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Gamification as a mean to promote user physical activity

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Mestrado Integrado em Engenharia Informática e Computação

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Abstract

According to the World Health Organization breast cancer is responsible for more than 500,000 deaths among women around the world.

Despite recent technological advances that enable multiple management possibilities to the disease, the survivors may potentially still experience multiple functional impairments resultant of treatment, which impact their daily life, thus requiring rehabilitation to improve their quality of life. Given that the five-year relative survival rate is of about 90% it becomes imperative that the rehabilitation process is improved.

The constant increase in the acceptance of serious games by society, especially in health, makes it so that tools that support the maintenance of good habits has increased, leading to a greater interest in the development of additional tools that are capable of not only encourage this type of behaviour, but also evaluate it and adapt it to the patient.

With the technology currently available to support the rehabilitation process, there is the possibility of reducing the need for the contribution of a trained professional and allowing the exercise to be performed from the comfort of the patient's home, reducing costs for both the patient and the service provider, improving overall patient comfort.

This work proposes the development of a serious game to act as a supplementary tool for the physiotherapist's kit, replacing the basic informational pamphlet and simple advising of exercising.

The game consists of an exercise routine in which the user must mimic, at his own pace, the movements displayed. A Microsoft Kinect v2 is used to track these movements. The movements are analysed and given a rating of how well they were done. Upon finishing the routine, the patient is given a classification and shown how well he did in each exercise set.

To enhance motivation through the perception of improvement, different visualization representation methods are developed and tested in a home-based application by a breast cancer patient.

The lack of socialization for patients suffering from this condition is also a concern. To address it, multi-player game modes were also developed to enable the patient to, locally, play the game with friends and family.

Resumo

De acordo com a Organização Mundial de Saúde, o cancro da mama é responsável por mais de 500 mil mortes entre mulheres em todo o mundo.

Apesar de recentes avanços tecnológicos que permitem múltiplas possibilidades de controlo da doença, os sobreviventes podem, potencialmente, sofrer de diversas deficiências motoras resultantes do tratamento, podendo estas afetar a sua vida quotidiana, exigindo assim o uso de reabilitação para melhorar a sua qualidade de vida. Dado que a taxa de sobrevivência relativa de cinco anos é de cerca de 90%, torna-se imperativo que o processo de reabilitação seja melhorado.

O constante aumento da aceitação de jogos sérios por parte da sociedade, especialmente a nível da saúde, faz com que ferramentas de suporte à manutenção de bons hábitos tenham vindo a verificar um aumento, levando a um maior interesse relativo ao desenvolvimento de ferramentas que sejam capazes de, não só incentivar este tipo de comportamentos, mas também avaliá-los e adaptá-los ao paciente.

Com a tecnologia atualmente disponível para apoiar o processo de reabilitação, surge a possibilidade de reduzir a necessidade da contribuição de um profissional treinado e permitir que o exercício seja realizado a partir do conforto da casa do paciente, reduzindo os custos tanto para este como para o prestador de serviços.

Este trabalho propõe assim o desenvolvimento de um jogo sério para atuar como uma ferramenta suplementar ao atual conjunto de ferramentas disponíveis ao fisioterapeuta, substituindo o atual uso de um panfleto informativo e o simples aconselhamento de exercício.

O jogo consiste numa rotina de exercícios onde o utilizador deve copiar, ao seu próprio ritmo, os exercícios demonstrados. Para captar os movimentos do utilizador é utilizado o Microsoft Kinect v2, que irá captar os movimentos e subsequentemente analisará e atribuirá uma classificação relativa ao quão corretamente estes foram desempenhados. Ao terminar a rotina é atribuída ao paciente uma avaliação final, onde é mostrado o quão corretamente efetuou os exercícios.

Para aumentar os níveis de motivação através da perceção de melhoria da sua condição, diferentes métodos de representação visual foram desenvolvidos e testados por um paciente numa versão da aplicação para uso em casa.

A falta de socialização dos pacientes que sofrem desta condição é também uma causa para preocupação. De modo a tentar resolver esta situação diferentes modos de jogo, para múltiplos jogadores, foram também desenvolvidos, permitindo que o paciente possa, localmente, jogar com amigos e familiares.

Acknowledgements

First and foremost I'd like to thank my supervisors Hélder Oliveira and João Monteiro, for their guidance and help, without whom this project would not had been possible.

A special thanks to António Nunes, for always being available to help with grammatical reviews and game design ideas.

Last but not least, a heartfelt thanks to my parents for the support provided throughout this project.

Nuno Correia Duarte

"Perhaps having the courage to find a better path is having the courage to risk making new mistakes."

Robin Hobb

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Abreviaturas e Símbolos

BIS	Bioelectrical impedance spectroscopy
CT	Computed tomography
DEXA	Bone Density Scan
HCI	Human-Computer Interaction
HER2	Human Epidermal growth factor Receptor-type 2
NPC	Non-Playable Character
PTSD	Posttraumatic Stress Disorder
ROM	Range of Motion
WHO	World Health Organization

Chapter 1

Introduction

In its simplest form, the project consists on creating a system that is able to detect human movement and correctly classify it, while giving the registered movement a score based on how well it was performed. This ability is then used to create a serious game that can complement a breast cancer patient's rehabilitation routine, by providing it with challenges and feedback on how these challenges were completed. The game is composed of an individualist main game mode, possessing two additional game modes created to encourage socialization through cooperation and competitiveness. Additionally, the game possesses different progress visualization modes to promote motivation. A special interface is offered to therapists in which information from the patient's routines is provided, including a virtual goniometer to allow for a better perception of the user's range of motion.

The project focuses on finding out if such a system is an option preferred to the currently used one at the São João Hospital.

In this chapter, a general overview of what encompasses the thesis is provided. The chapter begins by providing context and motivation, followed by goals focused by the thesis and contributions resulting of it. At the end of this chapter, a small approach to the structure of the remaining of the document is taken.

1.1 Context

Of all the types of cancer-related deaths, breast cancer is one of the most common [134]. Of all types of cancer, for both genders, it accounts about 12% of all incident cases, 6.4% cases of mortality and highest prevalence in periods of 1, 3 and 5 years, with immensely more cases being registered in women [42]. Although curable, if detected early on and correctly treated, there are many long-term complications that can result of such events [101] [102]. The symptoms resultant as complications of some treatments impact the quality of life of the patient, not only by restricting many of its movements, but also by demotivating the patient. All of these symptoms can somewhat be alleviated by the patient through the performance of a plethora of exercises to improve the mobility of the affected regions and its overall psychological state [101] [102]. Although exercise helps with most of the psychological symptoms, some complications of the breast cancer treatment will require more specific exercises.

Since the late 80's a genre of video game called exergaming has risen. Exergaming or exergames can be described as a type of video game or multimedia interaction that requires the player to physically move in order to play [136].

With the evolution of video game acceptance by the general public, serious games have begun to surge, spreading into the health system where they can provide a more personalized health option to the patients, improving not just physical but also mental aspects [120] [84] [45]. This surge and the evolution of visual computing allow the development of a personalized home system which can not only evaluate the patient's state, but also suggest and evaluate exercises [108] [17].

Specifically for rehabilitation, research has already been done, where small game prototypes were tested for very specific circumstances such as: lower limb rehabilitaiton [122], upper limb rehabilitation [61] [71], stroke rehabiliation [53], neurological injury rehabiliation [70], and multiple sclerosis rehabilitation [127].

1.2 Motivation

As patients begin their rehabilitation, in some cases, additional exercises are recommended by therapists, through the distribution of a pamphlet [22], to do at home as a reinforcement to the supervised session, to further increase the speed of their recovery. These unsupervised exercises are many times ignored or poorly performed, due to the inability of the patient to correctly measure if he himself is correctly performing these, or by fear of hurting himself in the process.

With the progress noted throughout the last decade, in terms of human movement recognition, new possibilities arise for home-based solutions regarding systems that can possibly observe, in some form, the user's movements and evaluate them. Such systems are commonly comprised of both a capture device and a processing device, which may be imbued in the capture device, such as [61] [127]. These capture devices can range from complex 3D camera setups [56], to simple webcams [29], or even inertial sensors[110]. The advances of the gaming industry have also contributed to this progress through the development of low-cost yet very efficient capture devices such as the PlayStation EyeToy[1]/Eye[2]/Camera[3] or the Microsoft Kinect [4], which allow many users the possibility to acquire such instruments.

Video games also possess an important role in the possibility of helping patient rehabilitation by providing the possibility of a gamified exercise routine. Some video games have already delved into this field, ranging from very basic dance representation, such as the arcade implementation of Dance Dance Revolution[5], to fitness specific exercises such as the WiiFit [6]. This gamification

[1] en.wikipedia.org/wiki/EyeToy
[2] en.wikipedia.org/wiki/PlayStation_Eye
[3] en.wikipedia.org/wiki/PlayStation_Camera
[4] developer.microsoft.com/pt-pt/windows/kinect
[5] en.wikipedia.org/wiki/Dance_Dance_Revolution
[6] wiifit.com

of the exercises routines provides a way to not just increase user engagement, but also continuous motivation by providing constant challenges to the user.

Through the usage of such a system that encompasses these aspects not only would the patient obtain an instrument to further boost his rehabilitation progress, but the supervising therapist could obtain extra data regarding the performance of the patient allowing for a better planning of the remaining rehabilitation process.

1.3 Goals

The aim of this thesis is the development of a system that through the usage of human movement recognition techniques is able to correctly classify a specific executed movement and evaluate it. This ability is to be then harnessed and used in the development of a serious game that can be used as a complementary tool in breast cancer patients' rehabilitation program, by providing new challenges to keep them motivated and provide the physiotherapist with additional information about the patient's capabilities. On the note of motivation, the system also aims to provide different progress visualizations so that the user can select the one that pleases him most.

The goal is thus to prove that this home-based system is not just preferred to the current one, but that it can also eventually be spread to different rehabilitation programmes.

1.4 Main Contributions

This work had the following main contributions:

- Creation of a prototype home-based game that has been clinically tested with breast cancer rehabilitation patients that demonstrated better results when compared to the current at home system and to a similar system tested in the same conditions.
- A small dataset was recorded, with Kinect Studio v2.0, with some of the patients performing the routine exercises, which can be used to create a new movement databases.
- The results obtained from this project have also been used by Dr. André Magalhães in a presentation at AECIMA.

1.5 Document Structure

In addition to this introductory chapter, the document is composed of 7 more chapters. Covering background literature review there are 3 chapters. The first covers medical concepts, 2, the second technological concepts, 4, and the third relates to human-machine interaction concepts, 3.

Following the literature review there is a chapter where the problem is again focused, presenting studies that have tried to tackle different parts of it. Next a methodology proposed for this project is discussed, 5, followed by a chapter covering its implementation, 6 and a chapter reviewing the results obtained from it, 7.

In the final chapter, 8 , an overall conclusion can be found along with other contributions, limitations, and future work is discussed.

Chapter 2

Medical Overview

The following chapter will go through a brief medical overview and is intended to give the reader a general sense of the disease, anatomy of the affected regions, treatments available, possible unwanted side-effects of what such treatments may cause, lymphedema and possible treatments for it.

2.1 Cancer

Cancer is a term given to a collection of diseases which involve abnormal cell growth in the body. This is a genetic disease and as such can be inherited, resultant of cell division errors or even from DNA damage derived from environment exposure, such as tobacco smoke, radiation, or ultraviolet rays [93]. Additionally, incidence of cancer increases with age, as cellular repair mechanisms become less effective [134].

The genes affected that contribute to the development of cancer are, proto-oncogenes, involved in the normal cell growth and division which in the case of cancer suffer and increase of function, tumour suppressor genes, also involved in the regulation of cell growth and division, this changes result in a decrease of function of these genes, and DNA repair genes, which when altered may provoke an increase in further gene mutation [93] [51].

Among the vast amount of types of malignant cancer, one can be defined as such if six cell alterations are present, being these, self-sufficiency in growth signals, insensitivity to anti-growth signals (antigrowth), evasion of programmed cell death (apoptosis), limitless replicative potential, sustained angiogenesis, and tissue invasion and metastasis [51].

As this uncontrolled growth and lack of cell death occurs, many types of cancer can begin to form a mass of tissue, usually referred to as a lump, growth, or tumour [92]. These tumours are malignant and capable of spreading or invading nearby tissue, even reaching the point where a part of it can break of and spread through the blood or lymph system, thus forming tumours in regions of the body very distant from the original one [93].

2.1.1 Breast Anatomy, Physiology and Lymphatic System

The mammae, or breast, exists in both sexes. While in the male they are rudimentary throughout life, in the female they are undeveloped before puberty and undergo considerable growth and elaboration after puberty [47]. The mammae consists of glandular tissue, which secrets milk, fibrous tissue, connecting its lobes, adipose tissue in the intervals between the lobes. The subcutaneous tissue encloses the gland and sends numerous septa (walls or partitions dividing a body space or cavity) into it to support its various lobules. From the part of the fascia which covers the gland fibrous processes pass forwards to the skin and the papilla, which are better developed over the upper part of the breast and constitute the suspensory ligaments. These ligaments may become contracted by fibrosis in breast cancer, causing the overlying skin to become pitted and retracted. The normal gland tissue forms a lobulated mass which consists of fifteen to twenty lobes. These are composed of lobules, connected by areolar tissue, blood vessels and ducts. The ducts are composed of areolar tissue containing elastic fibres.

A representation of the secretory lobules can be seen in 2.1.

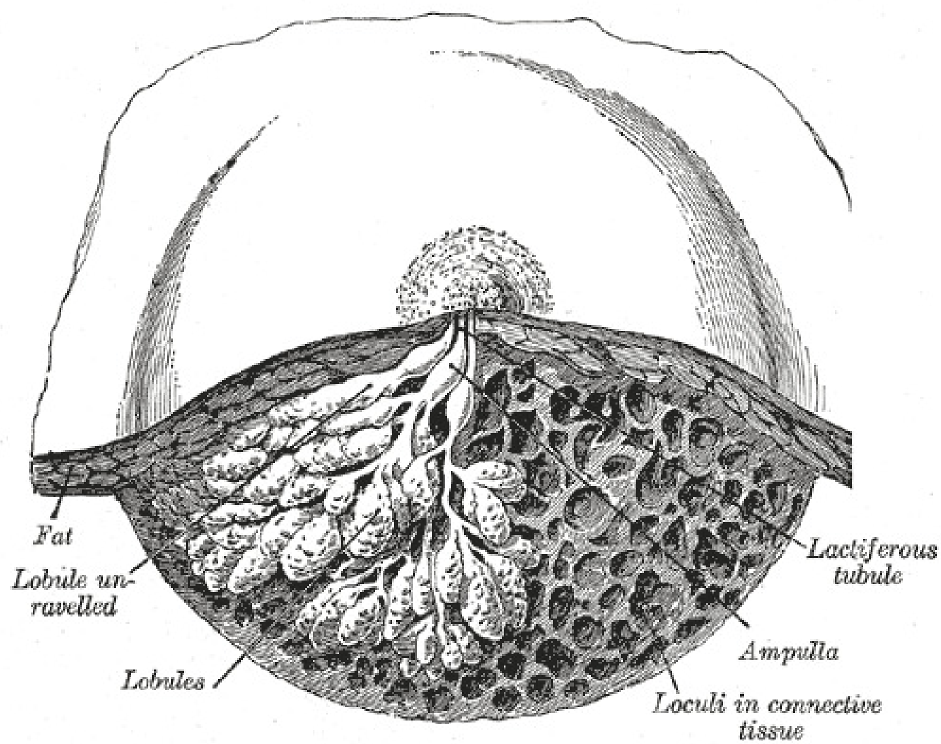

Figure 2.1: A dissection showing increased secretory lobules in the breast during lactation (From [48]

The lymphatic system comprises plexuses of minute vessels (lymph capillaries), that ultimately empty their contents (lymph) into certain veins, lymph nodes, consisting of small solid masses of lymphoid tissue, into which the lymph vessels at some part of their course pour their lymph, collections of lymphoid tissue and circulating lymphocytes. The lymph capillaries form the pathway for absorption of colloid material from the tissue spaces, whereas the blood capillaries are more concerned with absorption of soluble crystalloid substances. Thus, if the lymph vessels become obstructed, the tissues drained by them become oedematous and distended with a fluid containing much protein.

The lymph vessels of the mammary gland originate in a plexus in the interlobular connective tissue and in the walls of the lactiferous ducts. This communicates with the overlying cutaneous lymphatic plexus especially around the nipple. It is also claimed to communicate with the plexus of minute vessels on the deep fascia underlying the breast, offering an alternative route when the usual pathways are obstructed.

Efferent lymph vessels arising directly from the breast pass around the anterior border of the axilla, pierce the axillary fascia and end in the pectoral lymph nodes. From the upper part of the breast, a few lymph vessels pass to the apical nodes. This pathway may be interrupted in the infraclavicular nodes or in small and inconstant interpectoral nodes. The axillary nodes commonly receive more than 75% of the lymph from the breast.

A representation of the lymph vessels can be seen in 2.2.

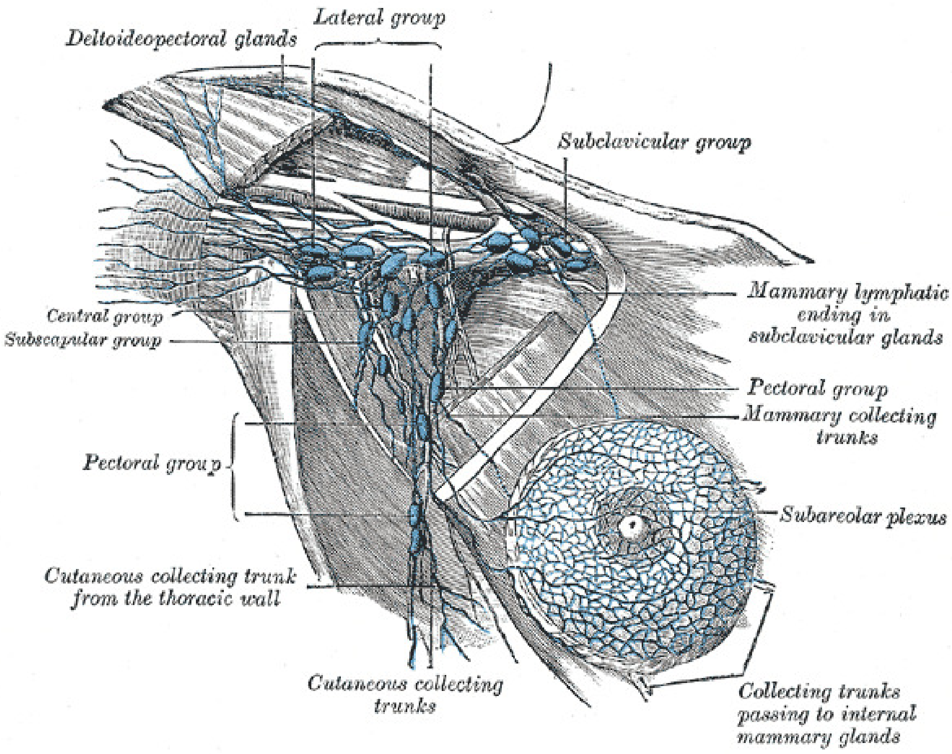

Figure 2.2: Lymph vessels of the mammary gland and the axillary lymph nodes (From [46]

2.1.2 Breast Carcinoma

When cells in the breast tissue start developing cancer symptoms it is considered a breast cancer. Despite being able to develop many different tissues, most breast cancers start either in the lactiferous canals, known as ductal cancers, or in the cells of the lobules, referred to as lobular cancers [5].

Breast cancer is usually divided into two classes, invasive and non-invasive. Non-invasive cancer, is a type of cancer in which the cells do not expand into other surrounding cells, thus earning it the name carcinoma in situ, which means “in the same place”. Invasive cancer on the other hand will spread into the surrounding cells and can even travel through the lymph nodes [4].

2.1.3 Breast Cancer Treatment

Treatment of breast cancer aims to control the disease while trying to achieve a cure. This control can be achieved through different options depending on various aspects of the disease and overall health of the patient. The treatments usually fall into main categories, with each having its own diverse methods, those being: radiotherapy, systemic therapy and treatment targeted at HER2. [16] [39].

Surgery is the most common sought out path, being employed for different reasons, not only for tumour removal but also to check if the cancer has spread to lymph nodes and/or remove it if necessary and thus trying to achieve total disease control. [16][39].

Initial surgery treatments of breast cancer were typically wide excisions, but the recurrence rates were high and survival rates were low, eventually being replaced with radical mastectomy, which had a much lower recurrence rate [39].

Now-a-days a wider range of surgical procedures are available being mostly divided in two types: mastectomy and Breast Cancer Conservative Treatment (BCCT) [96].

A mastectomy involves the full removal of the breast, having different procedural approaches such as [3]:

• Simple mastectomy: most common type of mastectomy used in breast cancer it consists on the removal of the entire breast, without removal of underarm lymph nodes or muscle tissue.

• Radical mastectomy: removal of entire breast, underarm lymph nodes and pectoral muscles under the breast.

• Modified radical mastectomy: a simple mastectomy that includes the removal of underarm lymph nodes.

• Skinsparing mastectomy: used by women who are considering breast reconstruction where most of the skin, other than the nipple and areola over the breast is left untouched. This procedure however is not recommended for large tumours or those that are close to the surface of the skin.

• Nipplesparing/Subcutaneous mastectomy: a variation of skinsparing, this procedure the nipple and areola are left in place.

BCCT as the name indicates aims to preserve the breast, while retaining an aesthetically acceptable result. This surgery consists in a small incision to remove the tumour and if necessary some lymph nodes. This type of surgery usually requires some radiation treatment to prevent recurrence [39]. This surgery is as effective as a mastectomy in early stages of breast cancer as indicated by their similar survival rates [129].

Besides surgery there are also other options available such as radiation, chemotherapy or systemic treatments which can either be used independently or as complements to one another.

Depending on the treatment chosen or mixture of treatments a plethora of side-effects may arise, some of which may remain for the rest of the survivor's life. Especially after surgery and radiation treatment there may arise problems which restrict movement of the arm [32] [55]. This arm restriction is mainly caused by a condition called arm lymphedema [55]. Along with the movement impairment it also decreases healing capacity of the tissue, increasing thus the risk of possible infection and even cause pain. This condition easily snowballs into anxiety, depression, emotional distress and other psychological distress, as the patient is unable to maintain its traditional life style, continually decreasing its overall quality of life [32]. It is needed to note that even though the patient might not suffer from arm edema there are other conditions that prevent the patient from returning to his daily routine causing him both physical and psychological distress, to which physical activity has been shown to help relief [102] [32] [75].

2.2 Lymphedema

Lymphedema is the result of an accumulation of fluid in subcutaneous tissue as a consequence of impaired lymphatic drainage. This condition can be congenital or acquired due to the development of anomalies in the lymphatic outflow, usually affecting one or more of the patients limbs, with the possibility of manifesting its effects in other organs [121]. The condition is usually acquired during the removal of lymph nodes as part of cancer treatment or even resultant damage to the lymph nodes during the removal of cancer tissue near the lymphatic system. This damage causes the lymphatic system to suffer a blockage which in turn prevents the drainage of the fluid that ends up building up in the blockage region and swell, thus leading to the oedema [47] [121].

