between the (x,y,z) coordinates of the elbow and the shoulder (Formula 4.18) and the (x,y,z)[1] coordinates of the elbow and the hand (Formula 4.19) which are used in the final formula to obtain the value of the angle (Formula 4.20). Finally, to calculate the angle between the arm and the torso there are two new vectors with similar values to the ones mentioned before but, in this case, the first vector refers to the difference between the coordinates of the shoulder and the elbow (Formula 4.21) and between the coordinates of the shoulder and the torso (Formula 4.22). However, as we can see in the Formula 4.21, the Torso.X is never considered because its position would lead to a very low variation of the value of the angle between the right arm and the torso. Given the necessary opening of the arm when playing the games, the best solution for achieving changes in the value of the angle to be significant and allow some kind of evaluation by the physiotherapist, was to simulate a new X coordinate for the torso. So, as we can see in Figure 4.15, there is a virtual translation of the *x* coordinate of the torso so it can be aligned with the shoulder in *x*. The last formula (Formula 4.23) gives the value of the angle. In both cases, the tracked side was the right side and the use of *180/PI* was to convert from radians to degrees.

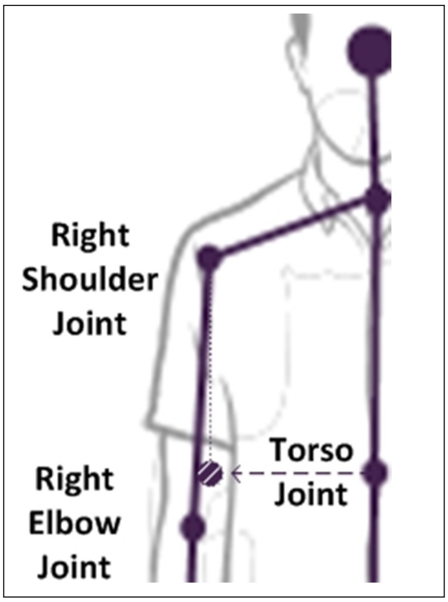


Figure 4.15: Torso.X translated

$$VecHandElbow : \vec{V}1 = [RightElbow.X - RightHand.X, RightElbow.Y - RightHand.Y, RightElbow.Z - RightHand.Z] \quad (4.18)$$

$$VecShoulderElbow : \vec{V}2 = [RightElbow.X - RightShoulder.X, RightElbow.Y - RightShoulder.Y, RightElbow.Z - RightShoulder.Z] \quad (4.19)$$

$$AngleArmForearm : Ang1 = \arccos(\frac{\vec{V}1 \cdot \vec{V}2}{|\vec{V}1||\vec{V}2|}) * \frac{180}{\pi} \quad (4.20)$$

[1]Although the only considered coordinates when playing the games are the (x,y) in these formulas the *z* value is also considered in order to have a bigger precision and take advantage of the features of the Asus XtionPRO LIVE

$$VecTorsoShoulder : \vec{V}3 = [RightShoulder.X - RightShoulder.X, RightShoulder.Y - Torso.Y, RightShoulder.Z - Torso.Z] \tag{4.21}$$

$$VecElbowShoulder : \vec{V}4 = [RightShoulder.X - RightElbow.X, RightShoulder.Y - RightElbow.Y, RightShoulder.Z - RightElbow.Z] \tag{4.22}$$

$$AngleArmTorso : Ang2 = \arccos\left(\frac{\vec{V}3 \cdot \vec{V}4}{|\vec{V}3||\vec{V}4|}\right) * \frac{180}{\pi} \tag{4.23}$$

Chapter 5

Evaluation and Testing Results

This chapter presents the obtained results in the testing phase and it is organized according to the ISO/IEC 25062 Common Industry Format For Usability Test Reports.

5.1 Executive Summary

This section describes the results of the conducted experiment to evaluate the inclusion of motion-based electronic games in a rehabilitation process. These tests were made in the scope of this dissertation.

Two electronic games were tested with 10 different participants. The first 5 participants tested the system in a non-medical environment, and the last 5 tested it in a healthcare center. Both groups tested the same features and were under the same conditions.

The obtained results proved that one of the games (Chasing Bubbles) had better impact on the perception of its rules and on how it should be played while the other was considered a bit more complex but still playable and applicable to this context.

5.2 Introduction

5.2.1 Full Product Description

PhysicTV is an Android application targeted for physiotherapy, running on GoogleTV, which allows the user to interact with the system through body movements that are collected by a movement sensor (Asus XtionPRO LIVE). This application can be used as a helper method for the physiotherapist because it will allow the inclusion of games in the rehabilitation sessions and the continuation of therapy at home for patients using the system. During this experiment we tested two electronic games in several difficulty levels with both user physically fit and with patients with upper limb hemiparesis.

Participant	Gender	Age	Hand	Experience with motion sensors applied to games
Participant 1 (P1)	Male	24	Left-handed	Some
P2	Male	31	Right-handed	Some
P3	Male	26	Right-handed	None
P4	Male	29	Left-handed	Plenty
P5	Male	30	Right-handed	Some
P6	Male	43	Right-handed	None
P7	Male	50	Left-handed	None
P8	Female	27	Left-handed	Some
P9	Male	43	Right-handed	None
P10	Female	41	Left-handed	None

Table 5.1: Characteristics of the participants

5.2.2 Test Objectives

This test was made with the purpose of evaluating the effects of including electronic games in the rehabilitation process. More specifically, the user performance in each game, the user satisfaction after finishing the game, if the users feel more motivated to perform their sessions, if the games are sufficiently compelling to keep the users focused during the entire session and if the users found the system easy to use and to interact with.

In order to evaluate that, this test will consist in short sessions for each game, with variation on its difficulty level.

5.3 Method

The method used during this experiment is described in this section. There is a brief description of the participants and their characteristics as well as the performed tasks, the used technologies, the evaluation metrics, among other aspects. The purpose of this section is to summarize what have been done and what was considered in order to evaluate the experiment.

5.3.1 Participants

The Table 5.1 contains the characteristics of all the participants.

Participants 1 to 5 tested the application in a non-medical context and participants 6 to 10 were recruited in a healthcare center. The fields of the columns are:

- **Gender** — Indicates if the participant is male or female;
- **Age** — Chronological age of the participant;
- **Hand** — Indicates if the participant is right-handed or left-handed;

- **Experience with motion sensors applied to games** — Indicates whether the participant has ever played a game with movement sensors or not.