This condition can however be managed with early diagnosis and a continuous care of the affected limb [10]. It however presents itself as a long-term physical and psychological difficulty to the patient and a complex therapeutic challenge for the physician [121]. It is important to note that this condition may not reveal itself immediately after surgery, with the possibility of even not presenting any of the symptoms for periods of time after already being diagnosed [55].

2.2.1 Lymphedema assessment methods

Early detection and treatment of lymphedema before fibrosis and fluid accumulation occur has been shown to yield better results for management of the disease. There is however no clear standard to be used in such cases [107].

The current commonly used methodologies rely on evaluating the limb's volume or extracellular fluid volume compared to non-affected limbs. This measurements can happen multiple times along the limb [107].

The procedures currently employed in the detection of lymphedema are water displacement, circumference measurements, perometery measurement, bioelectrical impedance spectroscopy

(BIS), DEXA scan and imaging techniques [79] [87]. A description of these procedures can be seen in 2.1, while a comparison between these can be seen in 2.2.

Table 2.1: Description of Lymphedema detection procedures (Adapted from [107] [79] [87]

Procedure	Summary
Water Displacement	Immerse the limb in a water container and the amount of displaced water will represent the volume of the limb.
Circumferential Measurement	The volume is estimated by assuming cylindrical/conical volumes between several measures taken along the limb.
Perometery Measurement	A device called a perometer is used to scan the limb with infra-red light and assesses limb volume at small intervals.
Bioelectrical impedance spectroscopy (BIS)	By having a small current pass through the body the volume can be measured by comparing the impedance values of both arms.
DEXA Scan	Uses a tissue-specific mode with attenuation of X-ray dependent on the thickness, density, and chemical structure of the tissue examined.
CT Scan	Determines the overall cross-section area and quantifies the density of the tissues.

Table 2.2: Comparison between Lymphedema detection procedures (Adapted from [79] [87]

Method	Time required	Home usage	Accuracy	Cost	Complexity
Water Displacement	Low	No	High	Low	Medium
Circumferential Measurement	High	Yes	Low	Low	Low
Perometery Measurement	Medium	No	High	Medium	High
Bioelectrical impedance spectroscopy (BIS)	Medium	No	Medium	High	Medium
DEXA Scan	Low	No	High	High	High
CT Scan	Low	No	High	High	High

Although water measuring is considered the preferred whole limb volume measurement technique, it has mostly been replaced by other techniques [107]. This change is due to patient difficulty in bending their arms in the water containers, or even holding the required position. There are also times where open wounds, such as ulcers or skin infection may prevent the usage of this technique. This technique also requires a more rigorous care with equipment sterilization in order to avoid cross-infection between patients.

It is also relevant to note that some of the above methods, such as BIS [130] [132], can be used for detecting and monitoring the development of lymphedema at early stages. Lymphedema can also be identified by methods that rely less on limb volume, by focusing on shoulder range of motion limitation, strength reduction and loss of flexibility [108].

2.2.2 Lymphedema treatments

As a chronic disease lymphedema requires life-long treatment to ease the symptoms the patient experiences, however failure to continue the treatment will be marked by a full return of the symptoms. A plethora of possible treatments exist ranging from surgery to medication, intermittent pneumatic compression, compressive garments, heat therapy, complex physical therapy, among others [121] [88]. Compression bandaging is a technique in which a compressing gauze sleeve is used to help decrease the amount of interstitial fluid formation, prevent lymph back flow and enhance muscle pump. Similarly, to compression bandaging, are the compression garments which are graduated and mainly exert their compression at the distal end of the limb, while exerting the least amount at proximal end. Manual lymphatic drainage (MLD) is a methodology which uses a variety of light massage techniques to encourage removal of interstitial fluid, increase lymphatic transport and soften fibrotic induration. Complex physical therapy (CPT) consists of a period of two to four weeks of daily manual lymphatic drainage being followed medically administrated compression bandaging, skincare followed by prescribed limb exercises and fitting the patient with a compression garment. Pneumatic pumps are single or multiple chambered pumps that inflate and deflate the limb at different cycles to encourage fluid drainage from the distal to the proximal end of the limb. Low level laser therapy uses low intensity wave lengths to increase the rate of lymph vessel pumping, promote lymph vessel regeneration, reduce pain and soften fibrous tissue along with surgical scarring. Limb exercises can also be executed and are recommended as a way of varying total tissue pressure, thus encouraging lymphatic drainage and improving limb range of movement as well as strength. In addition, it has been found that home-based exercises can effectively improve affected upper-limb symptoms, thus leading to an improved quality of life [41]. Some exercises include shoulder flexion, shoulder abduction, elbow flexion, etc. [64].

A representation of some exercises for upper limb lymphedema can be seen in 2.3.

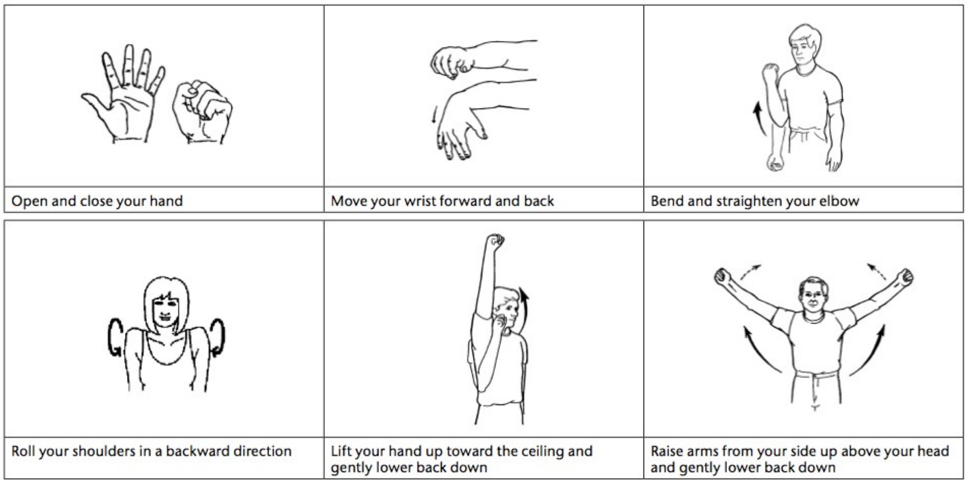

Figure 2.3: Exercises for upper limb lymphedema (From [91]

2.3 Summary

Concluding this chapter, we now have an extensive enough comprehension of breast cancer and its treatments, which have been gaining a trend to follow a more conservative approach, which avoid damaging the surrounding region. These conservative treatments aren't however fully devoid of side-effects as we have seen with the case of lymphedema. This condition heavily restricts the patient's movements in his upper body, causing discomfort or even pain. The condition although not fully curable has shown to be quite receptive to treatments, of which exercise is a focal one, not only helping the patient in the recovery of the condition, but also providing a general improvement to his quality of life.

Regarding the measurement techniques of the condition, many exist, but few seem to make usage of video based technologies.

Chapter 3

Human-Computer Interaction

This chapter gives a brief overview regarding games and serious games, as well as game engines capable of being used to create such games.

A small view of how learning strategies can be applied to them to boost gains and increase motivation.

Additionally, this chapter also covers how visualization and informative art can be applied to the visualization of physical activity and how it can affect the user's motivation.

3.1 Games

A game is something that has gone hand in hand with mankind since very early on. Despite this long-lasting relationship there is no definition of games that is fully agreed on. Some examples can be seen on 3.1.

These definitions tend to focus on different points of what a game is ending up sharing between themselves many common aspects but not encompassing them all. A more generalist definition that can fully encompass a game is suggested in [114] where a game can be defined as a junction of technological, aesthetic, mechanical and narrating elements that together lead the user to an experience.

Table 3.1: Definitions of games (Adapted from [66]

Johan Huizinga (1950)	[...] a free activity standing quite consciously outside ”ordinary” life as being ”not serious”, but at the same time absorbing the player intensely and utterly. It is an activity connected with no material interest, and no profit can be gained by it. It proceeds within its own proper boundaries of time and space according to fixed rules and in an orderly manner. It promotes the formation of social groupings which tend to surround themselves with secrecy and to stress their difference from the common world by disguise or other means.
Roger Caillois (1961)	[...] an activity which is essentially: Free (voluntary), separate [in time and space], uncertain, unproductive, governed by rules, make-believe.
Bernard Suits (1978)	To play a game is to engage in activity directed towards bringing about a specific state of affairs, using only means permitted by rules, where the rules prohibit more efficient in favor of less efficient means, and where such rules are accepted just because they make possible such activity.
Avedon & Sutton Smith (1981)	At its most elementary level then we can define game as an exercise of voluntary control systems in which there is an opposition between forces, confined by a procedure and rules in order to produce a disequilibrial outcome.
Chris Crawford (1981)	I perceive four common factors: representation [“a closed formal system that subjectively represents a subset of reality”], interaction, conflict, and safety [“the results of a game are always less harsh than the situations the game models”].
David Kelley (1998)	a game is a form of recreation constituted by a set of rules that specify an object to be attained and the permissible means of attaining it.
Katie Salen & Eric Zimmerman (2003)	A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome.

3.1.1 Digital Games

Digital games can be described as games which can be played in the computer or any other electronic device. The first computer game ever created was “Spacewar” in 1962 by Steve Russell. This single game created more for the purpose of showing expertise rather than profit was quickly viewed as a business opportunity, leading to the creation of Atari, the founding firm of the video game industry [137]. In conjuncture with the rise of personal computers, the video game industry developed into an entertainment industry with titles whose revenue surpassed that of even box-office smashes such as “Pirates of the Caribbean”. Games can be classified in two non-exclusive ways, according to [44], genre and type, in which genre describes the narrative content of the game and type describes the game play. 3.2 shows some of the major categories of game types, according to [44] and [133].

Table 3.2: Major categories of game types (Adapted from [44] [133])

Action	Emphasizes the need for reflex responses to complete the challenges presented
Adventure	Usually associated with captivating storytelling, it focuses on exploration and to some degree a type of puzzle solving
Puzzle	Presents the player with mental challenges in the form of puzzles
Role Playing	Highlights the possibility of the player creating or take on a character to represent himself
Simulation	Attempt to expose the user to a recreation of a real-world situation
Strategy	Stresses the usage of strategy to overcome the presented challenges
Sports	Emulate existing sports or variations of them
Quiz	Tests the player’s knowledge through the presentation of quizzes

According to [45], in the United States, around 91% of children between the ages of 2 and 17 play video games. This demonstrates that a vast majority of the younger population is already susceptible to the benefits this medium can bring, be it cognitive, motivational, emotional or social.

3.1.2 Serious games

The concept of serious games is one that’s hard to define but usually refer to games used for training, advertising, simulation, or education [120]. Many definitions have been discussed but none has been agreed upon, although a taxonomy can be produced categorizing serious games depending on the their main intent and who they are built for [119].

Although until recently games and education have been something of opposites, they both share similarities, both offer goals to be achieved following a set of rules, while returning feedback in a form of grades or scores, while possibly unlocking new challenges based on the feedback received, among other similarities. These types of similarities show that games should in fact be able to be used as an educational tool, beyond the entertainment only stigma they have received [114]. It has in fact been noted that children's brains, especially, have been changing to accommodate the usage of new technologies [104]. These types of games, however, have some technical difficulties when applied to a classroom environment such as time constraints, where it is hard to design an experience that won't be too long, variable pacing which makes it hard for the class to advance as a whole [114], and they can even at times be discarded in favour of the other tools such as books and paper based material from a familiarity of usage up until now [114] [98].

These characteristics allow games to also be used in a health rehabilitation environment by trying to promote positive behaviour on the patient [125] or as means to encourage the patient to continue his rehabilitation program [30].

These type of games have already been used by major companies such as Microsoft, Oracle and Google and have shown to bring positive reinforcements for the workers [128]. A taxonomy of these types of games can be seen in 3.3.

Table 3.3: Serious games taxonomy table (Adapted from [30])

	Games for Health	Adver-games	Games for Training	Games for Education	Games for Science Research	Production	Games as Work
Government NGO	Public Health Education and Mass Casualty Response	Political Games	Employee Training	Inform Public	Data Collection/Planning	Strategic and Policy Planning	Public Diplomacy, Opinion Research
Defense	Rehabilitation and Wellness	Recruitment and Propaganda	Soldier/Support Training	School House Education	Wargames / planning	War planning and weapons research	Command and Control
Defense	Rehabilitation and Wellness	Recruitment and Propaganda	Soldier/Support Training	School House Education	Wargames / planning	War planning and weapons research	Command and Control
Healthcare	Cybertherapy /Exergaming	Public Health and Policy and Social Awareness Campaigns	Training Games for Health Professionals	Games for Patient Education and Disease Management	Visualization and Epidemiology	Biotech manufacturing and design	Public Health Response Planning and Logistics
Marketing and Communication	Advertising Treatment	Advertising, marketing with games, product placement	Product Use	Product Information	Opinion Research	Machinima	Opinion Research
Education	Inform about diseases/risks	Social Issue Games	Train teachers/Train workforce skills	Learning	Computer Science and Recruitment	P2P Learning Constructivism Documentary	Teaching Distance Learning
Corporate	Employee Health Information and Wellness	Customer Education and Awareness	Employee Training	Continuing Education and Certification	Advertising/ Visualization	Strategic Planning	Command and Control
Industry	Occupational Safety	Sales and Recruitment	Employee Training	Workforce Education	Process Optimization Simulation	Nano/Bio-tech Design	Commandand Control

3.1.3 Game Engines

Serious games and serious gamified applications implementation and use is dependent on the the quality of the gamification platform used or game engine [128]. This process of selection is, however, not straightforward due to a lack of detailed classification of features [24], paired with the constant change in some of the engines, due to being actively updated.

A recent comprehensive review (2017) of multiple game engines can be seen in [2]. More specifically for 2D game engines a recent review (2017) can be seen in [100].

From the engines reviewed in [2] and [128] we can see that some of the engines with higher scores or available features are very similar between them. As such the selection method may end up being decided by personal preference, be it due to ease of usage and knowledge of the used script languages or due to the size of the community and ease of access to assets provided by it.

3.2 Cooperation, competitive and individualist learning strategies

Highly emphasized from the 1940's up until the 1960's, competitive learning was viewed as the correct learning strategy, being supported by slogans like "survival of the fittest", pitting a student's results against other students' results. After critics to this system, individualist strategies were adopted where the student could learn at his own pace, without the need for peer interaction or social relationships. After this system was also criticized the cooperative strategy was finally adopted having developed immensely throughout the years [65]. A comparison between the effectiveness of these strategies can be seen in 3.4.

Table 3.4: Mean Effect Sizes for Impact of Social Interdependence on Dependent Variables (Adapted from [106])

Dependent Variable	Cooperative vs. competitive	Cooperative vs.Individualistic	Competitive vs. Individualistic
Achievement	0.67	0.64	0.30
Interpersonal attraction	0.67	0.60	0.08
Social support	0.62	0.7	-0.13
Self-esteem	0.58	0.44	-0.23
Time on task	0.76	1.17	0.64
Attitudes toward task	0.57	0.42	0.15
Quality of reasoning	0.93	0.97	-0.13
Perspective taking	0.61	0.44	-0.13

It is worth noticing that both cooperative and competitive strategies seem to achieve even closer results when used in gaming scenarios, although this can be attributed to how a game itself is constructed [119]. Games have proven to be able to be excellent users of these strategies even in rehabilitation scenarios as was demonstrated by [82].

3.3 Visualization

The broadest term that can more globally encompass the representation of information is information visualization, however this term is now generally applied to the visual representation of large-scale collections of non-numerical information. On a more narrower view, data visualization can be defined as information that has been abstracted into a schematic form, or simply as the science of visual representation of data [38].

3.3.1 Informative art

Informative art are works of art that are computer augmented or amplified to produce not only aesthetic objects but also information displays, such that they can dynamically reflect information about their environment. It can thus be a kind of technology that promotes moments of concentration and reflection [106]. This type of technology has shown results that indicate that it may even indeed be able to trigger behavioural changes [111].

3.3.2 Visualizing physical activity

As physical activity has been rising as a solution for mental, heart illnesses, among others, as well as a means of preventing or managing others such as cancer and lymphedema [111]. This interest in the usage of physical activity as a treatment or solution as lead to the focus on the combination of physical fitness and technology to obtain not only new methodologies to combat specific diseases, but also to encourage healthier behaviours from the populace [111] [43]. As such, ways to visualize the data obtained from the monitoring of such activities and its representation becomes a key challenge in this domain.

The process of capturing the data for this visualization usually depends on diaries, heart rate monitors, pedometers, accelerometers and GPS's [73]. This type of data is usually converted into tables or graphics, but these types of visualization are not efficient at maintaining motivation.

Some implementations also represent their data through the means of small games, such as the case of [82], where the amount of physical activity is represented by the growth and activity of an animated virtual character. This representation encourages positive reinforcement, fostering long-term behavioural change. Abstract representation of data has also been demonstrated to be a good motivator for physical activity where the amount of a certain exercise alters certain aspects of the representation, making the subject sometimes perform extra exercise in an attempt to obtain his desired representation [34].

A different capture method that obtains subjective data is the capture of photos, be it by the subject himself or by someone else portraying the subject [54] [58] [52]. This type of data capture reveals that, in the case of health-related issues, it becomes very important that the subject is able to travel, spend time with family and go on holidays as a means of motivation, showing that social inclusion and independence are key points when designing rehabilitation programs.

3.4 Summary

The field of HCI, like the other areas discussed through this paper, has also seen significant development through the last years. Particularly the field of serious games has been a much-revised topic, as researchers and developers try to branch out games to a wider audience. Besides education, an area that has gained increased interest in the field of serious games, healthcare has also note an increasing interest, with examples such as [11] and [125].

Other interesting areas of the usage of games as a means for motivation has been the area of personal exercise, where games have been created to drive people into being more physically active.

Still in the area of motivation, we have seen research that attempt to boost motivation through the means in which people visualize progress, going from the traditional graphs and tables, to approaches that resemble a Tamagotchi game [82] or even through the usage of abstract art [34].

Abstract art as a means of progress visualization has been shown to be a particular interesting approach as it has been reported to have the users do exercise beyond the one they were recommended as shown in [34]. This shows that there might be interest in gamifying this experience as a way to increase motivation levels.

Chapter 4

Technological overview

This chapter will allow the reader to understand some of the existing technologies that may be useful to the development of this project. This literature review will concentrate on technical aspects starting by giving a general sense of computer vision and steadily driving the topic towards movement recognition and this can be used.

4.1 Visual computation and Computer vision

As the human visual system is one of the most important sensory systems we possess the need to further visual representation and analysis of information, thus giving birth to the research area which has been entitled visual computing.

In a simple sense, visual computing is the integration of computer graphics and imaging techniques that include the features and proprieties of the human visual perception. As visualization integrates both image understanding and image synthesis it creates an immense area of research that encompasses a large amount of fields of research such as computer vision [49].

Although alike in the name with visual computing, computer vision is a research field that concentrates purely on the transformation of data from a visual source, such as a still image or the constant flow of frames captured by a video camera, into a decision or a new representation. This field thus concentrates in being able to take a visual source, analyse it, retrieve the information that is of our interest from the vast amount of noise such source usually contains and finally proceed to the creation of a new representation or delivering of a decision [40].

A simple way of distinguish visual computation from computer vision is to regard visual computation as being about humans seeing the computation, such as viewing density charts, while computer vision focuses on making the computer able to see the world and understand it is visualizing using recognition algorithms and machine learning.

4.1.1 Computer Vision-Based Human Motion Capture and Analysis

Motion is an integral part of how the human visual system works as it allows us not only to recognize different objects or individuals at long distances by the way they manoeuvre themselves, but also feed us information relative to the space surrounding said object, such as depth [19]. The process of registering the motion of human actions is known as human motion capture. This process is mostly oriented to the capture of large scale body movements such as that of the torso, arms, legs, etc., thus not including small movements such as hand gestures or facial expressions [85]. The possible applications of such technology reside in three major categories: surveillance, control and analysis. Thus, the range of operations can go from systems that automatically monitor an area, being able to count the number of individuals in it, crowd flux and flow, individual tracking, control functionalities such as game interfaces, animations, or even used in clinical studies, automatic diagnostics and optimization of athletes' performances [19] [85] [86] [103] [35].

The general structure used by systems that analyse human body motion can be divided in four phases as ordered: initialisation, tracking, pose estimation and recognition [107] [79].

The initialisation phase exists to ensure that operations commence with a correct interpretation of the current scene. This phase can be seen as a pre-processing data phase where the main concerns fall on camera calibration, adaptation to scene characteristics and model initialization. In computer vision systems, this process is of utmost importance since the parameters of the camera are often requirements for a correct capture. These parameters can be obtained offline or through online calibration. Tracking involves two parts, the segmenting and the temporal correspondence of a human in one or more frames. Segmentation is concerned with separating an individual or part of it from the remaining objects and individuals present in a scene while temporal correspondence is concerned on finding where this separated element was in past frames. Pose estimation concerns itself with the estimation of the configuration of the underlying kinematic or skeletal articulation structure of a person. This process can in some systems be considered an integral part of its tracking process.

Finally, the recognition phase is the process of identifying actions, activities and behaviours and labelling them accordingly.

Tracking systems used in this area can vary and are categorized as active sensing or passive sensing. Active sensing involves the usage of devices that are placed in the subject and in the surroundings, being simple in ways of processing and easy to use in well-controlled environments. Passive sensing is on the other hand based on signal sources such as visual light, magnetic wavelengths, etc. A note should be made that the usage of markers to aid in the capture process fall under this category, as markers are not considered as intrusive as the devices used in active sensing. This type of technology is mainly used in applications where the allocation of devices in subjects is unfeasible [85]. Another possible classification for these systems can also be between non-visual, visual and combinatory [139].

4.2 Non-visual tracking systems

These types of sensors are devices that adhere to the subject to collect information and can vary immensely from mechanical, inertial, acoustic to radio, magnetic or many others. These types of systems can be used to detect from a wide range of amplitudes from movements of a limb to the very movement of just a single finger. Each type of sensor has its advantages and disadvantages mostly due to sensor noise or offsets, demanding some external correction. They however can many times be used in combination to cover up each other's flaws [139] [109].

4.2.1 Inertial sensors

Easy to use and cost-efficient these inertia based sensors have been commonly used in navigation and augmented reality modelling. The information can be transmitted wireless and can capture large areas, however these sensors suffer from measurement noise and fluctuation of offsets which makes the determination of position and angle often be incorrect [139].

A simple inertia activity recognition system can be dissected into 5 stages: acquisition of raw data, pre-processing, segmentation, feature extraction and classification [12]. Acquisition of raw data is done by attaching multiple sensors to different locations on the body. Some systems can also make use of sensors placed in the environment that provide extra data, such as objects in use.

The pre-processing phase requires that we indicate the vector notation used to describe the sensor's output. This phase also covers the synchronization process of the different sensors, since different types of inertia sensors can have different sampling frequencies, allowing to also remove artifacts created by the environment such as electromagnetic interferences. Additional calibration is also present within this phase. Data segmentation searches, within all the pre-processed data, the periods where information about activities is likely to be, known as activity detection or "spotting". This task contains many challenges since it is difficult to distinguish an activity from another. To this challenge some approaches can be taken such as sliding window, energy based or through the usage if additional sensors and contextual sources. The feature extraction phase is composed of the stage where signals are converted into features that are discriminative of the activities, having a wide variety of feature types.