5.3.2 Context of Product

This product can be used in two different contexts. The first one is in a medical context, that is, in a clinic or in a health center. In this case, the physiotherapist can keep an eye in the patient's performance so he can aid the patient's interaction with the system while evaluating how is the patient responding. The second context of this project is more personal because the system would be used at the patient's home. Since the main purpose of the system is to be used in a medical context, we decided to do the product testing in a medical environment, where we can get a more accurate feedback from the users considering their physical limitations and the need of rehabilitation sessions.

Tasks

To perform this test, there are several tasks that need to be done in order to evaluate the usability and the role of this system in the context of rehabilitation sessions. So, to perform those tasks, there are some aspects that must be taken into account for this set of tests:

- Since this system is targeted for the physiotherapy patients, all the users must be somehow conditioned in order to conclude if the electronic games are playable even in adverse conditions. So, when dealing with users in perfect physical condition, one of their arms must be immobilized in order to focus his attention on the treatable arm;
- In the non-medical context of this test, users should vary between left-handed and right-handed. The developed games include that feature, allowing the physiotherapist to treat patients with injuries in both arms. However, when dealing with rehabilitation patients, the arm used to play those games will depend on the patient's injury. So, in order to check if the effectiveness of the platform is equal for each arm, this feature should be tested with healthy participants.

Once defined the possible scenarios for the users, there are some main tasks that will have to be performed by the users:

- Playing one game where the goal is to reach bubbles that appear in random positions on the screen, by moving the right/left hand into that position. This game will be played in three different sets: first, the game will start in the easiest level and will progressively become more difficult as time goes by. In the second set, the game will start in the medium difficulty and will reach the hardest after some time. Finally, in the third set will be entirely in the most difficult level;
  - In this game, the sets will have the duration of 60 seconds, 60 seconds and 30 seconds, respectively. The main goal is to see how many bubbles are caught, how much time

the user spends catching each one and what are the values of the angles (arm-forearm, arm-torso) that the user reaches.

- Playing one game where the goal is to drag an apple into a basket. First, the user must keep his hand above the apple for a few seconds, and then drag it to the destination, which is a basket. This game will be played in three different sets: first, the game will start in the easiest level and will progressively become more difficult as time passes. In the second set, the game will start in the medium difficulty and will reach the hardest after some time. Finally, in the third set will be entirely in the most difficult level;

  – In this game, the sets will have the duration of 60 seconds, 60 seconds and 30 seconds, respectively. The main goal is to see how many apples are dragged, how much time was spent picking the apple, how much time was spent dragging the apple to the basket and what are the values of the angles (arm-forearm, arm-torso) that the user reaches.

- In both games, the obtainable angles will function as a measure of how much effort was done by the user to reach his goal;

- Other factors to evaluate include the user satisfaction when playing the games, their opinion about that kind of rehabilitation inserted within medical context, their opinion about the complexity of the games and its rules, their performance in the game, among others. These factors are common to both games.

Test Facility

The tests were conducted in two distinct environments. In the first one, a non-medical environment, the participants performed the tasks individually because being with other participants could influence the performance of the current participant and the future ones. In the second one, a medical environment, the participants also performed the tests individually so their performance wasn't influenced too.

Participant's Computing Environment

The sensor used to track the user movements was the Asus XtionPRO LIVE with a depth sensor and a range between 0.8 and 3.5 meters. The device used to communicate with the server was a GoogleTV, model NSZ-GS7, with Android 3.2. The device used to establish a connection between the server and the client was a Toshiba Laptop, with Ubuntu 12.04. In the non-medical environment, the display device was a Samsung Television, with a resolution of 1920x1080 and in the medical environment was used a projector as a display device and speakers as a sound device in order to play the game sounds.

5.3.3 Experimental Design

This experiment was divided in two different sub-experiments: the first one took place in a non-medical context and had 5 participants who tested both games; the second one took place in a specific health center and also had 5 participants who tested both games.

The two groups tested both games and included both left and right-handed participants. For each game the users performed 3 sets where the difficulty level increased throughout the time. Although these groups were in a different physical condition, we provided equal conditions to them so the performance could be natural and not influenced.

Procedure

In order to ensure that the participants could understand what they were testing, the first thing done in both experiments was a brief introduction to the application, what it does and how it works. After introducing the system, we decided to explain how to play the games and which are their goals.

Once concluded the theoretical part, it was time to begin the practical one. The participants knew how much time the session would last and which hand should they use to interact with the system. They also knew that the administrator was there to evaluate the system and to help them if they needed and if he thought he should intervene to help or correct some detail.

The following topics summarize the procedure taken for each testing phase:

- Personal presentation of the administrator and his dissertation theme;
- Introduction to the system, its goals and its features;
- Four questions asked:
  - 1st – "What is your name?";
  - 2nd – "How old are you?";
  - 3rd – "Are you left-handed or right-handed?";
  - 4th – "Have you ever used any platform/system with this kind of interaction?"
- Brief explanation of the first game to test and in what conditions it should be played;
- Ensure that the administrator will be ready to help the participant if asked or if he thinks he should;

  [Game Session - Game 1]
- Brief explanation of the second game to test and in what conditions it should be played;
- Ensure that the administrator will be right to the participant ready to help him if asked or if he thinks he should;

  [Game Session - Game 2]

[Perform the questionnaire]

- Thank the participant for his collaboration and feedback.

Participant General Instructions

The first thing to highlight was the fact that this experiment was completely voluntary and they could stop whenever they wanted.

We also said, right before playing the games, that they could inform us whenever they could not perform a task or if they needed any kind of help and that we would be vigilant and ready to help whenever we considered appropriate to do so.

Participant Task Instructions

Participants were asked to perform the main task of trying to complete the games in the best way they could. So, in order to do that, it was explained to them how they should interact with the system and where they should be placed. We also asked them to point out any possible system errors or some suggestions to improve the project.

5.3.4 Usability Metrics

The metrics used to evaluate the obtained results in the experiment are described in this section. The effectiveness, efficiency and satisfaction of the participants are shown in tables in order to give a better idea about the performance of the participants. There are also two tables that show the number of errors made and assists required by each participant.

Effectiveness

Effectiveness relates the goals of using the product to the accuracy and completeness with which these goals can be achieved. In this experiment, the effectiveness was measured by evaluating the participant's perception of how the game is played, the success during the game, the number of errors made and the number of assists provided during the tests. The Table 5.2 gives the percentage of patients that understood both the interaction and the goals of each game.