Finally, the classification phase is comprised of two steps. First the system needs to be trained, where a quantity of activities are human labelled and the machine uses them to learn how to distinguish the actions labelled. The second step, the classification is when the machine that has now been trained will attempt to correctly label unlabelled activities that are provided.

As systems become more and more complex they may require additional phases as shown in [110].

4.2.2 Magnetic sensors

Used commonly in tracking users' movements in virtual reality, these sensors excel by having high sampling rate, shortage of blockage and an overall convenient size. They however are not without fault since they possess latency issues, due to their asynchronous nature, jitters in the presence of electronic and ferrous devices. Despite these faults some workarounds to them have been investigated [139].

4.2.3 Other sensors

Acoustic sensors work by transmitting sound waves and later sensing them when they bounce back, being able to calculate the flight duration and as such know exactly how far an object is. Although commonly used in medical applications they possess some drawbacks that hinder their usage in human capture systems such as the need for large equipment, as detection range increases so does latency, and need for a line of sight between emitter and receiver.

Radio and microwave dependant systems have been used in navigation systems but they are very low resolution and as such cannot be applied in human motion tracking [139].

4.3 Visual tracking systems

This type of systems make use of optical sensors, usually cameras. This type of system is usually divided into two classes: marker based or marker-free.

4.3.1 Marker based systems

Through the usage of fiducial markers, the system can minimize the uncertainty of the subject's movements. There are two types of possible markers: passive and active. Passive systems emit no light, reflecting only incoming light, such as infrared, which is then captured by the optical sensors. This types of systems are common practice in medical science and bioengineering.

On the other hand, active systems will emit light intended to be distinguishable for the optical sensors to easily attain amidst the background noise [139] [35].

Both types of system usually operate on the same principle of having attached small markers to the subject's body and having two or more cameras focused on him and image processing program will then detect these markers and combine the acquired 2D data to calculate the three-dimensional positions of these markers throughout the recording [67] [89].

These systems however suffer from the problem of unreliability of the markers. Markers make the system be limited not only by degrees of freedom but they can also suffer from obstruction, making it impossible for the camera to pick up the marker's location, thus losing possible information about the pose [88] [41]. The usage of skin based markers also creates noise in the data, whereas the system only presents acceptable error limits in large motions [89].

4.3.2 Marker-free based systems

Circumventing the marker's unreliability and the preparatory time of their application has been one of the major conditions for the furthering of the marker-free based approach. Much like marker based approaches there exists two types of approaches active, through the emittance of light and passive, through the reliance of merely captured images [89]. Two main types of approaches can be discerned, 2D based approaches and 3D based approaches [139].

This type of motion capture systems assume that a subject is observed by a single or multiple video cameras and thus the captured images are analysed in order, allowing the subject's pose to be estimated at every observation time [6].

4.3.3 2D based approaches

2-D based approaches are commonly used due to the ability to flexibly adapt and quick response to reduced spatial dimensions when capturing an image plane. These approaches are employed in one of two ways, with and without explicit shape models [139]. The model based approach relies on a priori knowledge of human movement by segmenting the human body and labelling it. The shape, relative size and configuration are then used to segment the visual-hull, allowing for the mapping between perceived parts and the model parts [86].

The model-less based approaches tend to rely on background subtraction or colour detection to recognize the intended body parts. Do to the unavailability of a model low level image processing is required, such as feature extraction [139].

4.3.4 3D based approaches

To respond to the angle view limitations of 2D based approaches, 3D approaches have been researched, attempting to recover 3D articulated poses over time or even projecting a 3D model onto a 2D image for later processing. These 3D techniques can be differentiated by the type of tracking they aim for. In this note there are three main branches one can follow: model-based, feature-based or animation of human motion [139].

Model-based tracking minimizes tracking issues such as self-occlusion or self-collision by modelling the human movements. This type of tracking contains a couple of models that can be used individually or mixed. The first is the usage of a stick figure which represents the skeletal structure, by modelling a collection of segments and joint angles. The second model is called Volumetric modelling which as the name implies usages volumetric models to represent the skeletal structure. This model however requires more parameters to build, thus leading to more intensive computation.

4.3.5 RGB-D cameras

RGB-D cameras are a type of sensing system that together with capturing RGB images also capture per-pixel depth information, meaning that we acquire 3D based information from such systems.

The depth capture relies on either structured light patterns combined with stereo sensing or time-of-flight laser sensing. Depth information is although limited and will not usually surpass the 5m limit mark, while having very noisy depth values, very reduced field of view and low resolution. The system is however rather cheap and portable which makes it a prime candidate for applications related to robot navigation, manipulation, etc. [60]. It also presents an interesting option when regarding the possibility of a diagnostics assistance tool for medical applications regarding not only breast surgery [95] but many others that would benefit from human body models [21].

4.3.6 Microsoft Kinect

One of the most commonly known RGB-D sensors is the Microsoft Kinect introduced as an instrument to broaden XBOX 360's audience by enabling games with unique interactions to be developed for the console. There have been released two versions for both the console and Windows platform. The lower cost of this product relative to its other rgb-d counterparts has made this one of the most used instruments in rgb-d related research, creating quite a large literature regarding its applications [50].

Besides the normal camera sensory capabilities of the Microsoft Kinect it also incorporated with other functions such as skeletal tracking, head-pose and facial tracking, having its own software development kit which again bolsters its dominance over other systems [138].

The Microsoft Kinect is composed of several hardware equipment, of which are distinguished a depth sensor, a colour camera and a four-microphone array.

The depth sensor is composed of an infra-red projector, an infra-red camera and a CMOS sensor. Occasionally the depth values of the Microsoft Kinect sensor may be inaccurate due to a calibration invalidation between the projector and the camera, which may be caused by heat, vibration during transportation or even a drift in the infra-red laser. This issue may be corrected with the usage of the Microsoft Kinect calibration card.

What truly elevates the Microsoft Kinect is its skeletal tracking capacities. Instead of determining directly the body pose in a high-dimensional space, the Microsoft Kinect treats the segmentation of a depth image as a per-pixel classification task, thus avoiding pairwise terms or conditional random fields. By evaluating individual pixels, a combinatorial search over different body joint is avoided. After inferring body parts through this method, the joint locations are hypothesized and a global centroid of probability mass is found. The hypothesized joints are then mapped to the skeletal joints and fitting a skeleton considering both temporal continuity and knowledge obtained a priori from skeletal train data [138].

Another advantage of the Microsoft Kinect is its marker-less approach and usage of a single camera contrary to very high-end RGB-D cameras. This advantage makes it so that the Microsoft Kinect becomes a valuable piece of equipment when the aim of the application is oriented to home-base usage, thus having to eliminate any steps that would require a more technical usage such as the ability to correctly place markers on the user [20].

The Microsoft Kinect currently has two versions available, the Microsoft Kinect v1 and the Microsoft Kinect v2. A comparison of their main features can be seen in 4.1.

Table 4.1: Comparison of main features of the two versions of the Kinect sensor (From [80])

Feature	Kinect v1	Kinect v2
Depth Sensing Technology	Triangulation with structured light	Time of flight
Colour Image Resolution	640x480 30fps 1280x960 12fps	1920x1080 30fps (12 fps low light)
IR Image Resolution	640x480 30fps	512x424 30fps
Depth Sensing Resolution	640x480 30fps 320x240 30fps 80x60 30fps	512x424 30fps
Field of View	43° vertical 57° horizontal	>43° vertical 70° horizontal
Depth Sensing Range	0.4m – 3m (near mode 0.8m – 4m (default mode)	0.5m – 4.5m Up to 8m without skeletonization
Skeleton Tracking	(with full skeleton) Up to 2 subjects 20 joints per skeleton	Up to 6 skeletons 25 joints per skeleton
Built-in Gestures	None	Hand state (open, close, lasso) Hand pointer controls; lean
Unity Support	Third party	Yes
Face APIs	Basic	Extended massively
Runtime Design	Can run multiple Kinect sensors per computer; One app per Kinect	At most one Kinect per computer; Multiple apps share the same Kinect
Windows Store	Cannot publish to	Yes

4.4 Upper-Body Function Evaluation

Upper-body function evaluation is a highly important topic when contextualized in a health environment as it can be applied to both preventive and rehabilitative measures [131]. Upper-body function evaluation is usually performed by two different methods, with the usage of non-vision based systems or through vision-based systems [108].

Non-vision based systems consist of systems that make use of subjective evaluations such as questionnaires, for example the DASH questionnaire [63], or of objective evaluations through the usage of tools such as the goniometer [123] or with the usage of sensors such as [131].

Vision-based systems use capture devices such as the ones mentioned in the previous section, for example [78].

The Microsoft Kinect makes for an interesting capture device for upper-body function evaluation, not just due to its capacities, but also for its relative low-cost, portability and ease of use. It may, however, require additional equipment such as gyroscopes and accelerometers to achieve better results [87].

4.5 Classification

Defined in 1959 by Arthur Samuel, machine learning is the "field of study that gives computers the ability to learn without being explicitly programmed" [90]. Many times also seen as a facet of the same field shared with pattern recognition [8]. A wide plethora of machine learning types exists such as regression, clustering, classification, etc. [8] [31].

One of the many types of machine learning, a classifier is a system that takes as an input a vector of features, such as a feature descriptor, and outputs a single discrete value, which is usually called a class [31]. This class is also commonly called a label.

The learning procedure is composed of three main components: representation, evaluation and optimization.

To be handled by the computer, the classifier must be represented in a formal language. Selecting a representation for a learner is comparable to choosing the set of classifiers that it can learn. This set can be called the hypothesis space of the learner. This means that if a classifier is not present in the hypothesis space then it cannot be learned. To distinguish between good or bad classifiers an evaluation is also needed. The selected evaluation function used by the classifier may be different from the external one that we want the classifier to optimize.

The optimization consists on the search for the highest-scoring classifier. This optimization choice is extremely important for the efficiency of the learner.

Some forms of each of these components can be seen in 4.

Table 4.2: Machine learning algorithm components (Adapted from [31])

Representation	Evaluation	Optimization
Instances	Accuracy/Error rate	Combinatorial optimization
k-nearest neighbour	Precision and recall	Greedy search
Support vector machines	Squared error	Beam search
Hyperplanes	Likelihood	Branch-and-bound
Naïve Bayes	Posterior probability	Continuous optimization
Logistic regression	Information gain	Unconstrained
Decision trees	K-L divergence	Gradient descent
Sets of rules	Cost/Utility	Conjugate gradient
Propositional rules	Margin	Quasi-Newton methods
Logic programs		Constrained
Neural networks		Linear programming
Graphical models		Quadratic programming
Bayesian networks		
Conditional random fields		

4.5.1 Boosting

Boosting is a technique used to produce a very accurate prediction rule by combining rough and moderately inaccurate rules [37] [113]. This means that when presented with a set labelled instances the booster will devise a distribution over the set and request a weak hypothesis/classifier with low error. The booster will repeat this operation a certain amount of time and in the end, combine all the weak hypothesis into a single prediction rule.

4.5.2 Adaptive Boosting

First presented by Freund and Schapire [37], and usually known as AdaBoost, this was the first practical boosting algorithm, and remains one of the most widely used and studied, having throughout the years been developed many alterations to it [113] [97]. AdaBoost differs from the simple boosting techniques by assigning weights to each classifier, adapting them for each round a distribution is done, thus the final combined classifier is not simply the addition of multiple weak classifiers, but the sum of many weighted weak classifiers.

4.5.3 Random Forest Regression

Random forest is a type of additive model that preforms previsions through the combination of decisions of a sequence of base models. Each classifier in this system is a decision tree. This system can be used for both classification and regression. That which distinguishes between classification and regression is the usage of a predicting variable, if this variable is continuous then we have a regression, if the variable is categorial then we have a classification [25]

4.6 Cross Validation

Cross validation is a model evaluation method where a part of our set is removed from the training phase and is instead used as part of the testing phase. This method aims to estimate the models' true error on the sample data that we possess [28] [115].

There are different types of cross validation that can be used, such as: Leave-one-out Cross Validation, known as LOOCV, k-fold cross validation, etc.

In the LOOCV method a data point is removed of the training and the error on the removed value is tested. This operation again occurs again, but a different data point is removed. This operation is repeated until all values have had a turn off rotation and report the mean error. The validation set the is repeated for each data point, while following the same logic of removing a different data point every time.

The k-fold method is less exhaustive version of LOOCV, in which the operation is done a k number of times and the error is averaged over all runs.

4.7 Summary

Computer vision has been the focus of many researches in the last years. This focus translated into the development of many techniques which can be used for the most diverse of applications.

Human tracking has also been a rising topic among researches, not only due to the upgrade in computational power, but also due to the emergence of new techniques and capture devices.

Human motion detection has begun moving from a marker type of usage into a more markerless type of environment. This move comes at the cost of robustness and efficiency in the system, but allows it much more mobility and longer term lower cost solutions, ending in the creation of more applications that are more prepared to handle real situations.

The accessibility to these new types of technologies now provides new ways of tackling problems such as upper-body function evaluation.

Chapter 5

Methodology

In this chapter, an overview of the methodology is discussed. The problem is focused, related works are analysed, we propose a solution, requirements are discussed, and an architecture is suggested along with a testing methodology.

5.1 The Problem

Treatment associated with breast cancer carries with itself consequences that negatively affect not just a patient's physical condition, but also its psychological state, leading to a general decline in quality of life.All the types of treatment mentioned in 2 bring a possibility of unwanted side effects. Most notable of these side effects are pain, fatigue, lymphedema and general reduction in arm movement, this last be it do to loss of musculature or simply by the loss of shoulder rotation. For many of these symptoms the suggested treatment is the usage of rehabilitation [27].

To have a successful rehabilitation, it has been deemed that a significant amount of repetitions of exercises are needed [72]. This is, however, not achieved by a majority of the patients as reported in [118], where only 31% of the patients reported to exercise 4 or more times per week, with 27% not exercising at all. Furthermore, earlier exercising is more effective not just with improving shoulder movement, but also with wound healing and limb strenght [77].

An added problem to the lack of exercise by the patient is the low amount of time available to the therapist and thus an inability to perform a wider array of exercises that could be more well fitted to the patient [69].

To increase the patient's predisposition and motivation towards the idea of rehabilitation some perception of control over his health should be given to him. This coupled with the intrinsic fear of death and illness have been perceived to be major motivation factors towards maintaining physical activity [52].

The idea of providing a routine is also a factor to be taken into consideration when creating a serious game for rehabilitation as it promotes a sense of accountability, which seems reinforced when there are other people expecting the presence of the patient or his completion of a task [52].

Quality of life is also an important part of the rehabilitation process. Although studies in this area are fewer and many inconclusive [77], some physical and psychological barriers have been noted in [57] and [76]. Among these barriers are dislike of gyms, low access to facilities, interfering seasonal weather or even traffic congestion.

5.2 Rehabilitation and Serious Games

The usage of games as a rehabilitation tool is a rather young topic especially taking into consideration that these usually tend to depend on virtual/augmented reality and thus low-cost; effective equipment has only begun being available recently, such as the Playstation EyeToy (2003) previously mentioned in 4.

Some of the rehabilitation games originated from studies come more as a proof-of-concept in which the objective is to test if a particular, or group of capture devices are feasible to use in a game context, or how to adapt such games to have dynamic balancing and thus adjust to the patients need. Examples of such systems are:

• Esfahlani, et al.[33], in which the system aims to address kinematic activity of upper and lower limbs by using a group of capture devices, Xbox Kinect, Mya armband and Rudder Pedal, to create a game in which levels are proposed based on the current and expected abilities of the user.

• Caurin, et al. [18], where the objective of the study is to test a dynamic difficulty adaptation game, using an adapted version of the Pong game with a wrist rehabilitation system as an input mechanic for patients with motor deficiencies.

• Barzilay, et al. [7], proposes the usage of neural networks paired with a virtual reality platform, composed of a Vicon^{TM} motion capture system, a wireless Aurion^{TM} surface EMG ZeroWire, to create a neuromotor training system for upper-limb rehabilitation that can propose exercises based on the feedback received from patient's initial usage of it and therapist input.

• Darzi, et al. [26], propose a system that regulates the difficulty of the game by analysing the physiological responses of the users, respiration and signal provided by an electromyography of the posterior deltoid.

• Ma, et al. [81], evaluate the Microsoft Kinect in terms of maximum range for hand movement, peak velocity and mean velocity, through the integration in a rehabilitation game, validating it by comparing it to a Vicon^{TM} motion capture system.

From these studies we can observe that multiple capture devices can be used, although some of them represent not just custom made solutions but also high-priced solutions, with the Microsoft Kinect showing to be a relative accurate device at a relative low-cost price.

There were also studies which were more focused on the usability of such games and how the patients reacted to them and elements that should be taken into consideration when developing such games. Some examples of these are:

• Alankus, et al. [1], created multiple games that used two wii remotes attached to the user's arm in order to detect elbow and arm movement. The study mainly contributes by providing a listing of game design elements that should be taken into consideration when attempting to create rehabiliation games.

• Seo, et al. [117], measures stroke rehabilitation patients' expectations for virtual rehabilitation games before these engage in three different games. After the games the patients are again asked to answer a survey in which they evaluate the games. The games were developed using as the Microsoft Kinect and P5 Glove as capture devices.

• Burke, et al. [14], conducted a study in which multiple games were tested, having different capture devices, such as the P5 Glove, Wii Remote or simple webcams. The study focused on the usability of these games on able-bodied users before conducting it on stroke rehabilitation patients. This secondary study [13] eventually occurred in which the webcam games were tested at home by the stroke rehabilitation patients, proving to be successful both in usability and playability, with potential to be deployed for home usage.

These studies show that these type of systems are not just viable, but even appreciated by such users. It is, however, important to note that although these games are graded as serious games, many of the principles described for the creation of purely entertainment games are present.

Although not as prominent, there are also studies of the usage of serious games for the rehabilitation of cancer patients, with some being specific to breast cancer rehabilitation, such as [83], in which the game aimed not just to create a compelling experience for patients to engage in, but also evaluate the condition of their lymphedema.

During the rehabilitation program, the patient's continuous participation is proven to further increase the benefits towards the patient [36]. The ability to keep a patient engaged in such activity is usually the biggest hurdle to overcome, as such, new forms of rehabilitation programs are being developed by making use of newer technology that has become common to the general public in the last decade.

In the case of [36], it has been noted that games that are created for the specific purpose of rehabilitation make the game effective, but end up lacking qualities traditional games possess, especially entertainment, thus leading to a less motivating experience, and less likely to be repeated. These games also tend to focus on the individual recovery, thus lacking social qualities to it. The opposite also happens when games that are designed purely for entertainment purposes but could be used for rehabilitation appear, in which the user with limited mobility is having fun, but is unable to complete the level without help from a therapist [105].

The studies carried out in [127] and [1] reinforce that the need to create a social rehabilitation game for added motivation suggesting the participation of a relative, or even between patients. An important note to take from [1] is the consideration for the possibly older audience and the need to hold their focus by the usage of colourful scenes and sound effects.

The ability of games to easily create fun challenges, be it for an individual or a group makes them an ideal candidate for a rehabilitation tool. This together with the existence of multiple platforms with multiple input controllers, publicly accessible prices and the possibility to be played in the user's house make it a very appealing candidate to help ease the problem described above.

5.3 Proposed Solution

Given the problem discussed and the general lack of rehabiliation games focused on breast cancer rehabilitation we propose, in this project, to develop a game that focuses on creating, a medically approved, exercise routine for breast cancer patients, to be used at home, as a complementary tool for their rehabilitation process.

We propose the usage of the Microsoft Kinect as a reliable, low-cost capture-device. With it we can, reliably, emulate the user's movements and provide feedback on them through the usage of an avatar, so that the user can, at all times, be aware of the movement he is doing.

The routine proposed aims to not just promote the user to exercise, but will also be recording how well the user completes it. This results are recorded so that the therapist can later have access to them and review the patient's off-site performance and help plan the rest of the therapy sessions.

In order to keep the patient's motivation we also propose the creation of different progress visualization methods for the patient so he has a way to confirm how he has been performing by the game's standards.

Given the need for socialization that was discussed above, the development of two different game modes that focus on multi-player interaction is also addressed in this project.

5.4 Requirements

In order to create the system, some requirements must be fulfilled before the system is considered functional.

The first requirement is how the system will capture the user's movements. As seen in 4 there are many possible ways of measuring a user's input and in order to recreate his movement, from simple inertia sensors, to very high-end 3D optic cameras. To decide which capture equipment to use, the following requirements must be fulfilled:

- Ease of setup
- Low-cost
- Ease of usage
- Ease of data handling
- Ease of data acquisition

Since the system is for the patient's use at their home, the equipment must be easy to setup. The same reasoning applies to the price of the equipment, since this equipment will have to be loaned to or acquired by the patients, it must be at a reasonable price. Again, recalling the need for ease of setup and ease of usage is the average age and how accustomed the patient is to a certain level of technology. With this in mind, solutions such as high-end 3D optic cameras and marker based systems are excluded. In the case of inertia sensors, the ease of data acquisition comes into consideration where multiple sensors would be needed and their calibration might be a problem in terms of setup, thus eliminating them as an option. This leaves two major options in the form of simple usage of webcams or low-cost 3D systems such as the Microsoft Kinect. The

Microsoft Kinect offers an already existent SDK while also offering more information related to the movements captured without having to sacrifice performance for it, unlike the webcam which would have to process through the collected data to acquire information about depth.

Taking into consideration that this system is developed to reach the general populace, some considerations must be taken relative to its interfaces.

The system's interfaces thus were designed taking Shneiderman's eight rules into consideration [124]:

1. Consistency - Similar actions should be presented in similar situations, be it at a menu, language or any other element.

2. Frequent user shortcuts – Allow the experienced users to reduce the overall number of interactions through the usage of abbreviations, functions keys, hidden commands or macro facilities.

3. Informative feedback – Each action executed by the user should provide a sort of response by the system, be it visual or audio based.

4. Dialogues that yield closure – Dialogue should be clear and structured so that actions have a sense of beginning, middle and ending.

5. Simple error handling – In case of an error the system should provide clear and simple instructions on how to handle the given error. 6. Easy reversal of actions – Actions should be easily reversible, thus encouraging exploration without fear of commitment or error.

7. Support internal locus of control – Design the system to make the user feel as if he is in control be acting as an initiator instead of a responder, thus giving him a sense of control.

8. Reduce short-term memory load – Displays should be kept simple, with enough time allowed for the user to commit to memory any codes, mnemonics and sequences of actions.

Regarding medical requirements of the system, exercises must be selected and other utilities must be provided for medical usage.

The exercise routine used by the system should:

• Be approved by a medical body.

• Take into consideration the various conditions and age of the person, making its execution intuitive and possible to do in different conditions, such as sitting down.

• Be possible to execute in several places.

• Be low time consuming.

• Must be easily captured and possible to analyse in future evaluations.

In conjunction with the help of the medical body at Hospital de São João, it was decided that the prototype system's game routine should be composed of 3 sets of 3 exercises where each exercise is performed 10 times per set. The exercises decided upon were shoulder flexion, shoulder abduction and horizontal shoulder abduction, which can be seen in 5.1.

Based on [1] and [15] some elements are also important although not specifically requirements. Among these elements are:

• Necessity of direct and natural mapping - Movements executed by the user should translate into similar actions in game or the action in-game should be a natural response to the user's movement.

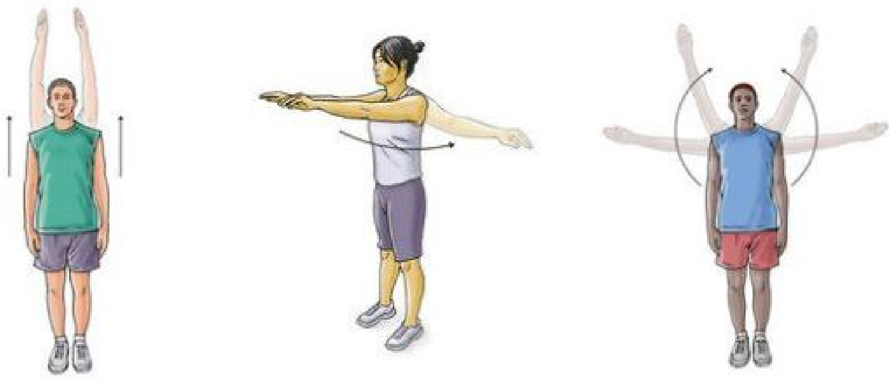

Figure 5.1: Exercises used in game (From left to right: Shoulder flexion, Horizontal shoulder abduction, Shoulder abduction

• Allow coordinated motions - Have motions that although early stage of recovery, patients cannot yet emulate, they should look to be able to eventually reproduce it.

• Audio and visual signals - Audio cues help the user understand faster if something has happened, while color and size help maintain focus towards areas of interest.

• Dynamic difficulty adjustment - To enable the patient to not be overwhelmed while he may be in the initial stages of his recovery and thus may have very limited range a system should be put in place to ease the challenges issued by the game or how they are evaluated.

• Existence of NPCs - The existence of NPCs allows for the user to establish a small sense of interaction with another person, thus providing a very simplistic social experience.

• Increase social connectivity - Besides the usage of virtual characters, the games should try to provide some sort of ability to interact with family, friends or other patients in similar situations.

• Feedback - The game should provide feedback not just when actions are concluded, but also on how the player performed.

It is important to note that most of the elements referred in this section are elements usually found in general game design such as [114].

5.5 Proposed Architecture

Having decided to work with the Microsoft Kinect two options are now available. The Microsoft Kinect v1 or the Microsoft Kinect v2. Besides the hardware improvements, the Microsoft Kinect v2 has shown to truly be more accurate than the Microsoft Kinect v1 [112]. Another novelty existent with new version is the gesture builder tool, which allows the creation of a database containing discrete and continuous movements, which when connected to a Kinect application will allow in real-time to perceive if the skeleton being tracked is performing a specific movement, and to which degree of completion is this movement being performed. Due to these reasons, the Kinect Microsoft v2 was selected.

To create the game environment, Unity was selected as the game engine, given its accessibility to resources, both general game related and Microsoft Kinect related plugins.

Given the selected hardware and software the basic architecture of the system is as shown in 5.2.

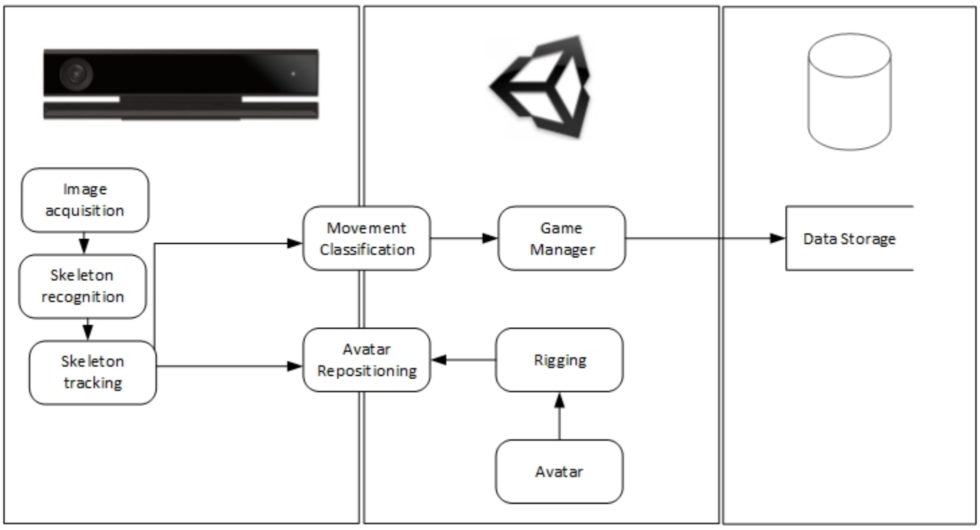

Figure 5.2: Workflow of the proposed architecture

Given the accessibility to patients, the game was divided in two prototypes. The first was just the main game with the purpose of evaluating how patients reacted to it and to assess the current balancing of the game and its function ability, being intended to be tested once per patient. The second prototype includes a motivational module and is intended to be used multiple times by the same user.

The game is composed of three phases:

- Login
- Pre-assessment
- Exercise

In the Login phase, as the name indicates, the user is able register himself or login into the system.

The Pre-assessment phase serves two purposes. First, it helps indicate if the overall capturing system is operational and if the user is correctly being captured by it. After these steps are concluded, the system proposes the user to execute 3 repetitions of the shoulder flexion exercise to determine the user's current physical condition.

The Exercise phase corresponds to the game experience itself where the user goes through the exercise routine. This routine is composed of 3 sets, each with the 3 exercises described before, where 10 repetitions of each are prompted per set. For each exercise, there is a stage where the user is shown how to execute the exercise and a stage where the user is prompted to execute the exercise. Between sets, the user is also prompted to take a small break. Concluded the sets, the user is shown how well he performed in each exercise per set and given a final evaluation based on that in the form of a classification from 1 to 5.

In both the Pre-assessment and Exercise phases the user will find himself represented by a virtual avatar which will mimic his movements. This representation was chosen based on the findings in [17].

A representation of the game's workflow can be seen in 5.3.

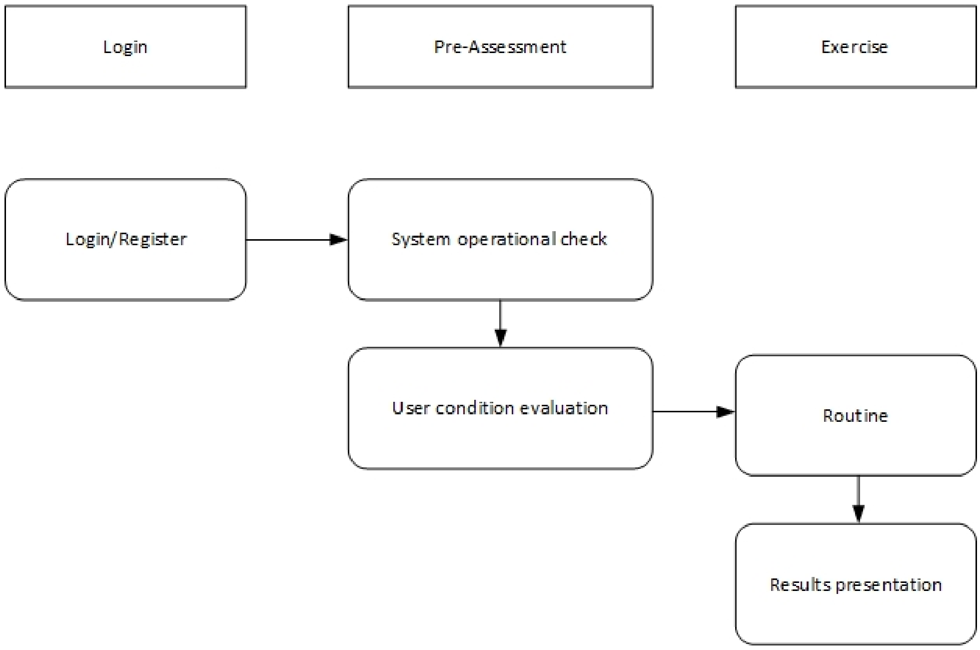

Figure 5.3: Workflow of the game

To help deal with motivational related issues, three different progress visualizations are proposed based on the data visualization studies reviewed in 3. These three visualizations are:

- Table and Graph
- Abstract Art
- Evolving Environment

The Table and Graph visualization serves as the standard baseline used by most systems nowadays to indicate how the user has been progressing as he uses the system. In the case of this game, the table will present the user with the scores obtained and the days these scores were obtained while being able to visualize the last seven scores in a graph. The Abstract Art view is based on [34] and creates shapes based on the number of exercises the user has been able to do in the current session. The intensity of colours and lighting is also affected by how well the user fared in the execution of those same exercises. The idea behind this progress visualization is that if the user is unhappy with the colour pallet, or amount of shapes displayed, he will, from his own volition, try to repeat the routine in order to generate a display more to his liking.

The Evolving Environment is a variation of the Tamagotchi like approach demonstrated in [82]. Instead of having an environment that constantly reacts to the latest routine much like the

Abstract Art view, this representation shows an environment that constantly builds on its previous state. What this means is that for every exercise session the user does, the score received will be accumulated and the environment will evolve its visual representation based on the total amount of points accumulated, much like a character gains statistics and access to new equipment in RPG games.

Regarding therapist interface, a view in which the therapist can load the skeletal recordings of the routines performed by the users and get information about their scores, time taken to complete the routine, range of motion frame by frame and more, allowing the therapist to perform an evaluation on how the patient has been exercising outside the regular therapy provided and what to expect from him. The range of motion is obtained by the usage of a virtual goniometer which registers the angles of shoulder rotation and elbow rotation.

Range of motion is an important element to take into consideration when evaluating body mobility in a clinical setting [74] [17]. It is also a measure highly difficult for a patient to self report. The Microsoft Kinect has been used previously to check if it could replace the goniometer as a virtual tool that could easily be used by the general public without assistance from a trained examiner [62] [74] [17]. These tests prove that the Microsoft Kinect is able, to a certain degree, give close results to the physical goniometer, if the correct conditions are met. Both tests were, however, done with the Microsoft Kinect v1, as such it is of interest to verify if the Microsoft Kinect v2 still holds the same capacity. To further enhance the social aspect of the game two different game modes were developed where two players can locally play simultaneously. One focusing on cooperation between the players and the other on competitiveness. Both games still use the same movements described in 5.1, while adding a new one 5.4.

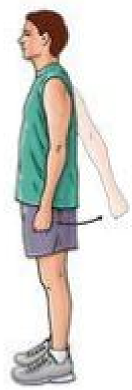

Figure 5.4: Example of a Shoulder Extension

5.6 Proposed Testing Methodology

To verify the game's functionalities and acceptance of it, a population of postoperative breast cancer patients is tested. The patients range from recently postoperative to 8+ years since the surgery. The test consists of filling out a questionnaire to get a sense of demographics, followed by the playing phase, where the patient experiments with the game, and ending on the filling out of a questionnaire to determine the patient's satisfaction with the game. For more details on the test procedure, a small guide was elaborated and can be seen in C. During the playing phase, the system will be registering the play sessions' duration along with score, user condition and overall completion of the routine exercises.

To verify the system's acceptance against the current existing system, a part of this population will, instead of playing the game, be receiving the currently used pamphlet and filling a similar questionnaire.

To test the motivational modules the system must be used multiple times by the user. This requires the user to be able to take the equipment with him. The ideal condition for this test would also involve that the patient has had the surgery recently, as to help verify if the system can potentially track the appearance of a potential complication with upper limb mobility.

To test the goniometer, a user is registered by the system performing one of the approved exercises for a short duration of time so that the reading can be stabilized. The user is to maintain the angle after the recording and be measured by a physical goniometer and the results compared. This measurement occurs in two different planes, sagittal and coronal.

To the test the socialization games modes, at least one patient and a non movement impaired subject should be able to play the game simultaneously, or two patients should play the game.

5.7 Summary

Rehabilitation games have been an increasing field of study with many applications attempting to deal with either the viability of capture devices for such games, experiments detailing how to design such experiences, or targeting specific types of rehabilitations and building the game around it.

A specific rehabilitation that lacks such gamified applications is breast cancer rehabilitation. In this project we propose the creation of a game that, not only is built around specific breast cancer rehabilitation exercises, but that also serves as an auxiliary tool for the therapist, instead of simply attempting to replace him. The game is intended to be played at home by the player, with the possibility of the therapist accessing the exercise recordings to help regulate the patient's therapy sessions.

As a capture device the system will be using the Microsoft Kinect v2, due to it's relative low-cost and relatively good capabilities as a motion capture device.

Chapter 6

Implementation

In this chapter we discuss details regarding the implementation. How we use the Microsoft Kinect in context of this project, the game's interfaces, its mechanics and changes that were done to the main game as it was tested and taken to another stage of development.

6.1 Microsoft Kinect

To create the movement database, two third-party software are used, Kinect Studio v 2.0 and Visual Gesture Builder.

The Kinect Studio is a tool capable of recording and reproducing video captured by the usage of the Microsoft Kinect. The tool allows that several features from the video be recorded, such as audio, depth map, colour, etc.

By recording the video, the tool automatically tracks and records the positions of the skeleton per frame which allows its usage by the Visual Gesture Builder to construct movements.

The Visual Gesture Builder is the tool that will henceforth create the movement database. By feeding it the recordings obtained in the Kinect Studio, the Visual Gesture Builder is able to learn two types of movements: discrete and continuous. The discrete movements allow to simply state if the movement being observed is or not X movement, while continuous allows to indicate the state of completion of X movement. To train a continuous movement, its discrete version must also be trained.

The training process is initiated by the creation of a project to which some properties can be set such as parts of the skeleton to ignore and the recognition of pre-built hand poses. Upon completion, the project must be fed its video clips in which a manual labelling of the frames must occur. Once labelling is complete, the application will proceed into the learning phase.

The learning phase for discrete movement will start by loading and mirroring any possible samples to increase the number of available samples. It will then proceed to generate a pool of weak classifiers based on 38 features, some of which may be excluded depending on the project properties initially set. The weak classifiers generated will henceforth be used to train strong classifiers through the usage of AdaBoosting. The training is done by doing an automatic optimization of the detection parameters. The trained data is then tested through the usage of cross-validation.

The learning phase for continuous movement diverges in the fact that it now uses a variation of Random Forest Regression, designated Random Forest Regression Progress. This variation does not look at all the frames, instead it uses only the frames from the discrete training in which the movement was labelled as true. The phase is compromised by less steps, where the samples are loaded, some automatic parameter adjustment is done based on project settings and the process is finalized by applying the classification algorithm. From the training, a database is generated which can then be accessed by our Unity application.

A representation of the workflow of the generation of the movement database can be seen in 6.1.

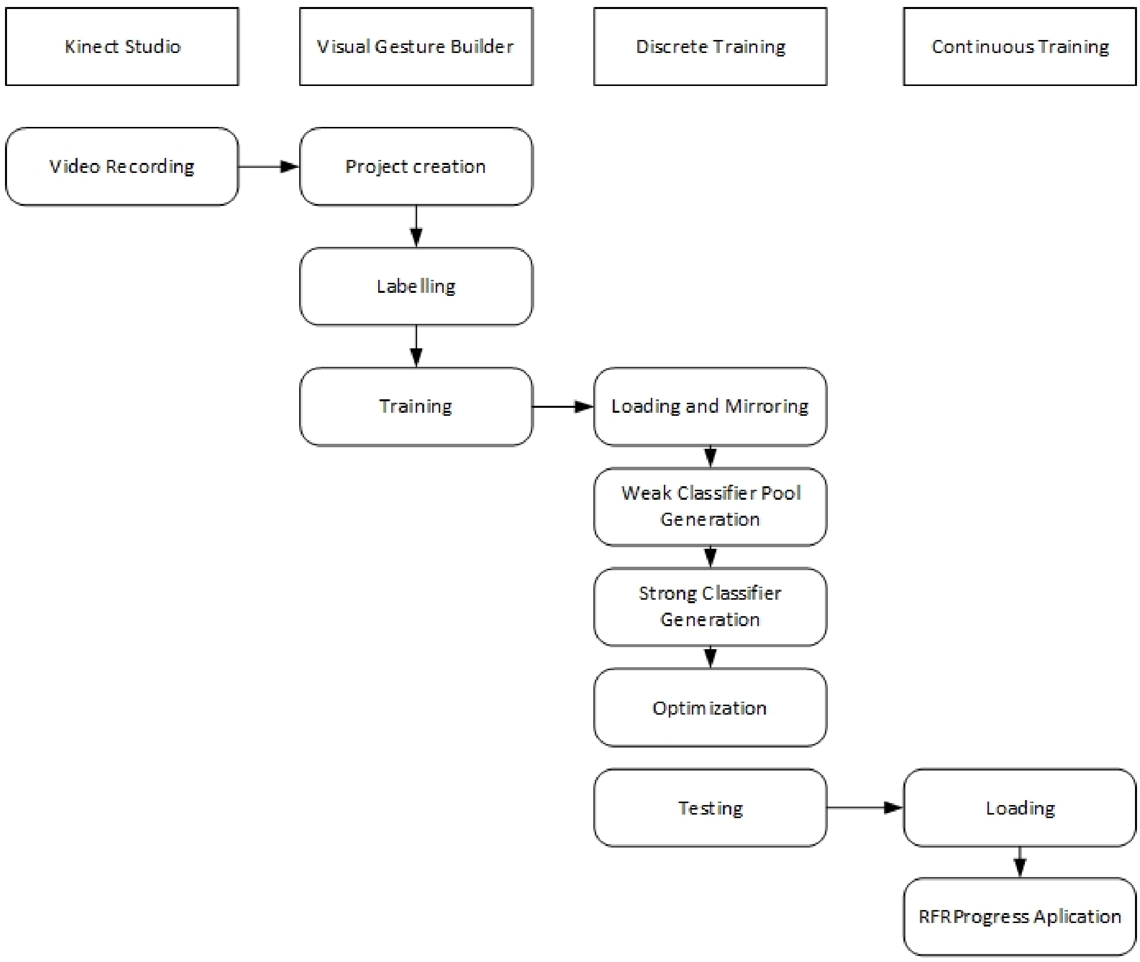

Figure 6.1: Workflow of how to create the movement database using the Microsoft Kinect

6.2 Game Interfaces

The Login phase is composed of two views: the login view and the main menu view. The login view shown in 6.2 allows the user to login or register into the system. To simplify the step, if the user is not registered, simply following the standard login will automatically register the user. From here, the user is projected to the main menu view where he can access the game or return to the login stage.

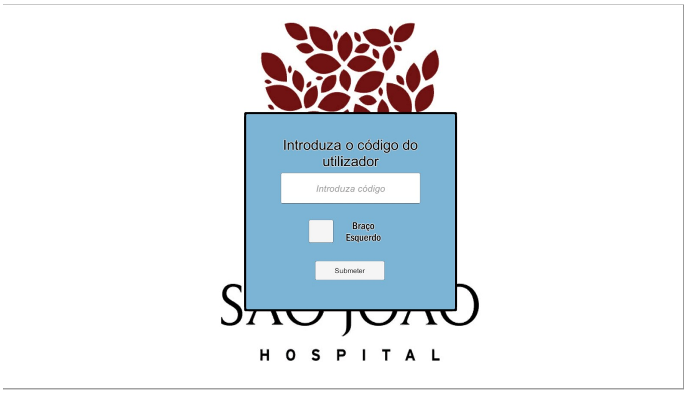

Figure 6.2: Login/Register screen

The Pre-assessment phase is composed of two views, 6.3. During the system operation check, the environment and avatar will be shown, alongside a blue window in which a representation of the user's skeleton will be shown when picked by the Microsoft Kinect. When advancing to the next step, a counter for the exercise repetition and a doctor avatar will appear to instruct the user.

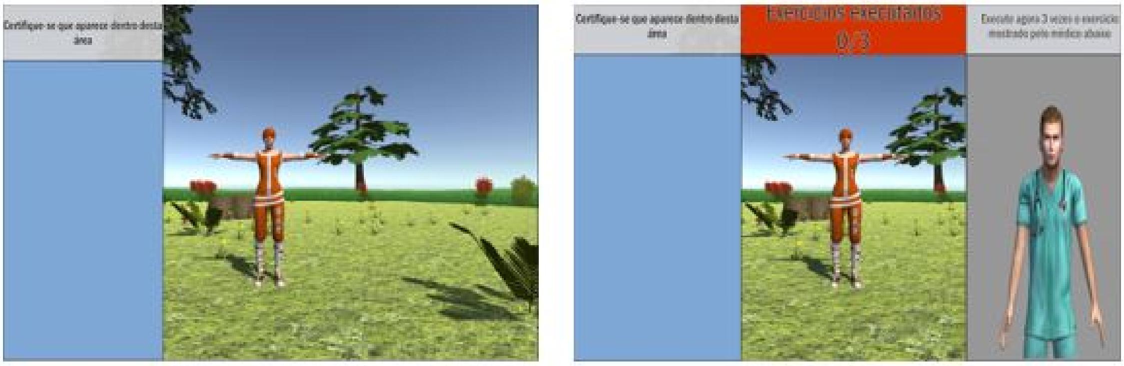

Figure 6.3: Pre Phase interface

The Exercise phase has a larger set of variations and is composed of five views. The first view will contain the environment, avatar and a text box instructing the patient that the exercise routine will now begin. Upon starting the routine, the instructions view will appear, showing the user instructions on how to perform the exercise and the doctor avatar performing the exercise. When ready, the user can proceed to the next view which will still maintain the instructions and doctor but will now add the exercise counter and a signal which identifies if the movement being executed is the correct one. These views can be seen in 6.4.

With the ending of a set, the first view will pop again this time prompting the user to take a small break.

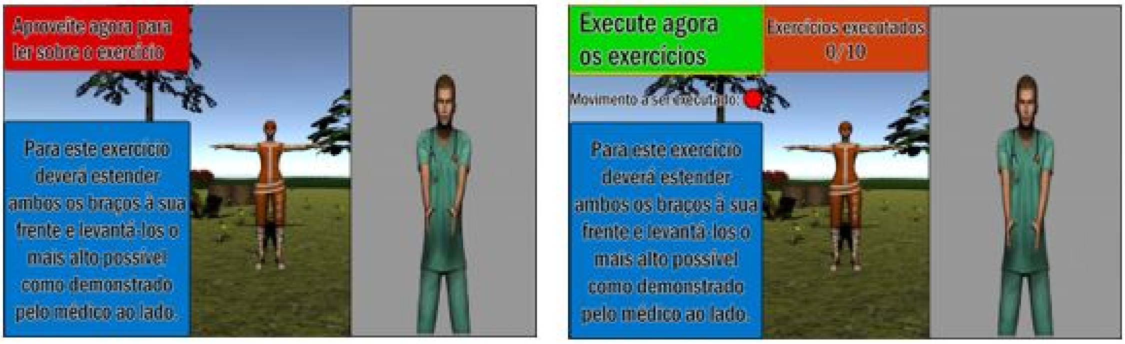

Figure 6.4: Exercise Phase interface

When all sets are complete, the user will be shown the results view, 6.5. On the left side of this view, the user will be shown progress bars representing how well he did in each exercise of each set, while on the right side the final evaluation of the user's performance will be shown in the form of stars, where each lit star represents one point in the classification.

Figure 6.5: Final Score screen

6.3 Game Mechanics

Every time a movement is perceived, after the user is prompted to execute an exercise, the system will check to see if that movement corresponds to the expected exercise with a 40+% certainty. Then the movement will be considered as valid. While it is considered valid, the system will continuously keep track of the progress of the movement, registering the highest progress achieved during this time. To avoid small tracking failures from the Microsoft Kinect, the movement will be considered as finished when it has subsided below 20% certainty of its execution for periods larger than 0.5 seconds.