	Chasing Bubbles		**Dragging Apples**	
	Understood Interaction?	Understood Goals?	Understood Interaction?	Understood Goals?
Completion Rate by Task (%)	100	100	70	50
Average Completion Rate (%)	100		60	

Table 5.2: Completion Rate table

	Chasing Bubbles	Dragging Apples	
Participant	Number of Errors	Number of Errors	Notes
P1	0	1	The error was on the goal of the game
P2	0	1	The error was on the goal of the game
P3	0	0	
P4	0	0	
P5	0	1	The error was on the interaction with the system
P6	0	0	
P7	0	1	The error was on the goal of the game
P8	0	1	The error was on the interaction with the system
P9	0	2	One of the errors was on the interaction with the system and the other was on the goal of the game
P10	0	1	The error was on the goal of the game

Table 5.3: Errors made by participants

Errors In this test, we defined as an error every time the participant could not know how to interact with the system and/or get the goal of one game while playing it.

Assists An assist, in the test, can be defined as a call for help from the user to the test administrator requesting some hints about the way the games are played or how the interaction with the system is processed. An intervention from the administrator to give some help, some hint or some explanation, without being requested, is also considered as an assist in this experiment.

	Chasing Bubbles		Dragging Apples	
Participant	Assists Requested	Assists Not Requested	Assists Requested	Assists Not Requested
P1	0	0	2	0
P2	0	0	1	0
P3	0	0	0	0
P4	0	0	0	1
P5	0	0	0	0
P6	0	0	0	0
P7	0	0	1	0
P8	0	0	1	1
P9	0	0	0	1
P10	0	0	0	1

Table 5.4: Assists provided to the participants

Efficiency

In this experiment the efficiency was evaluated considering the mean time spent by each participant to perform every task. Each participant performed 6 sessions, 3 for each game with equal times and difficulty levels. There was not a manual time register because the obtained times were captured by the system.

The Tables 5.5 and 5.6 contain the obtained results in each game from the tests made with patients from rehabilitation sessions. The results obtained in the non-medical environment are not relevant in this case, because the purpose of this section is to evaluate the efficiency of people performing the movements with an upper-body injury so it is possible to conclude about the feasibility of the developed games.

Chasing Bubbles					
1st Test		*2nd Test*		*3rd Test*	
ANB	ATS	ANB	ATS	ANB	ATS
42	1.34	32	1.82	13	2.44

Table 5.5: Efficiency on Chasing Bubbles

Dragging Apples								
1st Test			*2nd Test*			*3rd Test*		
ANA	ATSP	ATSD	ANA	ATSP	ATSD	ANA	ATSP	ATSD
8	5.01	2.51	7	4.40	2.87	2	7.81	2.62

Table 5.6: Efficiency on Dragging Apples

ANB – Average Number of caught Bubbles
ATS – Average Time Spent (seconds)
ANA – Average Number of dragged Apples
ATSP – Average Time Spent Picking (seconds)
ATSD – Average Time Spent Dragging (seconds)

Satisfaction

After performing both games and concluding the experiment, each participant was asked about his opinion and satisfaction with the system. To do so, they answered a customized SUS (System Usability Scale) questionnaire, which contains 16 questions instead of the traditional 10 questions and can be found in Appendix B. The choice of adding six questions to the traditional model was made in order to cover more aspects about the satisfaction of the user. The results of this questionnaire are divided in two distinct groups: one for the physically fit users and the other for the rehabilitation patients. That way it is possible to see the appreciation of the system from the two groups that underwent the tests in different physical conditions.

Each one of the 16 performed questions has a scale number from 1 (Strongly Disagree) to 5 (Strongly Agree) and has different weight when calculating the final score. The contribution of questions present on odd items is the scale position minus 1. On the other side, the contribution of questions present on even items is 5 minus the scale position. The Table 5.7 show the answers by the participants in each question.

	Question																	
Participant	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Score	Average
P1	3	1	4	1	4	2	3	1	5	1	4	1	3	1	3	2	127,5	
P2	5	1	4	1	4	1	5	1	5	1	5	1	5	1	5	1	155	
P3	5	1	4	2	5	1	4	1	4	1	5	1	4	1	4	2	142,5	
P4	5	1	5	2	5	2	5	1	5	1	4	2	4	1	5	1	147,5	142
P5	4	1	5	2	5	2	5	1	4	2	4	2	4	1	4	1	137,5	
P6	5	1	5	1	5	1	5	1	5	1	5	1	5	4	5	1	152,5	
P7	5	1	5	4	5	1	5	1	5	1	5	1	5	1	5	1	152,5	
P8	4	2	4	2	4	2	4	2	3	1	4	2	3	2	3	2	115	
P9	5	1	5	4	5	1	5	1	4	1	5	1	5	1	5	1	150	141
P10	5	1	4	2	5	2	4	2	4	1	4	2	4	1	4	1	135	

Table 5.7: Questionnaire results

5.4 Results

5.4.1 Data Analysis

This section details the results of each participant regarding the perception of the goals of the system. The following table was filled by the administrator for each test:

			Chasing Bubbles			**Dragging Apples**			
Participant	Age	Gender	Interaction	Goals	Avrg %	Interaction	Goals	Avrg %	Final %
P1	24	Male	Yes	Yes	100	Yes	No	50	75
P2	31	Male	Yes	Yes	100	Yes	No	50	75
P3	26	Male	Yes	Yes	100	Yes	Yes	100	100
P4	29	Male	Yes	Yes	100	Yes	Yes	100	100
P5	30	Male	Yes	Yes	100	No	Yes	50	75
P6	43	Male	Yes	Yes	100	Yes	Yes	100	100
P7	50	Male	Yes	Yes	100	Yes	No	50	75
P8	27	Female	Yes	Yes	100	No	Yes	50	75
P9	43	Male	Yes	Yes	100	No	No	0	50
P10	41	Female	Yes	Yes	100	Yes	No	50	75

Table 5.8: Participant's perception analysis

For each task the administrator gave a Yes (100% score) or a No (0% score) if the task was completed successfully or unsuccessfully. Due to the simplicity of the tasks, there were not any between scores. In both games, the two tasks (Interaction and goals) were completely independent because a participant could know what he had to do and do not know how to do it or he could know how to interact with the system but do not know what were the rules of the game.

5.4.2 Performance Results

The two graphs below show the number of caught bubbles and dragged apples and the average time spent to do that, in each test. The values of 0,1 and 2 in the 'x' axis correspond to the test that started in the difficulty level of Easy, Medium and Hard, respectively. These performance results are relative to the rehabilitation patients. As explained in Section 5.3.4, only these values can be taken into account to verify the effectiveness of the PhysicTV.

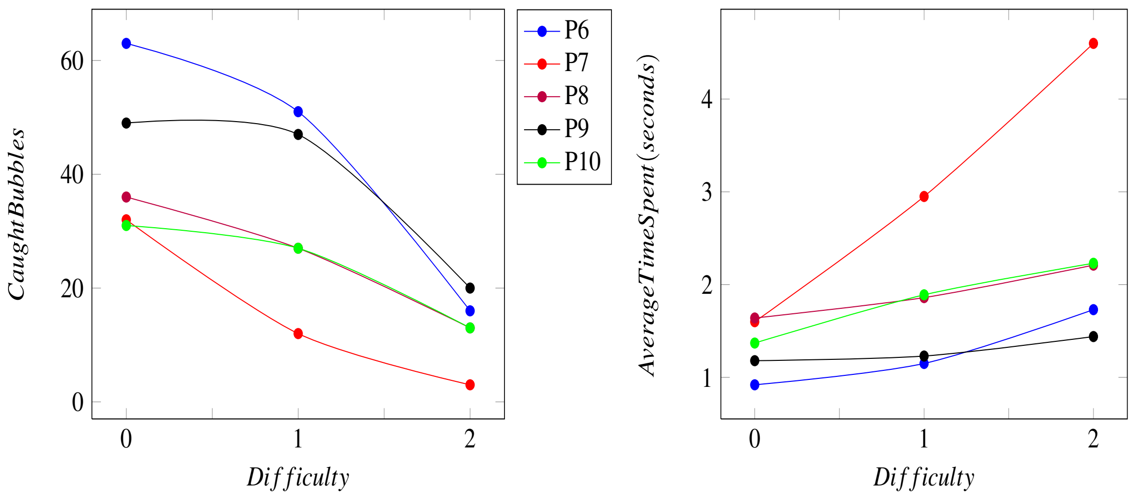


Figure 5.1: Chasing Bubbles graph

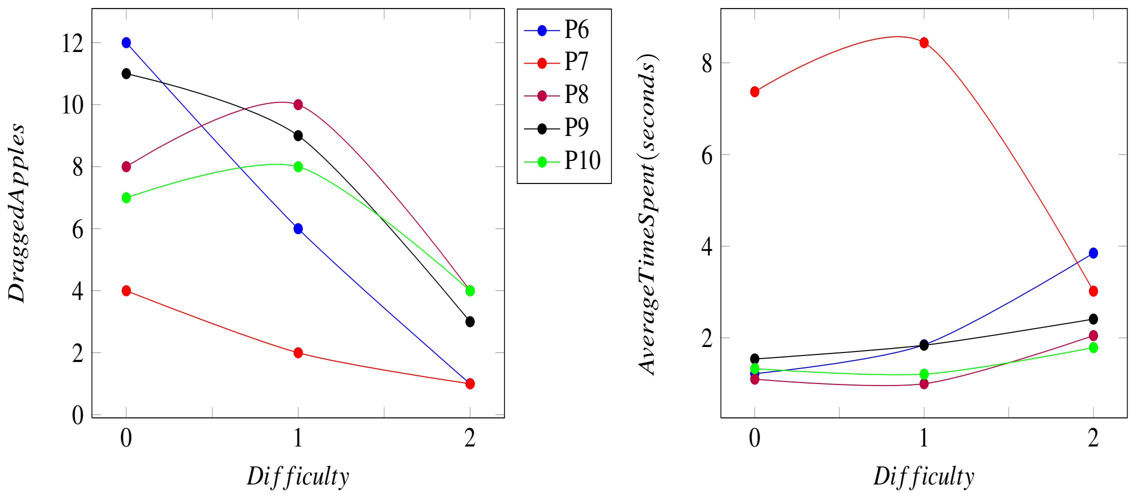


Figure 5.2: Dragging Apples graph

5.5 Results Analysis

The tests were intended to evaluate the PhysicTV system not only by the values obtained during the games, but also by analyzing whether the participants knew what they had to do with the least possible assistance and by their final appreciation.

So, starting by the table of the errors (Table 5.3) it is possible to see that in the Dragging Apples game the number of errors when playing it was minimal and was balanced between errors about the interaction and the goals of the game. Overall the number of requested and non requested assists per participant (Table 5.4) was less than the number of errors which indicates that the provided assists really helped the participant to overcome his error or that the game itself was easily understandable as well as the interaction with the system. On the other hand, the Chasing Bubbles game had perfect results regarding the interaction with the system and the perception of its goals. If we consider that half of the participants never had experience with motion sensors applied to electronic games, the completion rate values of 60% and 100% in the Dragging Apples and Chasing Bubbles game respectively (Table 5.2), for these two tasks (understand the rules and understand the goals of the game) proved to be very satisfatory. Besides, there were two participants, one in each set of tests, that completed the experiment without errors and assists (Table 5.8) and in both cases the experience with similar systems was nonexistent (Table 5.1), which reinforces the simplicity of PhysicTV.

As previously mentioned, the values of the performance of the patients were considered only in the set of rehabilitation patients. Thus, the average times that were collected are very positive due to their limitations in moving their arms to reach the goal. In the Chasing Bubbles game the first two tests had a ratio of number of bubbles per second greater than 0.5 and a very good capture time (Table 5.5). The third test was the worst in these matters because it had less time and was entirely played in the highest difficulty level and as we can see in Figure 5.1 the number of caught bubbles was decreasing and the average time was increasing as the test progressed in every participant. In the Dragging Apples game the existence of standards is not as evident as in the previous case because some patients improved their performance when the difficulty of the tests increased as it is possible to verify in Figure 5.2. However, in the third test there were two participants who only got one apple dragged which can be explained by the fact that they had to make a double effort in the test (by first picking the apple and then dragging it) and it was the last test to perform which led to an accumulated fatigue thus hindering their performance. The detailed values of the performed tests can be consulted in detail in Appendix D (Table D.1 and D.2).

Lastly the satisfaction questionnaires give us an idea of the opinion of the participants that tested the system. So, as we can see in Table 5.7, both sets of participants were satisfied by analyzing the average results obtained through their replies. In a maximum of 160, the first set gave PhysicTV a score of 142 while the second set gave it a score of 141. Both results are close to the maximum value and give us the notion that they really were pleased with what they used and felt good while experiencing and interacting with the system.