The evaluation of the user condition, conducted during the second step of the Pre-assessment phase, is done by registering the highest progression during the 3 exercise repetitions and then averaging them. This evaluation is performed so that a dynamic game balancing technique, which is commonly referred to as rubberbanding mechanic, can take action during the score attribution during the Exercise phase.

A rubberbanding mechanic relates to a game mechanic that attempts to facilitate the game for those who have a poorer performance, usually without letting the user know it is being applied in an attempt to try to avoid certain emotions [126]. In the case of this game, the rubberbanding mechanic will attempt to attribute more points to the player based on how poorly he scored on the condition evaluation.

The normal scoring of the game attributes 1 points for every 1% of progress in each repetition, this means that for each repetition, a maximum amount of 100 points can be won. Given that the complete routine is composed of a total of 90 repetitions, the maximum score amount is thus 9000.

6.1 represents the score calculation.

$$Score = MaxProgress * 100 + Rubberbanding \tag{6.1}$$

As can be seen in 6.2, the rubberbanding mechanic adds a percentage of the maximum progress to the score, making it so the maximum score obtainable goes beyond the previous established maximum score of 9000.

$$Rubberbanding = Condition^{-1.55} * MaxProgress - 1 \tag{6.2}$$

The final classification which is set on a scale from 1 to 5 is then obtained by using the 6.3 and rounding the result up.

$$Classification = Score/MaximumScore * 5 \tag{6.3}$$

Given that game balancing is usually done by internal testing, with play testers, not much documentation exists to help with this process, thus the values used here are themselves tentative and later suffered changes upon user and medical expert feedback.

6.4 Home-based Variation

After some tests with patients with the first game, the second variation of the prototype was conceived, adding the motivation module and making small adjustments to the classification and the login view as well as the menu view.

The login screen changed slightly to feel more intuitive and to allow a way to exit the game if it was opened by mistake, without the need to go through this step and access the main menu, 6.6.

Figure 6.6: Home-based Variation Login/Register Screen

The menu was simply adjusted to include the new options of the motivational module. The motivational module implements the three progress visualizations previously referred in 5.

The Table and Graph visualization is thus a simple view containing a scrolling table where all scores sorted by date is shown on the left and a simple graph of the last 7 scores is shown on the right as seen in 6.7.

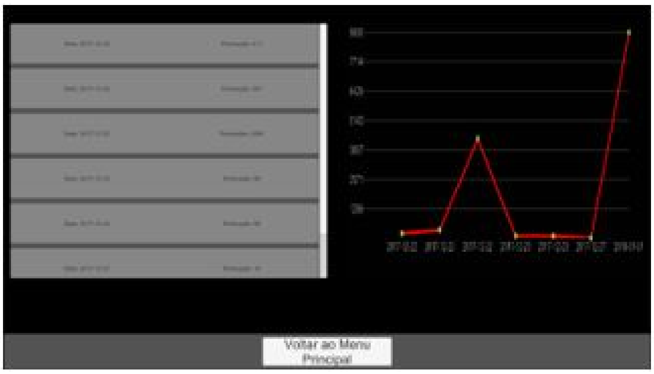

Figure 6.7: Table and Graph visualization

The Abstract Art representation, 6.8, can generate 7 different shapes that are slightly altered shapes of any colour. The representation is randomized and different every time it is viewed. Some elements from this representation are, however, controlled. The number of shapes is related to the number of repetitions done in the last session; colour and intensity of lighting are based on the latest score available.

This randomization of the representation prevents the user from seeing too many repeated patterns, while discovering that doing well in the session triggers changes in some elements despite the randomness. This visualization thus intends to distract the user of the idea of a rehabilitation game by introducing a more exploratory component.

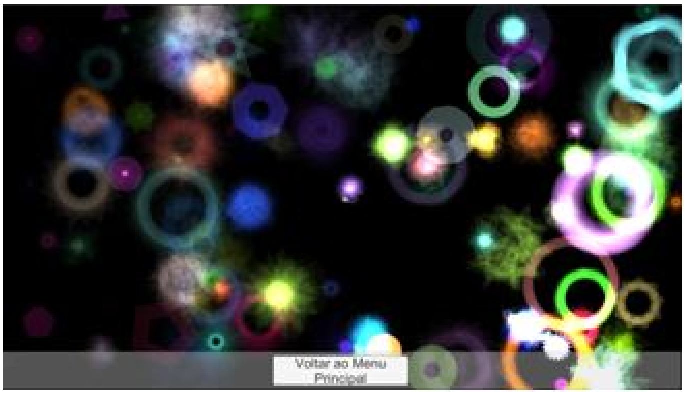

Figure 6.8: Abstract Art visualization

The Evolving Environment is composed of 12 different stages, which can be seen in E. As the user completes routines, the score gained in these is accumulated. When certain stages of points are reached, the environment evolves into the next stage. The score needed is decided by the following 6.4. The required amount of points for each stage can thus be seen in 6.1.

$$((Stage - 1) * 150)^{1.5} \tag{6.4}$$

Table 6.1: Required score for each stage of the Evolving Environment

Stage	Score Needed
1	0
2	1837.117
3	5196.152
4	9545.942
5	14696.94
6	20539.6
7	27000
8	34023.89
9	41569.22
10	49602.17
11	58094.75
12	67023.32

Additionally, to the new features just referred to, the classification system seemed to be either too forgiving or too punishing as can be seen in 6.2.

Table 6.2: Scores obtained by the patients in the experiment

Classification obtained	1	2	3	4	5
Number of patients	4	1	0	8	42

Given that the average time since a patient has been through the surgery is around 3.7 years, it is expected that a lot of patients will be in a considerably good condition. However, the non-existence of patients with a classification of 3 is indicative of poor balancing. To fix this a new classification system was adopted, based on the Portuguese basic education system classification, thus the classifications now work as shown in 6.3

Table 6.3: Percentagem needed to obtain each classification

Classification obtained	1	2	3	4	5
Percentage required	0-19	20-49	50-69	70-89	90-100

With this system in place, comparing to the results in 6.2, the patients would now have had a score orbiting more the classification 4 as can be seen in 6.4. Although this classification is not perfect since no one is able to obtain a score of 5, many are very close to it. This classification system seems to also be more lenient towards the lower brackets in general.

Table 6.4: Scores patients would had obtained with the new classification system

Classification obtained	1	2	3	4	5
Percentage required	3	2	6	44	0

6.5 Goniometer

The goniometer functions by providing the angle between two vectors. In the case of shoulder rotation the vectors can be seen as the vector defined by the points consisting of the chest and the hip, against the vector defined by the points consisting of the shoulder and elbow. In the case of elbow rotation, the angle is obtained by the vector defined from the shoulder to the elbow and the vector from the elbow to the wrist. These vectors can be seen in different planes in 6.9.

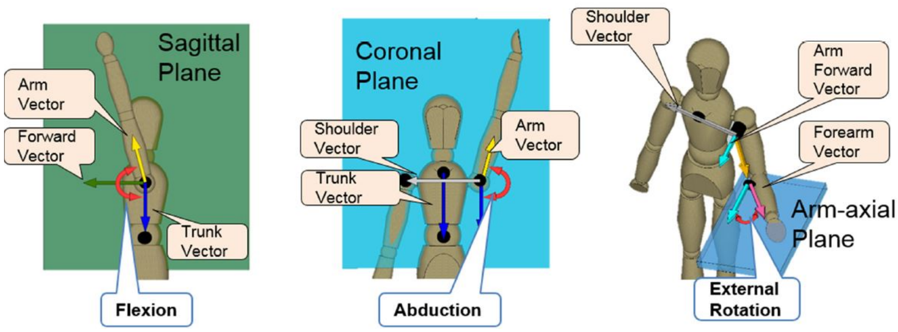

Figure 6.9: Measurment of shoulder and elbow ROM angles. (From [74]

The Microsoft Kinect is capable of recording these points reducing the process of calculating the angle to three steps:

Vector calculation from skeleton points, chest (p_1), hip (p_2) , shoulder(p_3), elbow(p_4), wrist(p_5):

$$Trunk\,Vector\,(v_1) = \begin{pmatrix} p_1x \\ p_1y \\ p_1z \end{pmatrix} - \begin{pmatrix} p_2x \\ p_2y \\ p_2z \end{pmatrix} \tag{6.5}$$

$$Arm\,Vector\,(v_2) = \begin{pmatrix} p_3x \\ p_3y \\ p_3z \end{pmatrix} - \begin{pmatrix} p_4x \\ p_4y \\ p_4z \end{pmatrix} \tag{6.6}$$

$$Forearm\,Vector\,(v_3) = \begin{pmatrix} p_4x \\ p_4y \\ p_4z \end{pmatrix} - \begin{pmatrix} p_5x \\ p_5y \\ p_5z \end{pmatrix} \tag{6.7}$$

Normalization of the vectors:

$$|v_1| = \sqrt{v_1x^2 + v_1y^2 + v_1z^2} \tag{6.8}$$

$$|v_2| = \sqrt{v_2x^2 + v_2y^2 + v_2z^2} \tag{6.9}$$

$$|v_3| = \sqrt{v_3x^2 + v_3y^2 + v_3z^2} \tag{6.10}$$

$$\hat{v_1} = \frac{v_1}{|v_1|} \tag{6.11}$$

$$\hat{v_2} = \frac{v_2}{|v_2|} \tag{6.12}$$

$$\hat{v_3} = \frac{v_1}{|v_3|} \tag{6.13}$$

Calculation of the dot product and conversion to degrees:

$$ShoulderAngle\,(degrees) = \frac{arccos(\hat{v_1}.\hat{v_2})}{\pi} * 180 \tag{6.14}$$

$$ElbowAngle\,(degrees) = 180 - \frac{arccos(\hat{v_1}.\hat{v_2})}{\pi} * 180 \tag{6.15}$$

It should be noted the variation for the calculation of the elbow angle 6.15. This variation takes into consideration that when the arm is extended it will have an angle of approximately 180º, when it is flexed however the angle recedes instead of increasing. The interface used can be seen in 6.10.

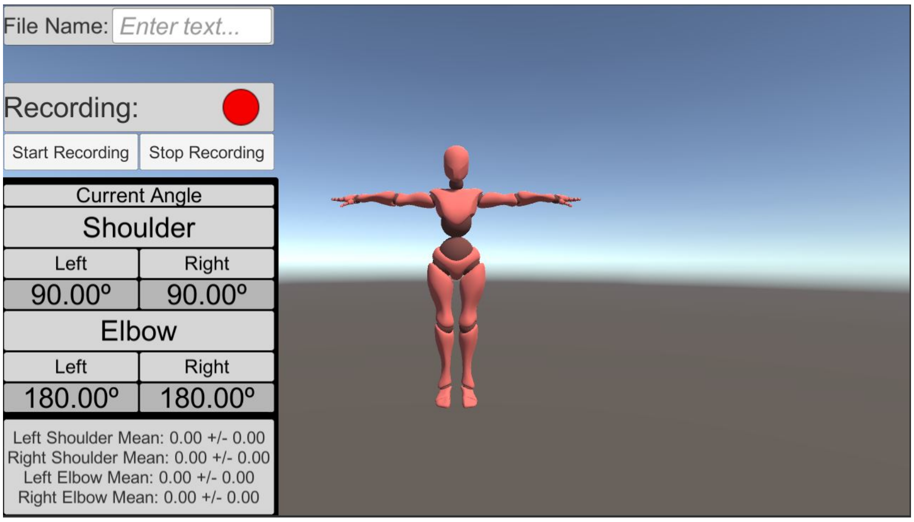

Figure 6.10: Goniometer testing interface

6.6 Therapist Interface

Available only to the therapist, this interface is capable of presenting multiple statistics obtained during the recording of the users skeletal representation during the performance of the game routine executed in the Exercise Phase. The interface can be seen in 6.11.

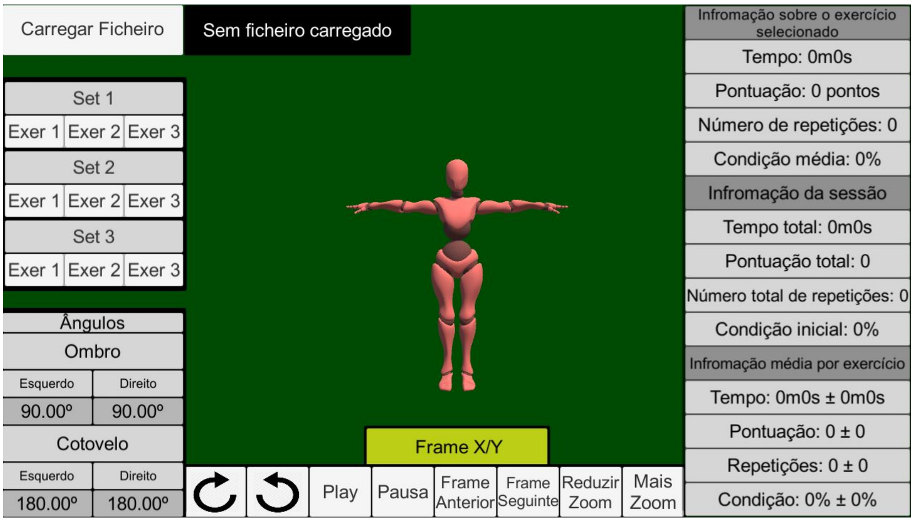

Figure 6.11: Therapist interface default view

This interface allows the therapist to load any routine recorded by the game, and analyse any of the exercises frame by frame through the reconstruction of the skeletal representation's positions during said exercise.

Statistics captured by the game are also presented when loading the routine. From these statistics the therapist can see the patient's initial condition captured in the Pre-Phase, how long it took to complete an exercise, how many repetitions he was able to do per exercise, etc.

This interface also makes use of the goniometer tool 6.5 to present the current frame's shoulder and elbow angles.

6.7 Cooperative and Competitive game modes

The idea behind these game modes comes not only because of the social incentives already discussed in 5, but also from the literature reviewed in 3 where competitive, cooperative and individual methodologies were tested in classrooms and other environments to verify how well the person developed. With this in mind the possibility of the rehabilitation game having more than just an individual mode arises. The concept lies in the disguising of the rehabilitation exercises so that the rehabilitation patient may play the game with friends and family that do not suffer from the same conditions. The game modes also rely on the idea of distracting the patient from his symptoms by making these exercises seem like simple commands that control the game, unlike the main game. For each game mode, a manual option is available on the menu.

6.7.1 Cooperative mode

The objective of this mode is to, through the usage of rehabilitation exercises, control a character, attempting to dodge balls that bounce of the corners of the screen.

The cooperative mode is composed of four elements, the controllable character, the number of lives remaining, the enemies (the balls) and a small collectible cube.

The character possesses the ability to move in four different directions, each triggered by the execution of a specific rehabilitation mode. The game is proposed for two players in which each player can control two of the directions. One may control the vertical movement and the other may control the horizontal movement. The exercises included in the game is the shoulder flexion, horizontal shoulder abduction and a new exercise not used in the original game which is shoulder extension, as seen in 5.4.

To control the vertical movement, the player can perform the shoulder flexion, to move the character up, and the shoulder extension, to move the character down. For the horizontal movement, a horizontal shoulder abduction performed with the left arm will move the character to the right, while the same exercise performed with the right arm will move the character to the left. The reason for the inclusion of the new exercise, as opposed to the shoulder abduction, has to do with the dissociation of the movement caused by the execution of the exercise, versus the demonstrated effect by the character. The rising of the arms does not translate well into the downwards trajectory followed by the character causing confusion to the player, requiring him to get used to this dissociation or simply give up on the game mode due to the frustration of confusing the movement with the upwards control movement. On the same note, this movement dissociation is the reason why the horizontal controls seem switched. When performing a horizontal shoulder abduction, the arm swings to its opposite direction, making it seem like we intend to push something to the other side, thus the right arm pushes the character to the left and vice-versa.

The game begins with a single ball in play 6.12. Each ball starts in one of its four possible stages. Whenever the ball hits a wall, it progresses to its next stage and accelerates up to a maximum speed. When a ball, in its final stage, collides with a wall it breaks in two new balls resetting back to their first stage and speed. A maximum of six balls can be present on the screen at any time. When a ball collides with the character, the player loses one of its three lives and the character is left invulnerable to another ball hit for a few seconds, the ball is destroyed, along with all other balls except one.

Lastly, the collectible cube is a small objective within the game which the character may collect to clear the screen of all balls except one. The cube spawns every 15 seconds since it was last seen. The cube acts as a small objective that makes the player have to decide if he should risk the safety of its current spot to reset the balls threats or simply hold out.

When all lives are lost the game ends and the score menu is shown displaying how long the players could survive.

Figure 6.12: Start of the Cooperative mode

6.7.2 Competitive mode

The competitive mode suffered through two iterations. The first was more similar to the original game in which the users would both be performing the exercises existent in the original, although they would compete to see which of the players can achieve a certain score the fastest. The score for each repetition of the exercise was attributed based on how well performed it was. The first to win two exercise competition would win the game. This type of game, however, presents a particularly hard to balance situation given that if one of the users is not a rehabilitation patient, then it will be easier for him to score points quicker. Some rubberbanding mechanics may be applied to counter this, but would be hard to conceal given that users would be able to observe, after repeated uses of the game, one player doing less to obtain a better score. This can translate to some frustration as the game will seem unfair for both players. This can possibly even trigger feelings of inadequacy from the rehabilitation player, since he'll be constantly reminded by the game that he is judged to not be in condition to face another player in equal footing.

An example of the game's main view can be seen in 6.13.

Figure 6.13: Example of the Competitive mode

To partly deal with the problem of the first version, a different competitive mode was created in which the players each control a ball with the objective of being the first to escape a maze, achieved by reaching the finish line indicated by a yellow stripe. The movements are equal to those explored in the cooperative mode with the exception that each user now fully dictates all movements of the ball he controls.

This type of solution, although sharing the same problem as the first, can more easily obscure the disadvantage by seeming like a more tactical problem. It is, however, imperative that the maze is symmetrical so that no advantage is perceived by the opposite side.

Some basic map examples can be seen in F.

6.8 Summary

The implementation of the individual game mode was successful and fully used for the clinical study proposed in 5, with results in 7.

The home-based version of the game although fully implemented for trial, revealed to contain a error that undercut the full game experience and has since then been fixed. This fix, however, could not be tested out due to a lack of patients with the required conditions.

The goniometer tool was implemented based on the work of [17]. It, however, had results below the expected which are discussed in 7.

The cooperative and competitve modes were also fully implemented and had positive results with a non movement impaired population, although results showed the game modes need work at an aesthetic level.

Chapter 7

Results

In this chapter, an analysis is made of the results obtained in both the test phase of game's first version, at Hospital de São João, and the test phase of the home-based version destined for usage of the model patient.

7.1 Results of Hospital Study

All the test relative to first version were done in Hospital de São João where we had access to 78 patients. From the 78 patients, 10 were used to verify that the system was working as intended and that the values from the experience were being correctly stored. It was also a core part to test the available space provided, since the amplitude of captured movements required the user to be a certain distance away from the Microsoft Kinect to allow it to frame the entire movement.

Since one of the objectives of the test was to register the preference of users to the usage of this tool versus the current used system, which consists of offering patients flyers where "to-do at home" exercises are explained, from the remaining patients, 13 were used as a control group. To this group of 13 patients we offered the usual flyer. After the patient was through with the reading it, he was presented with a questionnaire. The remaining 55 patients were prompted to use the new system. After the usage of the system was finished, each patient was inquired of its satisfaction level of the usage of the system through a questionnaire similar to the one presented to the 13 patients that made usage of the flyer.

Each test session took on average no more than 15 minutes per patient.

7.1.1 Questionnaires

During the test session, the patient was submitted to two questionnaires, one at the beginning of the session, and a second one at the end of it.

One of the main problems in the conception of these questionnaires was the lack of ability to validate a questionnaire created by us. This problem makes so that we are forced to use generic questionnaires.

The first questionnaire served the purpose of helping us understand the demographic of our population. Given the short amount of time available per session and that this questionnaire only served the purpose of obtaining a generalist overview of the population, the questionnaire used was created by us.

The second questionnaire oversaw testing the satisfaction level of the user relative to the usage of the system. The usability of the system is one of the most important qualities being one of the most contributing factors for its success [94]. In highly competitive scenarios, where the existence of multiple applications with similar functions are available, one usually witnesses that the preferred application is the one which possesses the most accessible interface [59].

To carry out this evaluation a questionnaire based on [99] was used. This questionnaire seeks thus to analyse eight criteria:

1. Suitability for the task
2. User control
3. Flexibility
4. Error management
5. Compatibility
6. Self-descriptiveness
7. Consistency
8. User Workload

This questionnaire A is thus composed of eight questions, where each can be answered with an evaluation on a scale of 1 to 5, where 1 is the worst classification and 5 is the best. Additionally, there exists an answer box where the patient can leave any comment relating the full test experience. This box allows to cover for the lack of a very specific questionnaire, while allowing some amount of time to be saved during the whole test sequence. It is important to note that as can be seen on A, the questions are more diluted and thus less objective, this was advised and approved by the overseeing medical body as a means to take into consideration the age and usual technological proficiency displayed by the studied population.

Lastly, a variation of this questionnaire was shown to the 13 patients that participated in the study through the usage of the flyers as can be seen in A.

7.1.2 Population Demographics

The general information obtained from patients that used the system during the test phase was: age, visual disabilities, Hearing disabilities, motor disabilities, difficulty in standing up 15 minutes or less, arm affected by surgery, practice of the recommended exercises, use of external physiotherapy, time since the surgery and previous experience with digital games.

Table 7.1: Hospital study population demography

Question	Answer
Age(mean)	59.09 ± 10.92
Years since surgery (mean)	3.9 ± 3.67
Visual disabilities (%)	80%
Earing disabilities (%)	23.6%
Motor disabilities (%)	5.5%
Difficulty standing up (%)	30.9%
Affected arm (% right arm)	65.4%
Practice of the recommended exercises (% yes)	34.5%
Use of external physiotherapy	9.1%
Previous experience with digital games	30.9%

One of the main characteristics that stands out in 7.1 is the low care with the practice of the recommended exercises. Relating the practice of the recommended exercises with the usage of external physiotherapy, it is possible to observe that about 36.36% of the population makes use of external physiotherapy or practices the recommended exercises at home, where about 7.3% of the population does both. This low proactivity towards the practice of exercises is especially high for patients whose surgery has been done in less than a year, where 23.08% of these does at least one of the two actions before mentioned and only 7.7% does both. This tendency shown by patients reveals the need of an additional tool that can act as a counter-measure to this behaviour.

Details to have in consideration for future developments of this type of tool is the fact that a great majority of the patients has visual disabilities and low experience with digital games. Of the patients with visual disabilities, 43.48% possess both far and near sight related problems, while 32.61% possess problems exclusively related to near sightedness. Of the patients that possess experience with digital games, only 47.05% feel confident in that experience. These types of difficulties by part of the target audience must be taken into consideration when developing interfaces for this type of audience.

A small detail that should also be taken into consideration is the inability, or a high level of discomfort, felt by the patients when it is required to be standing up for per certain amounts of time, even short periods. From the patients witnessed with this difficulty, 23.53% required that the tests were made while the patient was sitting down. This particular detail reminds us that future implementations should take into consideration that a significant amount of the audience for these types of solutions will need it to allow them to be sitting.