Chapter 6

Conclusions

The increase in technological solutions strengthens the belief that over time certain tasks performed by humans can be done faster by machines and thus lead to a permanent replacement. However, it is useful to say that in healthcare many people do not feel comfortable with the use of technologies, relying more on the human component and on the interaction with other people.

What this dissertation provides is a technological solution that is not only an extra motivation for patients but it is also a complement to the physical therapist and not a substitute. The goals of this dissertation were well defined: First, to check with the physiotherapists the feasibility of implementing a project of this kind (Section 3.2.2); Second, to develop the system and games (Chapter 4); Third, to verify the acceptance of patients when using the PhysicTV in their sessions.

Since arm injuries can occur in any person, the variation of the ages of the patients could be very large. Considering that, the game design could not be too complex but at the sime time it had to captivate the users, the game rules could not be too hard to understand but at the same time had to challenge the patients and the games themselves could not be too difficult to play but at the same time had to motivate and to make the patients exercise their injured arm. These challenges were taken into account when developing the PhysicTV and the final product in part agreed with each side of the matter, when analyzing the obtained results.

6.1 Discussion

At the beginning of this project the structure of PhysicTV was a bit different from what it turned out to be. One of the initial concerns was the possibility of integrating the Kinect sensor directly into the GoogleTV in order to have a very innovative technological component to add to the dissertation. However, the sequence of events that happened brought some changes to the project:

- **Sensor change** – The motion sensor to track the users went from the Kinect to the Asus XtionPRO LIVE. This change proved to be very helpful for the development of PhysicTV because the new sensor platform has provided a clear and organized development platform thereby improving the system performance and, more specifically, the server performance.

The new device also proved to be more convenient to work with because it is smaller and lighter than the Kinect;

- **Indirect integration** – The initial plan was to connect directly the motion sensor to the GoogleTV but it soon proved to be impossible so the alternative solution was to use a bridge to allow the connection between the two devices;

- **Target audience** – This project was initially inserted in the Ambient Assisted Living program, with the goal of improving the life conditions of the older users [Liv12], but after the first interview with the physiotherapists it was possible to verify that the patients age could vary a lot leading to an enlargement of the target audiance.

These three changes influenced the course of the project and its development phase but considering the final product and its results they proved to be very advantageous modifications. Regarding the technological components of the system, both GoogleTV and Asus XtionPRO LIVE were suitable for the tasks in the project, both in terms of communication between them and user-system interaction.

Regarding the development of electronic games this project had to meet some requirements:

- Interface with low complexity – The purpose of the project was to develop electronic games to apply in rehabilitation sessions and an interface with the main features that allow trouble-free use by physiotherapists and not an interface full of special features and complex;

- Appealing games – In order to give patients a small escape from the routine they follow during their therapy sessions the developed games should motivate them to exercise while playing them. So, the audiovisual elements should captivate and entertain patients while giving them an idea of what they should do during the game;

- Good efficacy / complexity ratio – The games should maintain a good ratio of effectiveness and complexity because they must be challenging enough to captivate patients and allow them to keep improving their performance but at the same time can not be very complex because if users do not understand what they have to do they will lose too much time trying to understand it and they can even feel demoralized and consequently lose interest in playing games.

The developed games were considered to be very simple to play but at the same time challenging enough for the patients who have never given up and tried to improve their performance from test to test. In the Chasing Bubbles game the perception of the rules was perfect but in the Dragging Apples game there were a few mistakes at the beginning due to the two challenges inherent to the game: picking and dragging. Two possible solutions for those committed errors are a better explanation of the game goal through visual elements and a better perception of when the goal was achieved through sound elements. The inclusion of a game with the objective of navigating a maze was also thought but the complexity of the game was too high due not only to the maze itself but also due to some faults of the sensor when tracking the user leading to slight variations of the cursor position and several colisions with the walls of the labyrinth causing the patient to lose too much time correcting his errors and delaying his arrival at the end of the maze.

The testing phase as well as the support from the physiotherapists proved to be very useful for the evaluation of the system. The process of constant communication and exchange comments and views with therapists allowed to keep the project within the line defined for the development of games. On the other side, tests conducted with physical therapy patients brought real usefulness and validity to the PhysicTV because levels of satisfaction were generally high and the results very satisfactory, as we can see in detail in Section 5.

6.2 Goals Achieved

The continuous interaction with professionals in this area so the system could have useful and completely approved features was on of the main concerns when this project started. At that point, there was a first meeting with them where they committed and offered to accompany the development of the project.

Thanks to that, the game designing was practically defined and the system could be prepared with care and time. Every aspect of the system architecture was taken into account which allowed a perfect communication structure between the server and the client (Section 4.3). Since both structure and operation of the games were already defined the only focus was on the development of the games.

Once concluded the development of the PhysicTV's system there were several tests made not only to verify if eveything was correctly developed but also to see the acceptance of the patients when testing them. As a final contribution from the physiotherapists they gave full access to their sessions room and provided five different patients to test the games. That way they could see the final result of the project and check whether their patients responded well or not.

As previously mentioned, there were three goals defined at the initial stage of this dissertation and they were all completed.

6.3 Contributions

As initially planned, the development of electronic games in Android for physical rehabilitation was successfully applied to rehabilitation sessions. Although there are several electronic games for rehabilitation purposes the innovation of this project was the fact that the alliance between GoogleTV, Asus XtionPRO LIVE and physiotherapy is completely new in the market.

This dissertation also proved that a small and low-cost system can be effective and the proposed solution was feasible.

6.4 Future Work

During the development phase there were several aspects that were considered to be improved. However, due the lack of time and to their lack of importance in this project, they started being sidelined. For future work and research there are two more games to be included (one similar to the existing games and the other a multiplayer game) and there is the chance of not restricting games to arm movements but also to other parts of the body.

In addition, there is also the possibility of adding a feature for the physiotherapist to create exercise plans for their patients to use in their sessions and to customize the angles that can be tracked not to be restricted to the two already defined.

Appendix A

Interview with physiotherapists from CRPG

On this appendix there is a transcription of an interview with health professionals from the CRPG, made on the date of December 13th 2012, with the purpose of publicizing the project and establish some prerequisites for the development of the game.