7.1.3 Analasys of Data from User Session

During the test session, data relative to the user condition and the execution of the exercises was captured. From the results displayed on the 7.2, the session time refers to the time it took to execute said exercises, which means it does not account for the time the users spent in the main menu or in the pre-game stage, as well as rest times, exercise preparation or results screen existent in the game scenarios. In order to cover for system fails, any time that occurs in which Microsoft Kinect is not able to identify the user is not considered. The condition of the user refers to the condition obtain during the pre-game phase as discussed in 5. The final evaluation is indicative of the final classification attributed to the user given its performance for the proposed exercises.

Table 7.2: Average resutls obtained from sessions for session time, condition and system's final evaluation of the user

Variable	Results
Session time (average)	303.08 ± 65.44 seconds
Condition (average) (%)	85.49% ± 10.83%
Condition (minimum)	45.42%
Condition (maximum)	97.22%
Final evaluation (average)	4.51 ± 1.11

From the 7.2 table, it's possible to observe that a session takes about 5 minutes. Regarding the demonstrated condition, we should highlight that there are cases in which the patient possessed a low movement amplitude which sometimes made it almost impossible for him to do the condition evaluation movement. However, since the exercises were trained to be recognized as a two-armed movement, the ability to lift the affected arm above the waist will be considered as about 40-45% progress towards the complete movement, as long as the unaffected arm is almost at the correct maximum position. It should be noted that 40-45% is near the lower limit possible of recognition since anything below that may be confused for another similar movement, which is a big possibility given that all exercises proposed start from the same position and follow a similar trajectory during their initial phase.

During the test phase, the classification was observed as probably too lenient towards higher ranges and too harsh towards lower values. These results can be attributed to both the need to better labelling during the training phase of the system as well as the balancing of the scoring and classification method.

From 7.3, we can check that the average duration of execution of each of the 3 exercises takes roughly the same time, showing that these exercises possess about the same degree of learning/execution. Shoulder flexion shows a superior execution rate compared to the remaining, which could mean that the other exercises requiring more effort or cause the user more pain to execute.

We can observe that throughout the game's course, the time spent per set tends to decrease. This indicates a quick adaptation by the user to system's use.

The number of repetitions per set also tends to decrease as the game progresses, although there is a slight increase in the third set compared to the second set. Since the user knew how many sets he would be doing, knowing that this would be the last set could have motivated the user to put more effort on this set compared to the previous set. Such last spurt motivation should be taken into consideration when creating routines for future development.

Table 7.3: Average time spent/repetitions executed per exercise set

Variable	Result
Average time per shoulder flexion set	33.38 ± 11.69 seconds
Average time per horizontal shoulder abduction set	33.70 ± 14.60 seconds
Average time per shoulder abduction set	30.97 ± 12.80 seconds
Average time spent on shoulder flexion set 1	41.32 ± 10.80 seconds
Average time spent on shoulder flexion set 2	35.31 ± 12.03 seconds
Average time spent on shoulder flexion set 3	32.50 ± 10.91 seconds
Average time spent on horizontal shoulder abduction set 1	41.73 ± 15.45 seconds
Average time spent on horizontal shoulder abduction set 2	30.95 ± 13.45 seconds
Average time spent on horizontal shoulder abduction set 3	28.41 ± 11.64 seconds
Average time spent on shoulder abduction set 1	34.23 ± 13.19 seconds
Average time spent on shoulder abduction set 2	28.82 ± 12.17 seconds
Average time spent on shoulder abduction set 3	29.81 ± 12.93 seconds
Repetitions executed per shoulder flexion set	9.12 ± 2.58
Repetitions executed per horizontal shoulder abduction set	8.40 ± 3.07
Repetitions executed per shoulder abduction set	8.65 ± 2.94
Repetitions executed per set 1	28.77 ± 2.20
Repetitions executed per set 2	26.45 ± 3.18
Repetitions executed per set 3	26.86 ± 3.11

7.1.4 Post Session Questionnaire Analisys

After the game session was complete, each patient was prompted to fill out the satisfaction level questionnaire shown in A.1.

As can be seen in 7.4, most users were very satisfied with the game averaging a score of 4.75 throughout all questions. Most questions scored between 4 and 5, except question number 7 which deviated closer to a score of 3. This question related to how fatiguing the game was in general, reveals that some balance should be done to the exercise sets when the game detects the patient's condition is low, or has shown difficulty completing the first set.

Relative to the minimum scores, especially in question 1 and 7, although this is a onetime occurrence that comes from a single user, it should be noted as an example of a case in which the application would not be the optimal solution and therefore should be other systems readily available for those patients.

Table 7.4: Post session questionnaire results

Question	1	2	3	4	5	6	7
Average	4.6	4.72	4.92	4.88	4.96	4.88	4.32
Standard Deviation	0.74	0.50	0.32	0.29	0.19	0.39	0.79
Minimum Score	1	3	3	4	4	4	2
Maximum score	5	5	5	5	5	5	5

Relative to the questionnaire, A.2, presented to the 13 patients that read the flyer instead of playing the game, the overall satisfaction level was lower, as can be seen in 7.5, the average question score was of 4.41. On the flyers we can see that the score levels fluctuate more make the score round between 3 and 5, showing a tendency for the proposed system to be preferred. The minimum score again presents two cases of extreme dissatisfaction with the system being tested, remembering us again that it is ideal to always consider a secondary system for some users even if the current one has a general high satisfaction level.

Table 7.5: Pamphlet questionnaire results

Question	1	2	3	4	5	6
Average	4	4.08	5	4.6	4.6	4
Standard Deviation	1.11	1.27	0	0.84	0.84	1.11
Minimum Score	1	1	5	2	2	1
Maximum Score	5	5	5	5	5	5

In another game developed for breast cancer rehabilitation [83], the same type of questionnaire as A.1 was used to evaluate the game. A comparison between the same questions can be seen in 7.6. The results show that, on the same topics, this game has been more accepted by the studied population, having higher results, while generally having smaller standard deviations. It is however relevant to indicate that this game was created with more focus on patient satisfaction than the one we compared to, where one of the focuses was the ability to monitor lymphedema.

Table 7.6: Comparison between post session questionnaire results with [83] questionnaire results

Question	1	3	5	6	7
Our Average	4.6	4.92	4.96	4.88	4.32
Their Average	4.4	4.4	4.4	4.4	3.8
Average Difference	0.2	0.52	0.56	0.48	0.52
Our Standard Deviation	0.74	0.32	0.19	0.39	0.79
Their Standard Deviation	0.7	0.7	0.8	0.8	1.2
Standard Deviation Difference	0.04	-0.38	-0.61	-0.41	-0.41

A reason why this game shows better satisfaction results may stem from the fact that the game and controllers are more direct in what it expects the user to do and how it expects him to do it. Another reason may also come from the presence of an NPC, which according to [1] is also an important element to increase patient motivation as it creates a small sense of socialization.

7.2 Home-based Variation Results

The second variation of the game which includes the motivational module and was tested on a single patient. The patient was selected from one of the 55 that experienced the game without this module. She was selected due to the recency of the operation and the state of the condition reported by the game, which attributed 2 stars in the final classification. This test, however, was not very fruitful due to two issues. The first was a bug that occurred within the database which did not record the exercises made. The second was that the patient only used the system a total of

7 times before her condition worsening making her unable to continue the program. Despite this, the patient was still submitted to two questionnaires. The first questionnaire was the same as the one shown during the first variation of the game. As can be seen in 7.7, the overall average score is lower than when evaluated in the single use setting. Additionally to this, a bug was detected in this version of the prototype which made one of the exercises sometimes not register the indicated movement, which in turn lead to an overall frustration feeling with the rest of the game. The scores regarded in question 6 indicate that the overall scheme of the UI may need to be simplified. In regard to question 7, the patient indicated that although feasible, the exercise routine was slightly tiring, which is to be expected given the condition of the patient.

Despite the lower than average score, the game still possesses an overall high score grade.

Table 7.7: Model patient post session questionnaire

Question	1	2	3	4	5	6	7
Score	5	4	2	4	5	3	3
Suggestions	Improve the avatar representation. The error detected was that exercise 2 was sometimes not registering, needing to be skipped.						

The second questionnaire was made by us to understand how the experience felt when carried out through a more daily basis and how the new module worked in that context. This questionnaire can be seen in A, while the asnwers given to it can be seen in 7.8.

Table 7.8: Model patient questionnaire results

Question	Answer
1	Personal use.
2	Table and Graph.
3	Adequate.
4	Improve the avatar representation.
5	Yes, at short term.
6	Yes.
7	Helped.
8	At this point, I can't evaluate.
9	Couldn't find out.
10	Can't evaluate, since I did not use it long enough.

Given the amount of time the patient was able to use the system, the patient was unable to feel like she could correctly answer some of the questions. A question that also suffers from this limitation is the preference for each visualization in which the patient indicates a preference for Table and Graph given its immediate translation into an easy to interpret result, unlike the other representations, especially the Abstract Art which takes time for a patient to realize the gradual differences, or the Evolutionary Environment, which requires multiple sessions. Beyond this, it is to note the patient's preference for the personal use system with the new module.

A current problem with this game mode is that it currently only has one set routine, this was originally done to have all tests throughout all patients be exactly the same, and left like this on purpose for this variation to maintain this same consistency. This possibility of becoming a tedious routine for the patient was, however, predicted, but we decided that it would be valuable to have the users confirm it before looking for solutions.

It is worth noting that the answer to question 7 seems to have been poorly interpreted by the patient and might have been interpreted has a questioning if the user felt that the usage of the system had helped her physical condition.

For the remaining questions, the patient felt she did not had enough time with the system to perform an evaluation of it.

These answers, although inconclusive as a whole, seem to indicate the system's potential, although some technical issues are already clear, namely avatar representation and the need to renew the challenge provided.

An important note to take from the first questionnaire is also how tiring the game felt. This suggests that the game should maybe instead of providing a rubberbanding mechanic, should possibly look to attempt to alleviate the amount of exercise repetitions asked in certain sets depending on the user's initial condition. This however would require a bigger Pre-Phase to unsure that all possible exercises were tested, since there was no clear correlation between the difficulty for each exercise.

7.3 Goniometer

To verify the virtual goniometer tool used in the therapist interface 6.6, a small study was conducted. The study consisted on the Microsoft Kinect v2 recording subjects in two different views, coronal and sagittal, while performing a shoulder flexion, shoulder abduction and elbow rotation with both arms. The goniometer used to compare the values of the Microsoft Kinect v2 had a range between 0º and 270º, with a scale of 2º and an error of $\pm$ 1º. An image of the goniometer can be seen in 7.1.

To obtain the angle values, for comparison with the goniometer, every frame the system records all of the 4 angles. When the recording process is over, the system returns the average for each angle and their respective standard deviations.

A population of 5 subjects with no known shoulder impairments was used for this study (7.9).

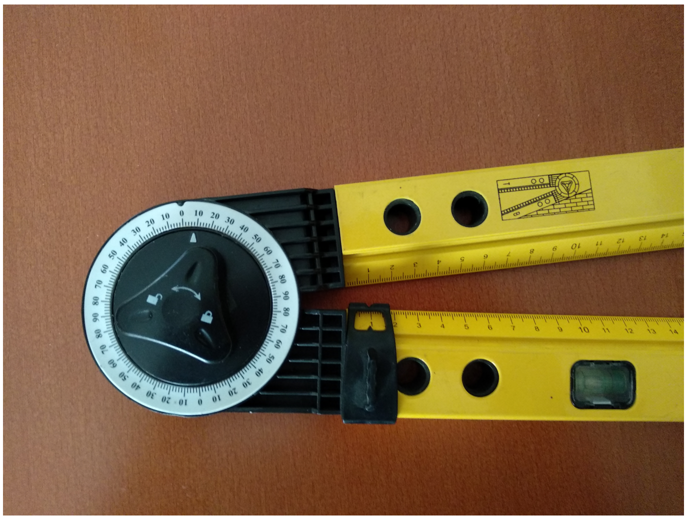

Figure 7.1: Goniometer used in this study

Table 7.9: Goniometer population demography

Age	43.4 ± 11.72
Male/Female	4/1
height	1.74 ± 0.08

7.3.1 Shoulder Flexion

Each subject was recorded performing a shoulder flexion at a random angle in a coronal position with each arm, followed by the recording of the movement set at a 90º angle which was recorded both in a coronal position and a sagittal position. The results of these recordings can be seen in G.1, while the average difference in the goniometers' measurements can be seen in 7.10.

Table 7.10: Difference between both goniometers for Shoulder Flexion poses (in degrees)

Pose	Right Side	Left Side
Free Angle - Coronal view	6.73±2.20	6.66±3.81
Set to 90º- Coronal view	7.22±7.00	5.17±6.50
Set to 90º- Sagottal view	6.35±5.95	6.57±7.91

7.3.2 Shoulder Abduction

For the shoulder abduction exercises, the same procedure as the shoulder flexion was taken, in with each subject is recorded performing a shoulder abduction at a random angle in a coronal position with each arm, followed by the recording of the movement set at a 90º angle which was recorded both in a coronal position and a sagittal position. The results of these recordings can be seen in G.2, while the average difference in the goniometers' measurements can be seen in 7.11.

Table 7.11: Difference between both goniometers for Shoulder Abduction poses (in degrees)

Pose	Right Side	Left Side
Free Angle - Coronal view	2.53±2.40	5.344±6.48
Set to 90º- Coronal view	2.52±1.78	3.86±2.63
Set to 90º- Sagottal view	7.50±5.94	4.22±3.05

7.3.3 Elbow Rotation

For the elbow rotation exercise, each patient rotated his elbow to a random angle in a coronal position. The results of these recordings can be seen in G.2, while the average difference in the goniometers' measurements can be seen in 7.12.

Table 7.12: Difference between both goniometers for Elbow Rotation (in degrees)

Pose	Right Side	Left Side
Free Angle - Coronal view	8.17±8.47	6.06±6.14

7.3.4 Discussion

As can be seen in 7.10, the virtual goniometer tends to work better in sagittal view. This can be expected as the Microsoft Kinect v2 may suffer from joint occlusion in this exercise when in a coronal view. The values obtained are, however, far from accurate, as no pose has a less than 5º difference between goniometers.

For the shoulder abduction exercise, the differences regarded in 7.11 are more acceptable, having a difference of about 2.5º between goniometers in a coronal view. Much like a reverse of the shoulder flexion situation, the measurements for this exercise are better in a coronal view, rather than a sagittal one, given that in the later the Microsoft Kinect v2 suffers from joint occlusion.

The elbow rotation exercises demonstrated to also be inaccurate, as seen in 7.12, this however may come from most elbow rotations recorded having been with the elbow next to torso, while having the forearm pointed at the capture device, possibly creating some occlusion of the points.

All of these results are, however, inferior to the ones recorded by a Microsoft Kinect v1 in [17], despite both having a similar approach in how they handled the Microsoft Kinect's data.

7.4 Cooperative and Competitive game modes

To test the cooperative and competitive modes, each game mode was played for a duration of approximately 5-10 minutes. Due to the unavailability of breast cancer patients to participate in this part of the study, the population that participated in was comprised of healthy adults that did not possess any motor disability. Due to this population not being the target audience, a smaller sample was taken to merely verify usability and get a general idea of the game's acceptance. To this end, the same questionnaire that was used on the hospital study was also used here A. A demography of the user population can be seen in 7.13

Table 7.13: Cooperative and competitive population demography

Question	Answer
Age	36.5 ± 12.86
Visual disabilities (%)	62.5%
Earing disabilities (%)	0%
Previous experience with digital games	62.5%

A note to make when comparing the population of this study with the population of the hospital study is that this population is much younger and has much more experience with digital games, which creates a different level of expectation of the game. This expectation can be seen in the average lower results scored by these game modes(7.14, 7.15) when compared to the one used on the hospital studies 7.4.

For both game modes, subjects reported that the game modes did help with exercising to a satisfactory level.

The tutorials were, however, criticized for being displayed in an outside of game environment in a "manual-esque" form, showing that the players expect the tutorial to show up on demand when they need to check a particular rule, or how to execute a specific action.

The errors reported were an occasional error in which similar movements, namely the horizontal shoulder flexion inputs would sometimes misjudge the direction, this has, however, been since fixed.

The game's aesthetics was something more heavily criticized. This was somewhat expected from subjects with higher levels of experience with digital games, as this is a major concern in most AAA[1] games, thus leaving the subjects expecting more.

All other values were within acceptable levels, although it should be noted that, for the last question patients indicated that these game modes were somewhat physically intensive. This may require some revisiting to level design/game balance to create a more enjoyable experience for breast cancer patients.

Regarding the slight difference in score in question 2 and question 5, this may stem from the players having always been introduced to the cooperative game mode first and thus being more acceptable when a very similar display is shown in the competitive game mode.

Overall,the subjects reported having enjoyed the different game modes, with a preference for the competitive game mode. This preference may however stem from the higher entry level into the cooperative mode, given that it requires players to not just learn the game, but to adapt to each other, making it so that more sessions are required before a certain level of satisfaction for playing the game is achieved.

[1] en.wikipedia.org/wiki/AAA_(video_game_industry)

Table 7.14: Cooperative game mode questionnaire results

Question	1	2	3	4	5	6	7
Average	4.50	3.63	4.00	3.63	4.25	4.38	4.13
Standard Deviation	0.53	0.74	0.76	0.92	0.71	0.52	0.83
Minimum Score	4	3	3	2	3	4	3
Maximum score	5	5	5	5	5	5	5

Table 7.15: Competitive game mode questionnaire results

Question	1	2	3	4	5	6	7
Average	4.63	4.00	3.75	3.63	4.50	4.50	4.25
Standard Deviation	0.52	0.76	0.71	1.06	0.53	0.53	0.89
Minimum Score	4	3	3	2	4	4	3
Maximum score	5	5	5	5	5	5	5

7.5 Summary

The overall system seems to be well accepted and even preferred to the currently used pamphlets by the general sample tested, having higher scores and more normalized deviations. The system also seems to be preferred to similar systems [83] previously tested in similar populations.

The general time for each session is within the requirements with acceptable fatigue levels reported. The final classification in the initial tests was deemed to tendentious towards its extremes and was changed for the home-based variation, although no conclusions can be drawn from the short amount of data gathered.

The home-based variation, although tested on a patient, must still be further tested in order to draw conclusions from it.

Overall, technical details must still be adjusted, especially regarding the avatar behaviour and the perceived game difficulty.

The goniometer has shown disappointing results, being less accurate than similar implementation with the Microsoft Kinect v1, despite having a similar precision.

For the cooperative and competitive games, functionality is acceptable, although certain details must be improved to encompass players with more experience with digital games, which have higher expectations of how a game looks and works. These game modes also appear to be more physically demanding than expected, which may require further balancing before presenting it to a rehabilitation population.

Chapter 8

Conclusion

In this chapter we review the original problem that lead to the realization of this project and how our proposed methodology faired as a possible solution to it.

We also briefly discuss the overall biggest limitations and future work recommended.

8.1 Conclusion

As breast cancer survival rates increase, there begins to exist an ever increasing need for the availability of method that can deal with the negative side-effect, be it physical or psychological, of both diagnosis and treatment [57].

Exercise has been identified as one of the most effective ways of dealing with the physical side-effects, while also helping with some of the psychological ones [57] [76]. The WHO recommends, for adults aged between 18-64 years, at least 150min/wk of moderate-intensity or 75min/wk of vigourous-intensity aerobic physical activity [135].

For the rehabilitation process to succeed such consistent exercise is needed [72]. There are, however, multiple factors presented by patients that act as an impediment, such are, nausea, fatigue, lack of time, low exercise support, pain, no counseling for exercising and time restricted by work [23].

Another difficulty with the rehabilitation process is maintaining the patients motivation. The rehabilitation process is not a one time event and will follow the patient for the rest of his life, although it may not have the same intensity. It is thus critical to also provide efficient ways of maintaining motivation, be it by enhancing the perception of benefits [9] or providing continuous fun challenges.

In this dissertation the creation of a tool to aid breast cancer patients through their rehabilitation phase was proposed.

In the case of Hospital São João, the current system in place consisted of the occasional distribution of informative pamphlets suggesting home-based exercises or the incentive for the patient to participate in physiotherapy beyond that offered by the hospital. This system has shown to not be put into practice as much as required and, therefore, requires alternatives or complementary systems to ensure that the patients exercise not just more, but also correctly.

The tool developed comes, thus, as a possible supplement to the current system with not just the ability to encourage the patient to exercise more frequently, but also to keep track of his progress and condition, allowing not just the therapist to better shape the patient's current treatment, but also for the patient to have a sense of how himself is progressing between the longer spaced therapy sessions.

The results obtained from the tests performed in an hospital environment with patients has provided positive results and a bigger acceptance and engagement from the patient's side in relation to not just the pamphlet method, but also to a breast cancer rehabilitation game tested in the same environment [83], with some patients regarding if the current prototype was already available for their use at home.

Although the system possessed a home-based variation which attempted to test the game's acceptance with multiples uses and be under a tighter scrutiny as to what aspects need to be improved, together with the testing of different progress visualizations to verify how this affected motivation, the test were inconclusive and no other patients with the required conditions appeared within the allotted time of the development of this project.

Goniometer tests have proven a below than expected accuracy, when compared to [17], showing that additional work is required for this tool to be valuable as a range of motion measuring instrument.

The cooperative and competitive game modes looked promising although some aspects need to be improved regarding tutorials and aesthetics, while balancing may have to be revisited. A small study should however be done with breast cancer patients before the balance revisit to ensure they feel the game is indeed overly physically demanding.

Despite the setbacks, the system has shown to be a step towards a solution, although requiring further work and testing in more conditions. This system, however, shows the capability to be adapted to more than breast cancer rehabilitation, possibly branching into any type of rehabilitation that does not require the additional use of other instruments that can interfere with the Microsoft Kinect's skeletal recognition.

8.2 Limitations

In the duration of this dissertation, a variety of limitations arouse due to patient availability, as well as equipment availability, making it so that certain functions of the game could not be fully tested. The patients that did participate, although available, were many times on a strict time schedule, as the test were performed in between consultations the patients had within the hospital, thus questionnaires and routines at to be very fixed and short.

The lack of a psychologist to help create valid questionnaires was also a difficulty to tackle and thus, sub-optimal questionnaire based on general ones had to be used. This is further worsened by the need to simplify the language used, thus losing some of the focus of the questions.

8.3 Future Work

A number of improvements can be made to the current system in varying areas.

First and foremost, the home-based system and multi-player game modes require more testing with patients to allow not just finer tuning of the game, but also to understand if such modules help with motivation.

The current game routine needs to have a larger array of exercises as well as a randomization of the routine to avoid repetition and thus alleviate the possibility of the user growing weary of the game.

The difficulty adjustment should not just be more easily influenced by the therapist, but it also should be aggressive in adapting to the patient's fatigue levels by possibly reducing the required number of repetitions.

A closer work should be done with therapists to determine what additional information they would like displayed in the therapist interface.

Given the importance of socialization, the game should consider offering a small social platform or integrate one of the existing social platforms as a way to help users interact between each other outside the boundaries of physical activity. This platform could allow restricted actions as simple mural postings to express current feelings and share some photos or fully integrate chat capabilities. It should be noted that the this platform should opt for simpler and clearer solutions, as the target audience may not have much ease with technological solutions.

Adaptations of the game for pre-surgery/prevention should also be studied as a means to not just prepare the user for the usage of the game post-surgery, but also as a way to monitor the development of underlying conditions. According to some studies such as [76], exercise has also shown to reduce the risk of developing such a disease and thus encourages the development of games that can also reach the general public.

Some technical details involving the avatar representation should also be addressed as this was an aspect that distracted the players when it failed to correctly mimic them even for minimal amounts of time. This topic although accounted for in the development of this system was not the main focus and as thus can still be further developed and tweaked to find ways on how to deal with the loss of joints and muscle restriction that can be placed on the avatar so it doesn't blindly follow the Microsoft Kinect's inferred joint posistions.

The Microsoft Kinect could also be used to detect patient expressions as a way to read the possibility of over-exertion during the realization of the game sequence. For more details on the Microsoft Kinect's facial expression recognition the following reference can be checked [116].

The goniometer tool also requires more adjustments to increase overall accuracy in coronal view. This is, however, an issue that has also been the focus of study as can be seen in [68]. Aesthetics of the overall game modes should be improved to accommodate players who have higher experience level with digital games and thus expect more from the game in that regard.

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Appendix A

A -Questionnaires

	1	2	3	4	5
O jogo ajuda com a prática dos exercícios?					
A informação é fácil de encontrar?					
Encontrou algum erro?					
O aspeto do jogo é do seu agrado?					
É fácil de compreender o que o jogo diz?					
O jogo mantem-se parecido ao longo do tempo?					
Não é muito cansativo?					
Sugestões					

Figure A.1: Post Session Questionnaire

	1	2	3	4	5
O folheto ajuda com a prática dos exercícios?					
A informação é fácil de encontrar?					
Encontrou algum erro?					
O aspeto do folheto é do seu agrado?					
É fácil de compreender o que o folheto diz?					
Não é muito cansativo?					
Sugestões					

Figure A.2: Pamphlet Questionnaire

Did you prefer the usage of the system used in the hospital tests or the version provided for personal usage?
Which of the progress visualizations was your favourite?
What did you think of each visualization?
What could be improved?
Did you find the number of exercises adequate?
Did you feel the game is too repetitive when used in long term?
Did you feel there was a change in your physical condition since the day you started to use the system?
How well did you feel the system represented your physical condition?
How well did you feel the game's classification was accurate?
Do you think the physical evolution you felt since the start of the usage of the game was manifested by it?

Figure A.3: Model Patient Questionnaire

Appendix B

B - Declaration of Consent

Declaração de consentimento informado

Faculdade de Engenharia da Universidade do Porto
INESC-TEC
Centro Hospitalar São João

Departamento de Engenharia Eletrotécnica e de Computadores
Mestrado Integrado em Engenharia Eletrotécnica e de Computadores
Unidade Curricular de Dissertação
Ano letivo de 2017/2018

Declaração de Consentimento Informado

Título do Estudo: Design de jogo assistido - Geração de conteúdo processual através de modelagem de usuários
Autor do estudo: Nuno Duarte

Eu, abaixo-assinado, compreendi a explicação sobre o objetivo do estudo que se pretende realizar,
bem como as suas implicações. Tive oportunidade de esclarecer qualquer tipo de dúvidas relativamente aos procedimentos, obtendo uma resposta satisfatória. Entendi que o método de avaliação de resultados do estudo não traz qualquer risco para a minha saúde. Foi-me garantido o anonimato, não havendo possibilidade de ser identificada qualquer informação pessoal. Tenho o direito de recusar a minha participação no estudo a qualquer momento. Deste modo, consinto participar no estudo.

Data: ..../..../2017
Assinatura do sujeito: ....
Assinatura do autor do estudo: ....

Figure B.1: Declaration of Consent example

Appendix C

C - Laboratory Guide

C.1 Context

The experiment consists of a system that, through the usage of the Microsoft Kinect v2, is able capture the movements executed by the users, recognize them and classify their execution.

Through this classification a game was developed where the users, breast cancer survivors in rehabilitation, are prompt to perform three sets of three different exercises, where each of these exercises is repeated ten times at max per set. It should be noted that these exercises are exercises already recommended to be done at home by patients as an auxiliary act to physiotherapy that they already receive at the hospital. At the end of the game a score is given to each user based on the evaluation provided by the classification of the movements captured by the Microsoft Kinect. The objective of the experiment is to understand if gamification of the recommended activities is seen as an upgrade compared to the system currently in place, which works by providing the patients with pamphlets where the same exercises are described, as well as evaluate the reception of this kind of tool for this specific population in an attempt to incorporate this new system in similar populations. Additionally, from this experiment a dataset can arise which could later be used for future uses in Microsoft Kinect related applications.

C.2 Equipment Used

• Computer (Requires Visual Studio(2015 or later version) and Microsoft Kinect for Windows SDK 2.0 installed)

• Microsoft Kinect 2.0

• Auxiliary monitor

• Speakers

Figure C.1: Experiment setup

C.3 Procedure

C.3.1 Before starting the game

Elucidate the user for the purpose of the experiment and sign the declaration of consent.

Fill the pre game questionnaire and other documentation

C.3.2 During the Pre-Phase

Incentivize the user to move around in order to familiarize himself with the virtual environment.

Clarify and correct the verification movement so that the condition evaluation is as accurate as possible.

C.3.3 During the Exercise Phase

Before starting explain to the user that:

• The instructions audio can be repeated at any time any amount of times.

• It is possible to skip an exercise even if all repetitions have not be performed.

During the exercises:

• Help the user correct its movements when they are clearly different from the one being requested.

• Register any tendencies users display in the laboratory notes

C.3.4 Post game

Present the questionnaire for the user to fill.

If no other user is waiting, ask the current user to allow the recording of him executing the exercises for the creation of a dataset.

Appendix D

D - Laboratory Notes

During the experiments some observational notes were taken when possible.

Entry 1

Patient 1:

• Tendency to keep pace with the medical avatar

• Patient tries to ease the second exercise movement by folding the elbow. When questioned if the medical avatar was folding the arm, this indicated that it was not.

Patient 2:

• High comprehension of the workings of the game.

Patient 3:

• Extreme poor cooperation.

• Reported low tolerance for games in the earlier questionnaire.

Patient 4:

• Did the experiment sitting down successfully.

Entry 2

Patient 1:

• Reported in the questionnaire to be very accustomed to playing digital games.

Patient 2:

• Reported in the questionnaire to be accustomed to computers, yet not digital games.

Patient 3:

• High difficulty in doing exercise 2.

• Microsoft Kinect seems to possess some difficulty in reading the correct movement of the patient given her need to fold her elbow to complete the movement motion. This might also be connected to the training videos used to teach the application this movement.

• Tendency to follow the medical avatar's rhythm.

Patient 4:

Lack of familiarity with technology caused some confusion about how to manoeuvre herself inside the game, however once the medical avatar showed a new exercise she would immediately attempt to copy it.

Entry 3

Patient 2:

• Avatar was very unstable at the leg level, with difficulty in mimicking during exercise 2. This maybe be due to the colour scheme of the patient's clothing in relationship to the environment or the need to fold her elbow.

Patient 3:

• Despite asking to advance exercise 2 and having difficulty doing the remaining exercises, insisted the difficulty level of the game was adequate.

Entry 4

Patient 4:

• 13 days since surgery, movements are extremely limited and could barely reach necessary height for the application to accept it as the designated movement.

Patient 5:

• Required the experience to be done while she was sitting down.

Entry 5

Patient 3:

• Required the experience to be done while she was sitting down.

Patient 7:

• Patient's sweater contained very wide sleeves that would hang making it harder for the application to correctly pinpoint skeletal joints accurately, resulting in difficulty reading the exercises and the avatar being enable to correctly mimic the user.