Question: What kind of injuries or illnesses do you usually treat? Is there any that affects a majority of your patients?
Answer: We treat several types of injuries (traumatic brain injuries, strokes, etc.), so there is not a type that stands out from the others. Anyway, we can state that we only treat patients with acquired injuries, for example, in work accidents.

Q: What is the average age of your patients?
A: We could say that the average age of our patients is about 40 years old.

Q: What can you tell about your patient's profile? About their attitude during sessions, the possibility of accepting a rehabilitation based on electronic games, the motivational impact of this type of physiotherapy, etc?
A: The attitude with which they face the physiotherapy sessions is different from patient to patient because it usually depends on the injury level and actual state of the patient. But we can guarantee that the inclusion of that kind of games and physiotherapy would have a great adherence and would result on an increase of the patients' motivation.

Q: Which exercises do you use the most on your sessions with the patients?
A: Due to the variety of injury cases that we deal with, we usually do not repeat exercises. The definition and choice of exercises for our sessions also varies a lot from patient to patient . Still, we are always looking to do dynamic movements even if they are a bit repetitve.

Q: The exercises you usually suggest and give to the patients are the same for everyone or is there any kind of customization for every patient?
A: The type of exercises is the same, but the movements that caracterize them are always different. Since every patient has his own injury level and evolution state, we always have to create exercise plans for every patient, therefore we can say that there is a certain customization for almost every patient.

Q: What kind of approach do you usually have with your patients? An approach where you compliment their effort and prefer not to force their movements during the exercises or an approach where you always try to get more from them?
A: Normally we choose to encourage them and try to ask always more, but we always do a preliminary study of the patient's potential, considering his psychological profile and his injury's state. We always try to get the most they can give, excepting cases of progressive disease.

Q: What kind of exercises or movements can be made autonomously? That is, if they could be done at home, which ones would not need supervision from a professional?
A: The movements that do not need a fulltime supervision are the simplest ones and, because of that, can be done at home. For example, slight movements of the body.

Q: Usually, which parameters do you consider on the exercises to evaluate the patients' evolution? For example, movement speed, strength, angle, etc.
A: What we usually evaluate on the exercises is the range of the movement. For example, on a patient with a functional deficit of the upper limb, we tend to define movement axis that, in this case, allow them to exercise the hand, the arm and the shoulder, in this order, so the recovery process can be more effective. It is important to help him do some functional movements such as the action of eating by taking the hand to the mouth and the opposite movement. By creating and and instilling these routines in patients we are helping them to quickly regain these simple but very important movements. Besides, we usually define a scale from 0 to 5 that determines the patient's movement ability. The lowest value applies to the patients with plegia (no movement) and the highest value applies to the patients with a good ability of movement. The type of patients we usually work with can be included in the middle of that scale because they are patients with paresis (some movement).

Q: What kind of exercises would you suggest to be included in this project that have a good complexity/efficiency ratio, that is, exercises that are not neither too complex nor too simple but that allow a good recovery for the patient?
A: Exercises involving dynamic movements. For example, touching a ball that would appear in random areas of the screen, dragging pieces on a board, moving an object in a maze, etc.

Q: Are there any manuals/bibliographic references where you usually get ideas for the conception of the exercises?

A: We usually do not use bibliographic references for that purpose. Whenever we want to inovate on the creation of exercises or exercise plans we normally search on the internet.

Interview with physiotherapists from CRPG

Appendix B

System Usability Scale Questionnaire

This appendix shows the questions of the questionnaire presented to the test participants in order to know their opinion about the PhysicTV. Each question had as a possible answer a value between 1 (Strongly Disagree) and 5 (Strongly Agree).

1 – *I think that I would like to use this system frequently*
2 – *I found the system unnecessarily complex*
3 – *I thought the system was easy to use*
4 – *I think that I would need the support of a technical person to be able to use this system*
5 – *I found the various functions in the system were well integrated*
6 – *Whenever I make a mistake using the system, I have difficulties in recovering*
7 – *I thought most people could learn how to use this system very quickly*
8 – *I thought there was too much inconsistency in this system*
9 – *I felt very confident when using the system*
10 – *I found the system very inconvenient to use*
11 – *The organization of information on the system screen was clear*
12 – *The information provided for the system is hard to understand*
13 – *The interface of this system is pleasant*
14 – *I needed to learn a lot of things before I could get going with this system*
15 – *I like using the interface of this system*
16 – *Overall, I am not satisfied with this system*

System Usability Scale Questionnaire

Appendix C

Patient's Graph Image

This appendix, mentioned in Section 4.2.2, is exclusively to show the image of a patient's graph in its original dimensions. The blue line is the maximum value of the obtained angle in the session and the green line refers to the average value of the same angle in the same session.

Patient's Graph Image

Appendix D

Tables

This appendix has the tables with the obtained values in the tests performed at CRPG on June 4, 2013. The first table refers to the Chasing Bubbles game and the second one refers to the Dragging Apples game. These tables aim to show, in a more detailed way, the values listed in the graphics present in Section 5.4.2.

	Chasing Bubbles																	
	1st Test						*2nd Test*						*3rd Test*					
	Dif	T	No	Fa	Sl	Av	Dif	T	No	Fa	Sl	Av	Dif	T	No	Fa	Sl	Av
P6	EH	60	63	0.02	2.38	0.92	MH	60	51	0.07	2.50	1.15	H	30	16	0.08	5.74	1.73
P7	EH	60	32	0.05	3.58	1.60	MH	60	12	0.19	6.26	2.95	H	30	3	2.24	9.19	4.60
P8	EH	60	36	0.04	4.47	1.64	MH	60	27	0.02	3.21	1.86	H	30	13	1.37	3.30	2.21
P9	EH	60	49	0.10	3.40	1.18	MH	60	47	0,06	2.68	1.23	H	30	20	0.20	2.29	1.44
P10	EH	60	31	0.05	4.10	1.37	MH	60	27	0.12	5.55	1.89	H	30	13	0.06	4.70	2.23

Table D.1: Chasing Bubbles detailed results

	Dragging Apples									
	1st Test		*Picking Apple*				*Moving Apple*			
Participant	Dif	T	No	Fa	Sl	Av	No	Fa	Sl	Av
P6	EH	60	12	2.37	4.23	3.20	12	0.01	3.62	1.22
P7	EH	60	5	2.7	8.17	6.05	4	0.03	23.92	7.37
P8	EH	60	9	2.71	16.05	5.58	8	0.51	1.90	1.10
P9	EH	60	12	2.23	5.52	3.53	11	0.03	8.28	1.54
P10	EH	60	7	1.18	17.00	6.71	7	0.01	2.37	1.33
	2nd Test		*Picking Apple*				*Moving Apple*			
P6	MH	60	6	2.47	8.65	4.51	6	0.90	2.57	1.85
P7	MH	60	3	2.82	6.54	5.02	2	5.30	11.58	8.44
P8	MH	60	10	3.05	6.87	4.53	10	0.18	1.78	1.00
P9	MH	60	9	2.24	6.53	4.45	9	1.12	2.52	1.84
P10	MH	60	8	2.15	6.51	3.47	8	0.01	1.69	1.21
	3rd Test		*Picking Apple*				*Moving Apple*			
P6	H	30	1	3.10	3.10	3.10	1	3.85	3.85	3.85
P7	H	30	1	19.38	19.38	19.38	1	3.02	3.02	3.02
P8	H	30	4	3.56	6.43	5.36	4	1.44	3.48	2.05
P9	H	30	3	4.18	8.69	6.44	3	0.99	3.15	2.41
P10	H	30	4	3.06	9.16	4.89	4	1.03	2.52	1.79

Table D.2: Dragging Apples detailed results

Dif – Difficulty level
T – Time (in seconds)
No – Number of bubbles/apples
Sl – Slowest time (in seconds)
Fa – Fastest time (in seconds)
Av – Average time (in seconds)
EH – Easy to Hard
MH – Medium to Hard
H – Hard

References

[AAB10] Fraser Anderson, Michelle Annett, and Walter F. Bischof. Lean on wii: Physical rehabilitation with virtua reality wii peripherals. In *Annual Review of Cybertherapy and Telemedicine 2010*, pages 229–234, 2010.

[acs07] acspike. male user icon. From `http://openclipart.org/detail/4749/male-user-icon-by-acspike`, 2007. Online: Last consulted in 17th June 2013.

[Ant08] Alissa N. Antle. Child-based personas: Need, ability and experience. *Journal of NeuroEngineering and Rehabilitation*, pages 155–166, 2008.

[Asu13] Asus. XtionPRO LIVE. From `http://www.asus.com/Multimedia/Xtion_PRO_LIVE/`, 2013. Online: Last consulted in 9th June 2013.

[Blo02] Stefan Blomkvist. Persona – an overview. Technical report, Uppsala Universitet, September 2002.

[BMC+09] J. W. Burke, M. D. J. McNeill, D. K. Charles, P. J. Morrow, J.H. Crosbie, and S. McDonough. Serious games for upper limb rehabilitation following stroke. In *2009 Conference in Games and Virtual Worlds for Serious Applications, VS-GAMES 2009, March 23, 2009 - March 24, 2009*, pages 103–110. IEEE Computer Society, 2009.

[CLS08] Yen-Ning Chang, Youn-Kyung Lim, and Erik Stolterman. Personas: From theory to practices. In *NordiCHI 2008: Building Bridges - 5th Nordic Conference on Human-Computer Interaction, October 20, 2008 - October 22, 2008*, pages 439–442. Association for Computing Machinery, 2008.

[Coo99] Alan Cooper. *The Inmates are Running the Asylum— Why High-Tech Products Drive us Crazy and How to Restore the Sanity*. Macmillan Publishing Company Inc, 1999.

[Coo08] Alan Cooper. The origin of personas. From `http://www.cooper.com/journal/2003/08/the_origin_of_personas.html`, May 2008. Online: Last consulted in 9th June 2013.

[CPM+06] Roberto Colombo, Fabrizio Pisano, Alessandra Mazzone, Carmen Delconte, Giuseppe Minuco, Silvestro Micera, M. Chiara Carrozza, and Paolo Dario. Motor performance evaluation to improve patient's compliance during robot-aided rehabilitation. In *1st IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechatronics, 2006, BioRob 2006, February 20, 2006 - February 22, 2006*, 2006.

[DCC+12] E. Davaasambuu, C. C. Chiang, J.Y. Chiang, Y.F. Chen, and S. Bilgee. A microsoft kinect based virtual rehabilitation system. In *The 5th International Conference FI-TAT 2012*, 2012.

[FTC+08] Eletha Flores, Gabriel Tobon, Ettore Cavallaro, Francesca I. Cavallaro, Joel C. Perry, and Thierry Keller. Improving patient motivation in game development for motor deficit rehabilitation. In *2008 International Conference on Advances in Computer Entertainment Technology, ACE 2008, December 3, 2008 - December 5, 2008*, pages 381–384. Association for Computing Machinery, 2008.

[gdg] gdgt. Microsoft Kinect for Windows. From `http://gdgt.com/microsoft/kinect-for-windows/`. Online: Last consulted in 17th June 2013.

[Gesa] GestureTek. The Best in Virtual Reality Physical Therapy. From `http://www.gesturetekhealth.com/products-rehab-irex.php`. Online: Last consulted in 9th June 2013.

[Gesb] GestureTek. Gesturetek Health Immersive Therapy Suite. From `http://www.gesturetekhealth.com/products-immersive-therapy-suite.php`. Online: Last consulted in 9th June 2013.

[Goo13] Google. GoogleTV Features. From `http://www.google.com/tv/features.html`, January 2013. Online: Last consulted in 17th June 2013.

[GSM+09] Rhona Guberek, Sheila Schneiberg, Patricia McKinley, Felicia Cosentino, Mindy F. Levin, and Heidi Sveistrup. Virtual reality as adjunctive therapy for upper limb rehabilitation in cerebral palsy. In *2009 Virtual Rehabilitation International Conference, VR 2009, June 29, 2009 - July 2, 2009*, page 219. IEEE Computer Society, 2009.

[Kat10] Pamela M Kato. Video games in health care: Closing the gap. *Review of General Psychology*, 14(2):113–121, 2010.

[KDZN12] M. E. Kho, A. Damluji, J. M. Zanni, and D. M. Needham. Feasibility and observed safety of interactive video games for physical rehabilitation in the intensive care unit: A case series. *Journal of Critical Care*, 27:219.e1–219.e6, 2012.

[LCH04] R.C.V. Loureiro, C. F. Collin, and W. S. Harwin. Robot aided therapy: challenges ahead for upper limb stroke rehabilitation. In *Proceed of Intl Conf on Disability, Virtual Reality and Assoc Tech*, pages 33–39, 2004.

[LCS+11a] Belinda Lange, Chien-Yen Chang, Evan Suma, Bradley Newman, Albert Skip Rizzo, and Mark Bolas. Development and evaluation of low cost game-based balance rehabilitation tool using the microsoft kinect sensor. In *33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS 2011, August 30, 2011 - September 3, 2011*, pages 1831–1834. IEEE Computer Society, 2011.

[LCS+11b] Belinda Lange, Chien-Yen Chang, Evan Suma, Bradley Newman, Albert Skip Rizzo, and Mark Bolas. Development and evaluation of low cost game-based balance rehabilitation tool using the microsoft kinect sensor. In *33rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS 2011, August 30, 2011 - September 3, 2011*, 2011.

[Lew90] Rebecca Lewthwaite. Motivational considerations in physical activity involvement. *Physical Therapy*, 70(12):808–819, 1990.

[Liv12] AAL Ambient Assisted Living. Objectives. From http://www.aal-europe.eu/about/objectives/, 2012. Online: Last consulted in 9th June 2013.

[LKM+12] Belinda Lange, Sebastian Koenig, Eric McConnell, Chien-Yen Chang, Rick Juang, Evan Suma, Mark Bolas, and Albert Rizzo. Interactive game-based rehabilitation using the microsoft kinect. In *19th IEEE Virtual Reality Conference, VR 2012, March 4, 2012 - March 8, 2012*, 2012.

[Mic11] Microsoft. Kinect Effect Reaches Into Hospitals, Senior Centers. From http://www.microsoft.com/en-us/news/features/2011/dec11/12-19KinectEffect.aspx, December 2011. Online: Last consulted in 9th June 2013.

[Mic12] Microsoft. Kinect For Windows Features. From http://www.microsoft.com/en-us/kinectforwindows/discover/features.aspx, October 2012. Online: Last consulted in 9th June 2013.

[Mic13] Microsoft. Skeletal Tracking. From http://msdn.microsoft.com/en-us/library/hh973074.aspx, 2013. Online: Last consulted in 17th June 2013.

[Pap09] Marina Papastergiou. Exploring the potential of computer and video games for health and physical education: A literature review. *Computers and Education*, pages 603–622, 2009.

[Pav11] Pavel. User Guide for Dual Depth Sensor Configuration. From http://wiki.ipisoft.com/User_Guide_for_Dual_Depth_Sensor_Configuration, 2011. Online: Last consulted in 17th June 2013.

[PG03] John Pruitt and Jonathan Grudin. Personas: Practice and theory. In *2003 Conference on Designing for User Experiences, DUX '03, June 6, 2003 - June 7, 2003*. Association for Computing Machinery, 2003.

[RB10] MPT Richard Bantion. Physical therapy in 2020. *Journal of The Spinal Research Foundation*, 5, 2010.

[Red11a] Rebecca Redmond. Wii Fit. From http://www.wiihabilitation.co.uk/games_wiifit.pdf, 2011. Online: Last consulted in 9th June 2013.

[Red11b] Rebecca Redmond. Wii-Habilitation. From http://www.wiihabilitation.co.uk/main.shtml, 2011. Online: Last consulted in 9th June 2013.

[Red11c] Rebecca Redmond. Wii Sports. From http://www.wiihabilitation.co.uk/games_wiisports.pdf, 2011. Online: Last consulted in 9th June 2013.

[RH07] David J. Reinkensmeyer and Sarah J. Housman. 'if i can't do it once, why do it a hundred times?': Connecting volition to movement success in a virtual environment motivates people to exercise the arm after stroke. In *2007 Virtual Rehabilitation, IWVR, September 27, 2007 - September 29, 2007*, pages 44–48. Inst. of Elec. and Elec. Eng. Computer Society, 2007.

[SCB] Jan Victor Soares Santos, Leonardo Cesar Carvalho, and Paulo Alexandre Bressan. Physioplay: Um exergame para reabilitação física aplicando a interatividade do kinect como biofeedback visual.

[STKRR09] Stuart T. Smith, Amir Talaei-Khoei, Mililani Ray, and Pradeep Ray. Electronic games for aged care and rehabilitation. In *2009 11th IEEE International Conference on e-Health Networking, Applications and Services, Healthcom 2009, December 16, 2009 - December 18, 2009*, pages 42–47. IEEE Computer Society, 2009.

[SWEBB09] Heidi Sugarman, Aviva Weisel-Eichler, A Burstin, and R Brown. Use of the wii fit system for the treatment of balance problems in the elderly: A feasibility study. In *Virtual Rehabilitation International Conference, 2009*, pages 111–116. IEEE, 2009.

[SWY+11] Richard H.Y. So, K.P. Wong, S.L. Yuen, J. Tang, H. Yeung, and J. Liu. Virtual reality gaming for rehabilitation: An evaluation study with physio- and occupational therapists. In *10th International Conference on Virtual Reality Continuum and Its Applications in Industry, VRCAI'11, December 11, 2011 - December 12, 2011*, pages 503–506. Association for Computing Machinery, 2011.

[Tek] Gesture Tek. Gesturetek health immersive therapy suite. From `http://www.gesturetekhealth.com/products-immersive-therapy-suite.php`.

[VFML04] Antonin Viau, Anatol G. Feldman, Bradford J. McFadyen, and Mindy F. Levin. Reaching in reality and virtual reality: a comparison of movement kinematics in healthy subjects and in adults with hemiparesis. *Journal of NeuroEngineering and Rehabilitation*, pages 1–7, 2004.

[Vin10] Vincent John Vincent. Point of View. From `http://www.gesturetek.com/newscenter/newsletters/autumn2010/autumn-2010.html`, 2010.

[Vir13a] VirtualWare. Virtualrehab. From `http://virtualrehab.info/`, 2013. Online: Last consulted in 12th June 2013.

[Vir13b] VirtualWare. Virtualrehab. From `http://virtualrehab.info/en/product/`, 2013. Online: Last consulted in 17th June 2013.

[WK09] PL Weiss and Evelyne Klinger. Moving beyond single user, local virtual environments for rehabilitation. *Studies in Health Technology and Informatics*, 145:263–276, 2009.

[WR] Wii-Remote. Wii-Remote. From `http://www.wiiremote.co.uk/`.

[WT12] WKYC-TV. Virtual video games get physical therapy patients moving. September 2012.

[YJC11] Jun-Da Huange Yao-Jen Chang, Shu-Fang Chen. A kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities. *Research in developmental disabilities*, pages 2566–2570, 2011.