Appendix E

E - Evolving Environment Stages

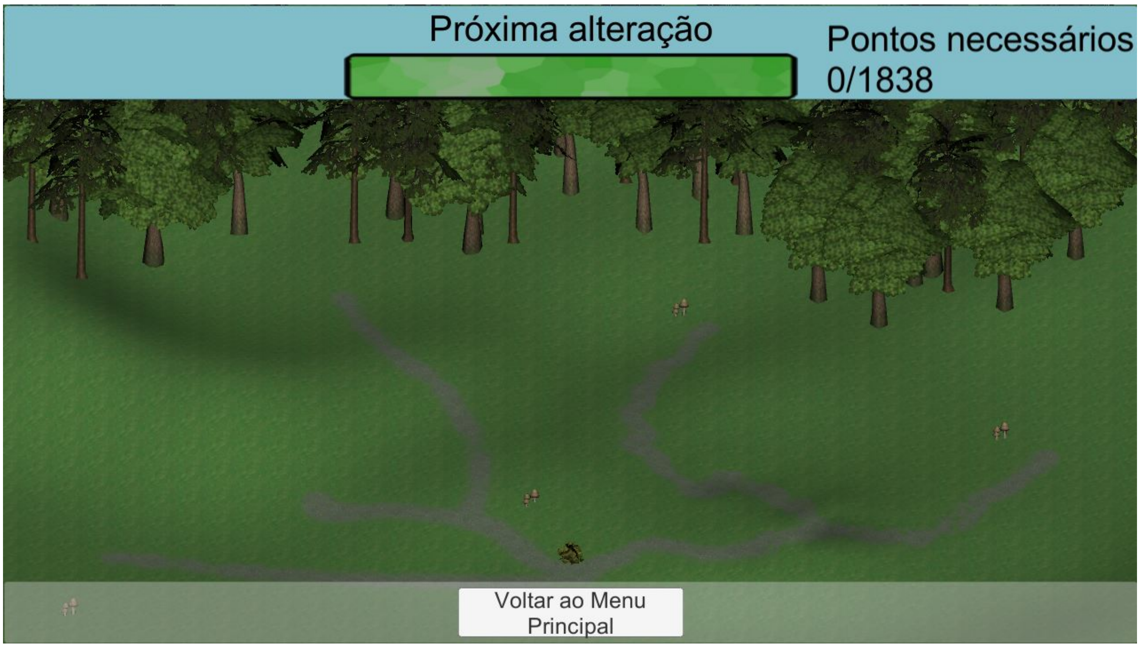

Figure E.1: Evolving Environment Level 1

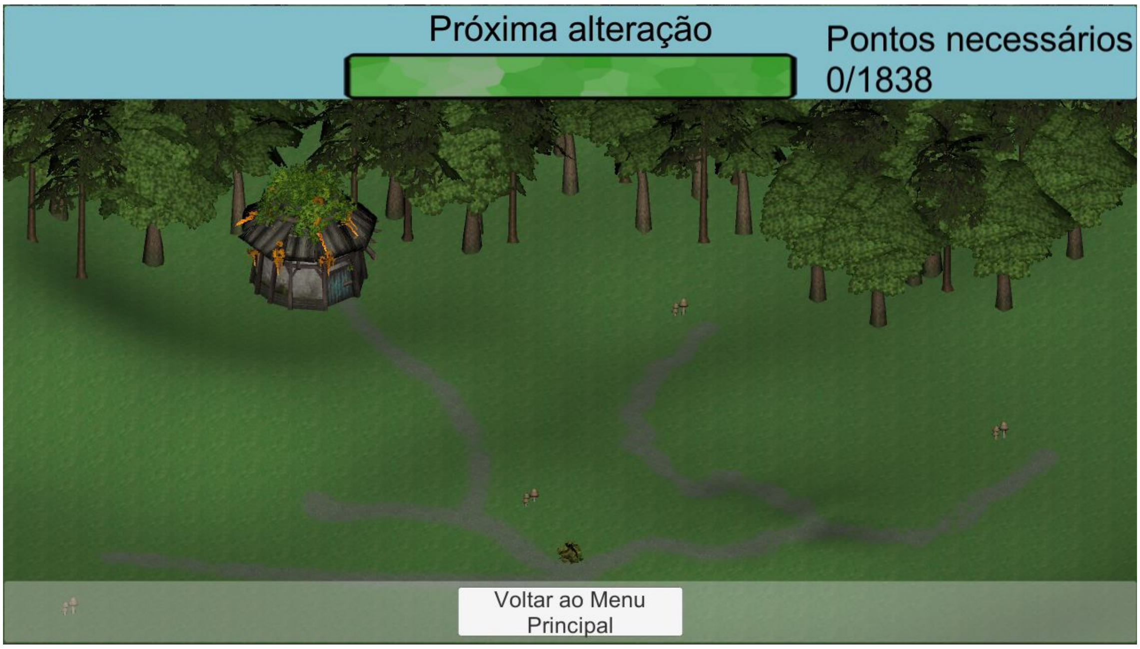

Figure E.2: Evolving Environment Level 2

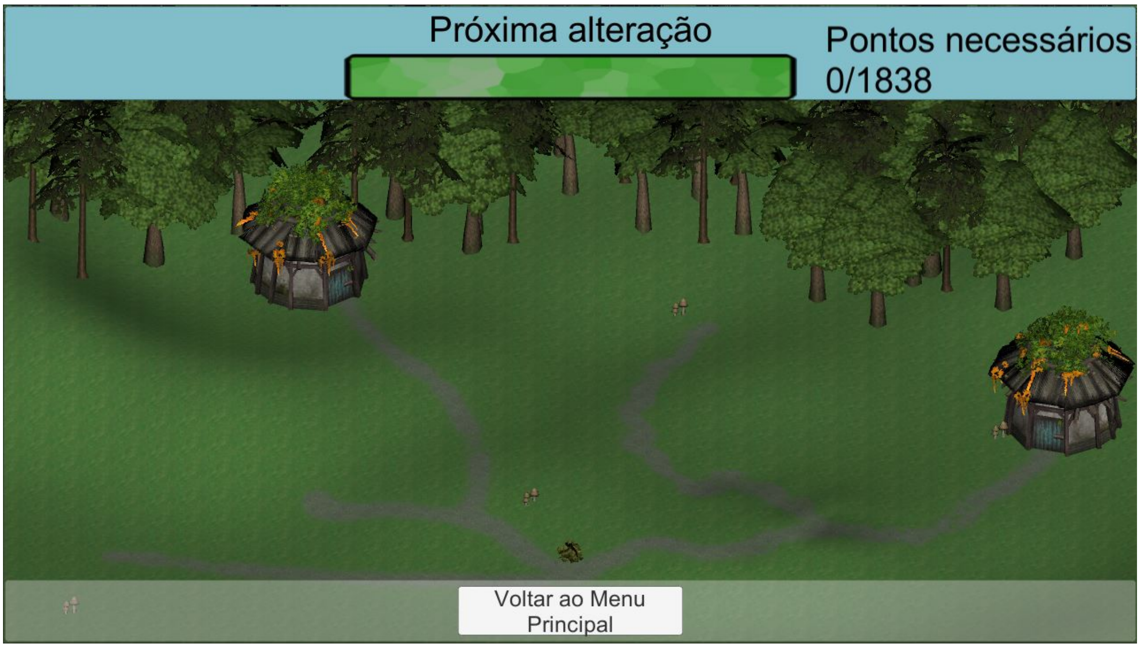

Figure E.3: Evolving Environment Level 3

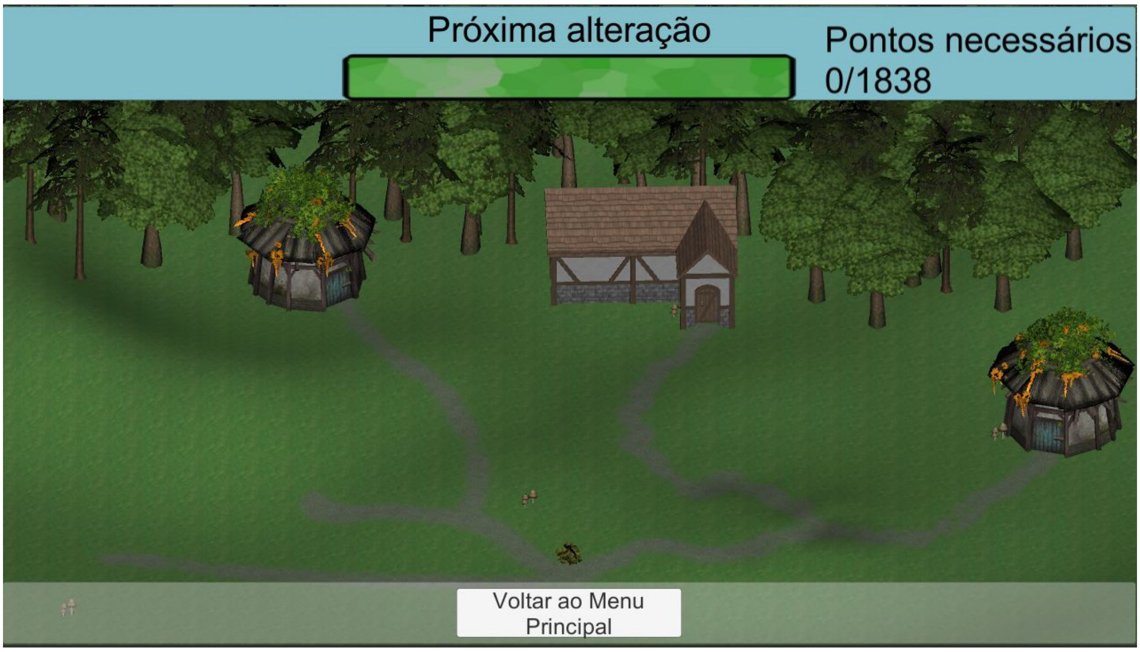

Figure E.4: Evolving Environment Level 4

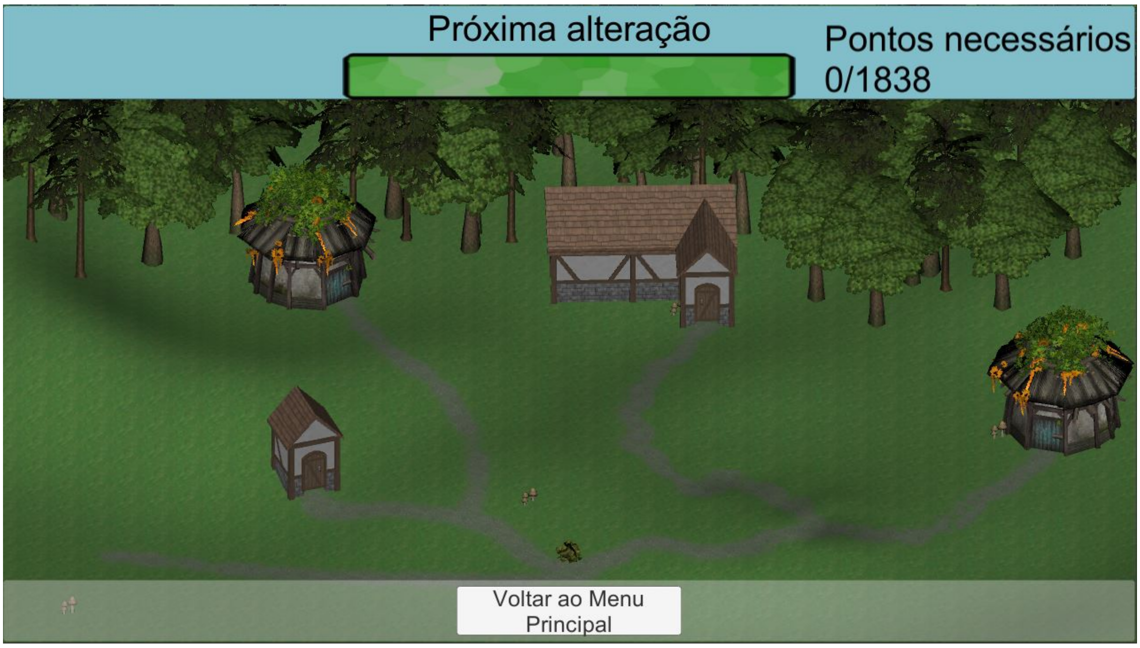

Figure E.5: Evolving Environment Level 5

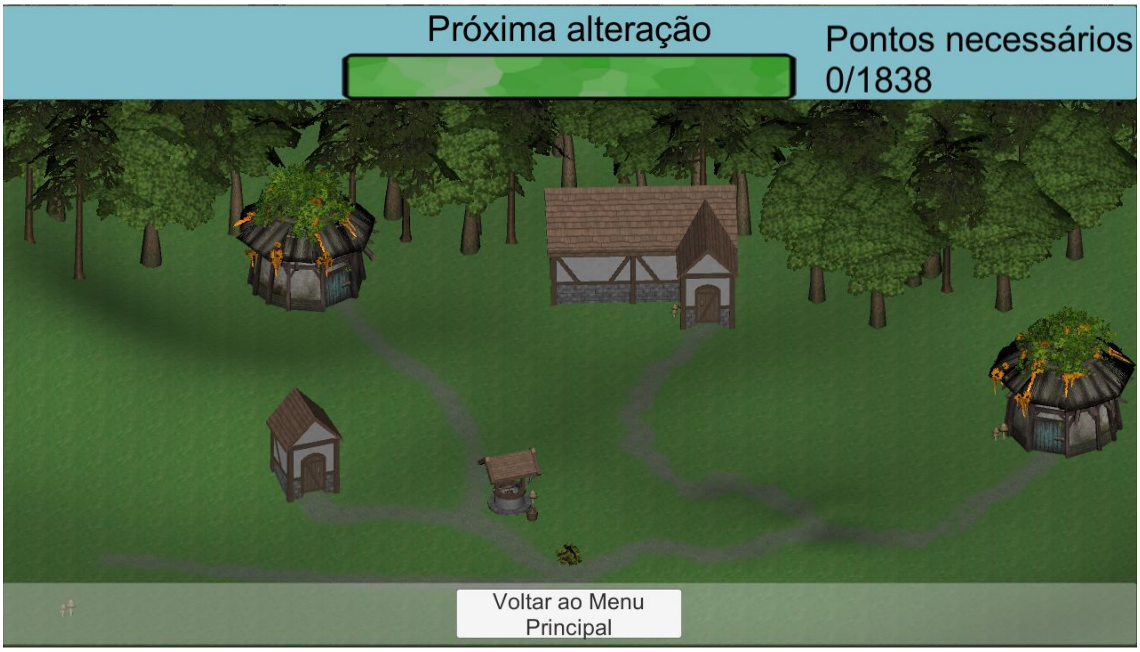

Figure E.6: Evolving Environment Level 6

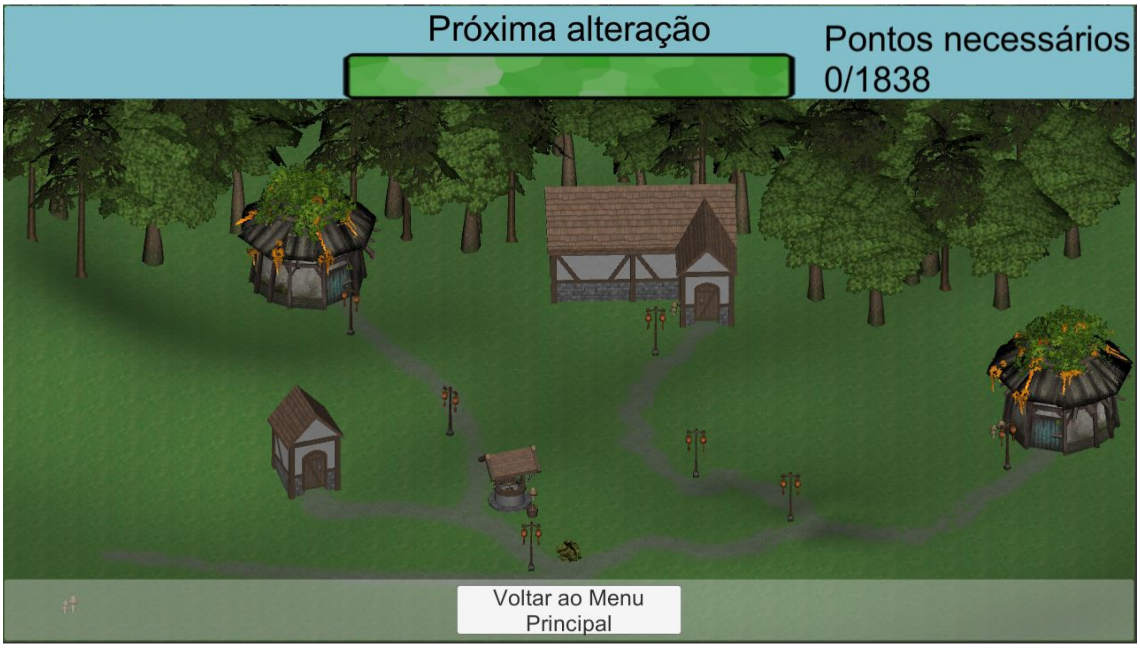

Figure E.7: Evolving Environment Level 7

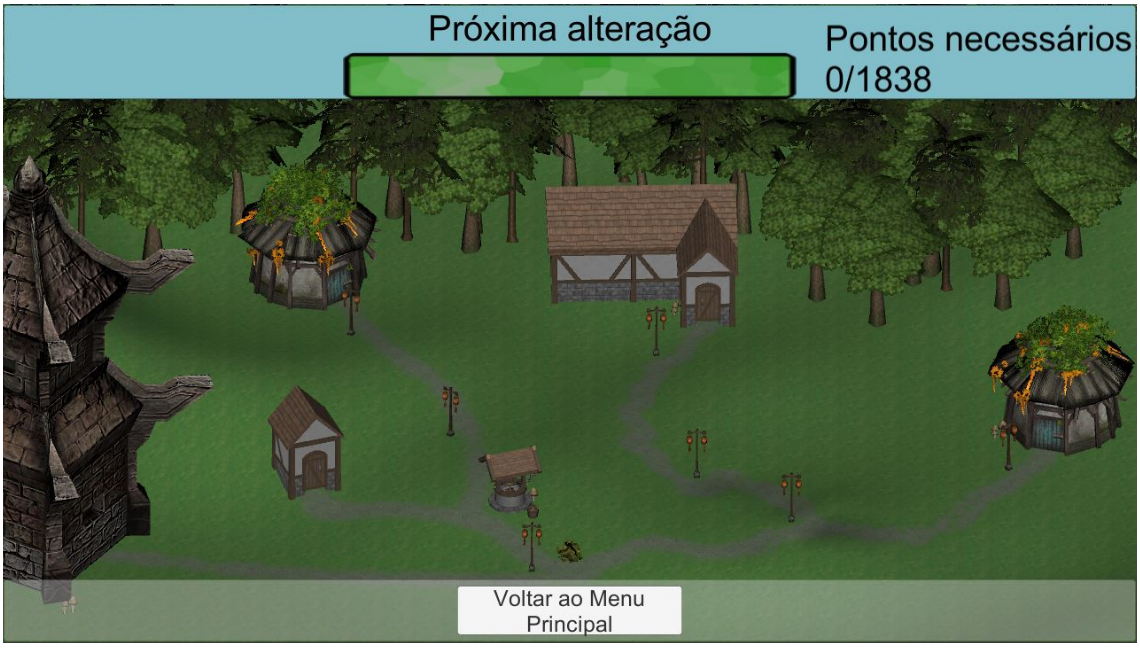

Figure E.8: Evolving Environment Level 8

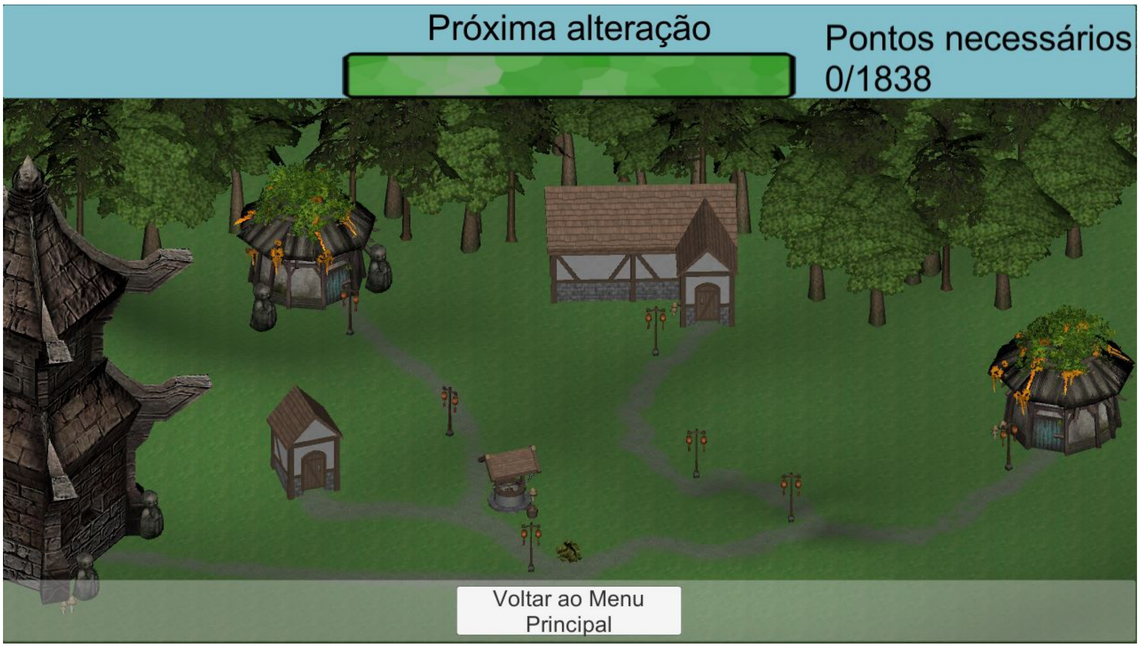

Figure E.9: Evolving Environment Level 9

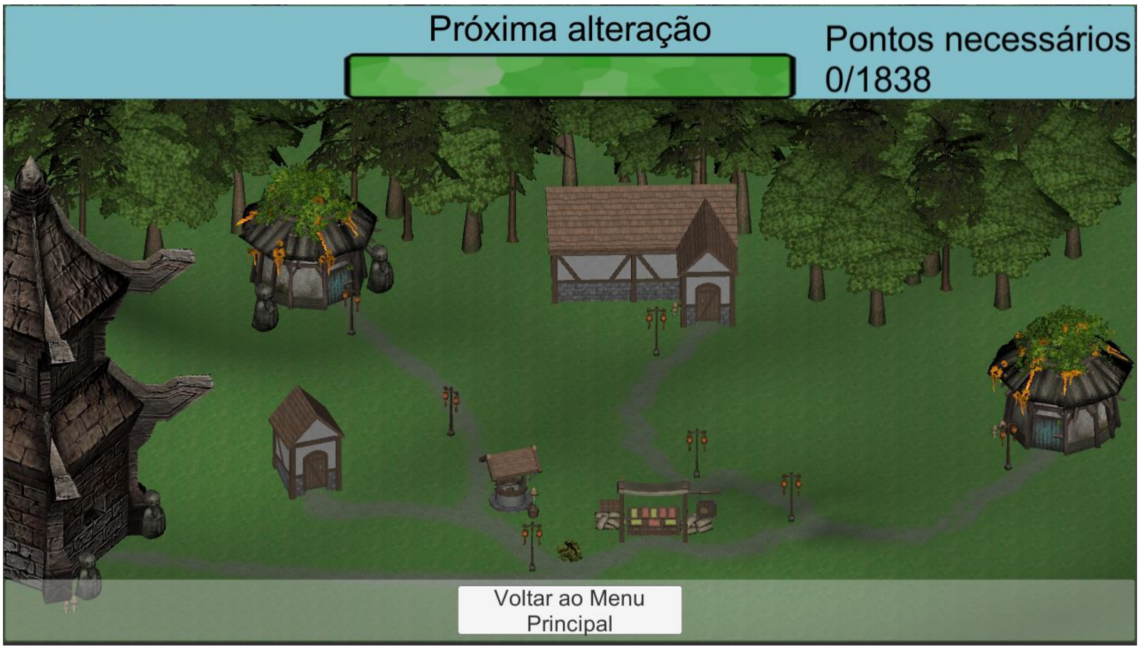

Figure E.10: Evolving Environment Level 10

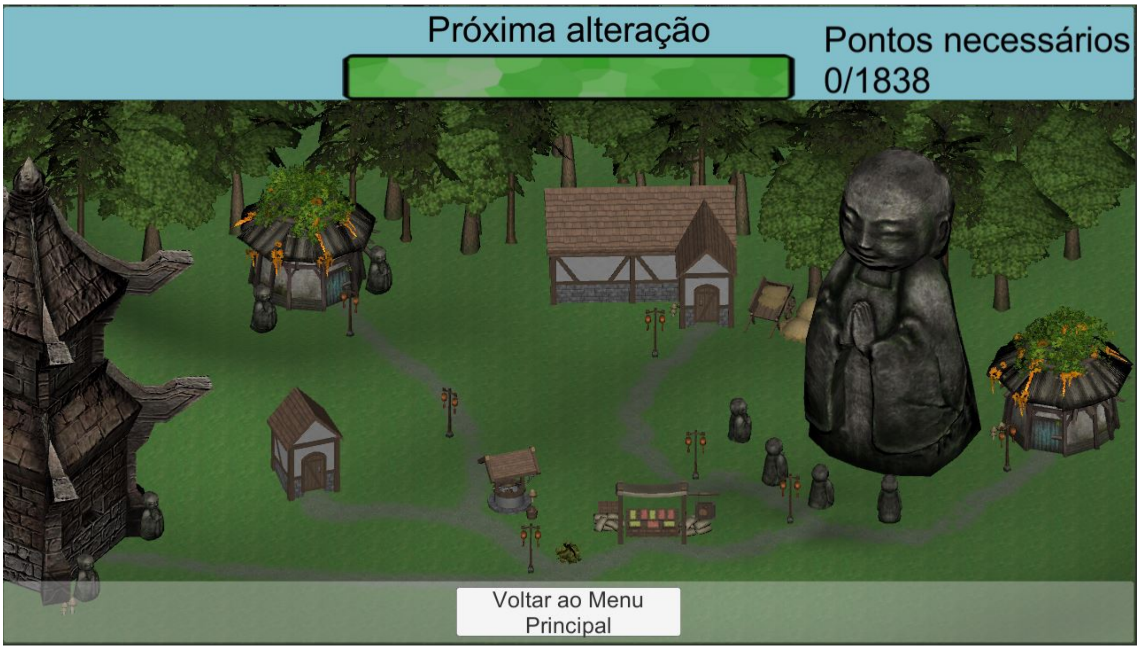

Figure E.11: Evolving Environment Level 11

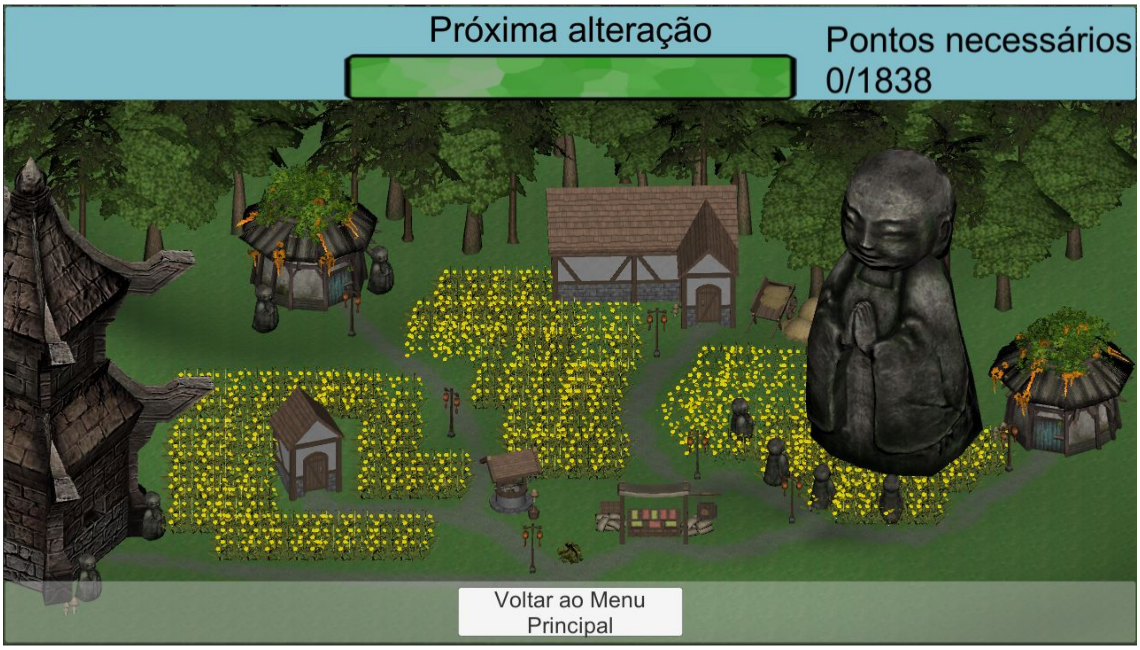

Figure E.12: Evolving Environment Level 12

Appendix F

F - Cooperative and Competitive game mode levels

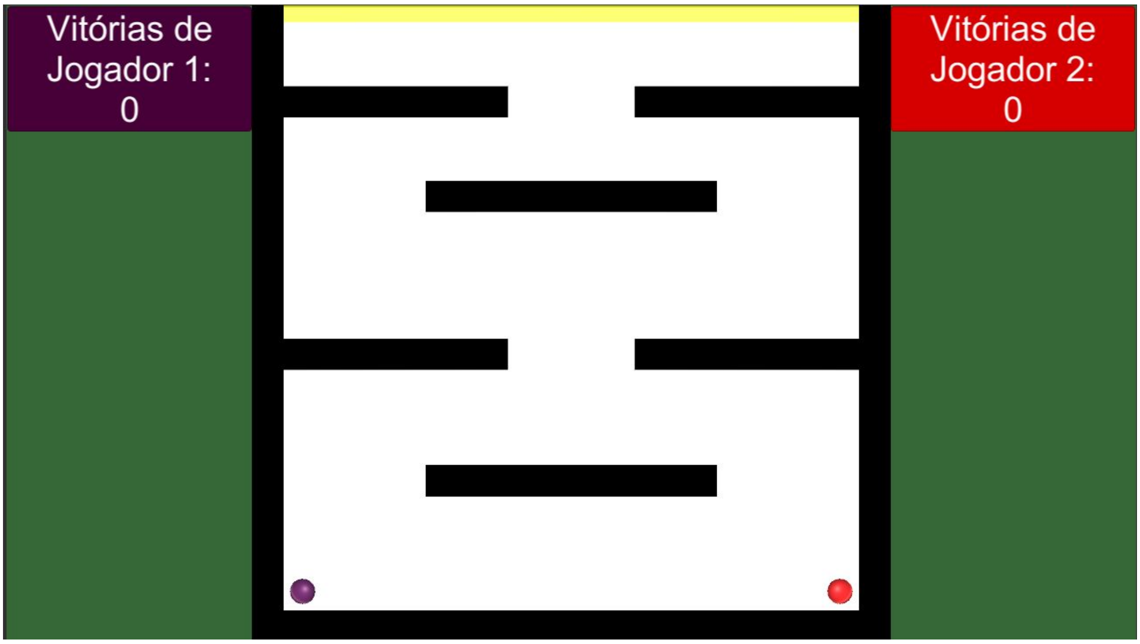

Figure F.1: Level 1 of the second version of the Competitive mode

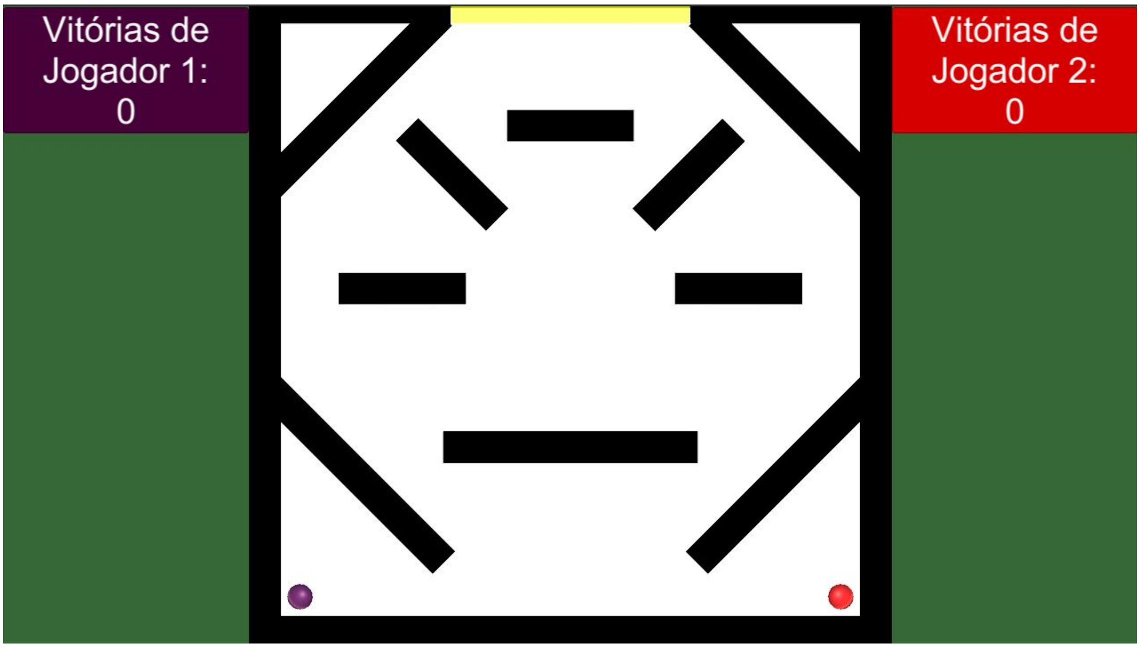

Figure F.2: Level 2 of the second version of the Competitive mode

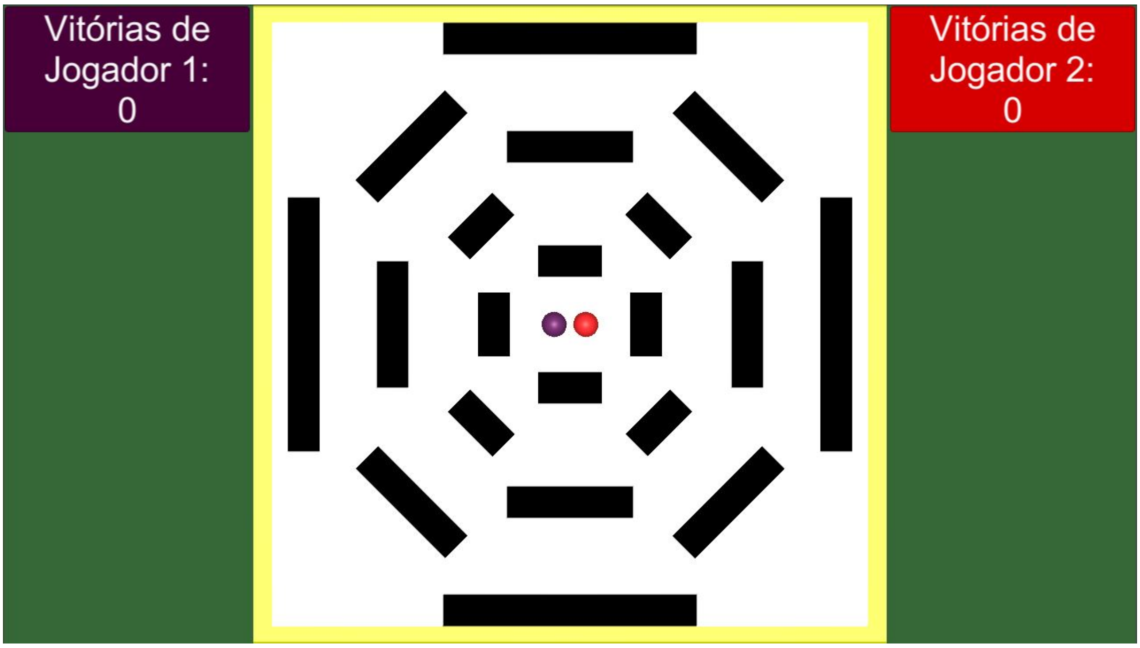

Figure F.3: Level 3 of the second version of the Competitive mode

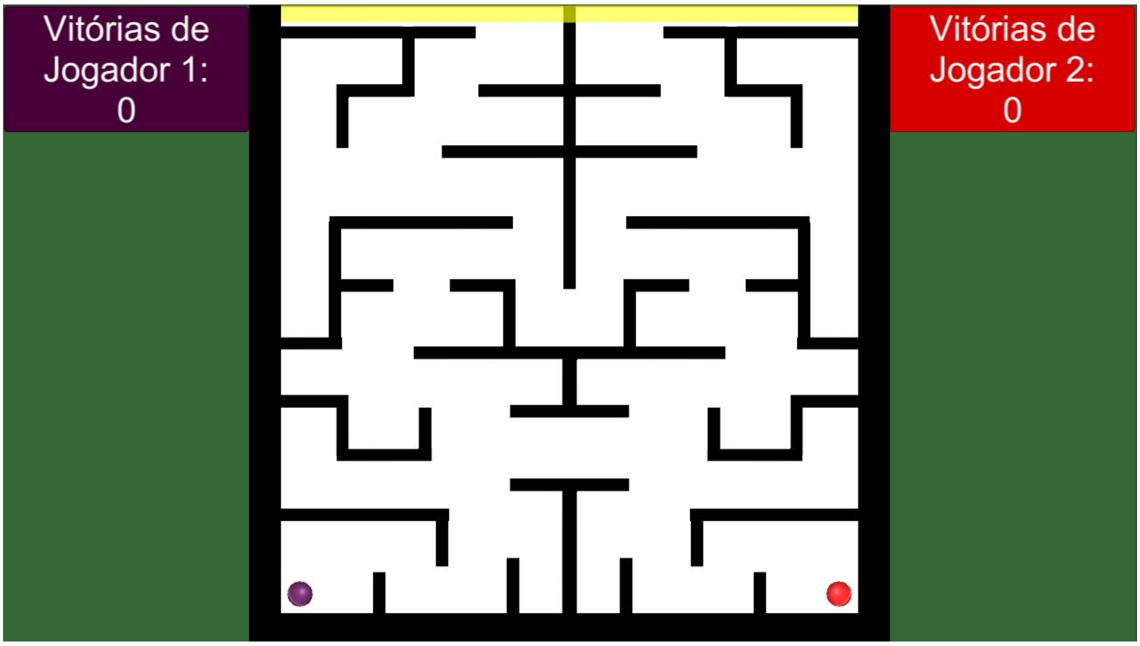

Figure F.4: Level 4 of the second version of the Competitive mode

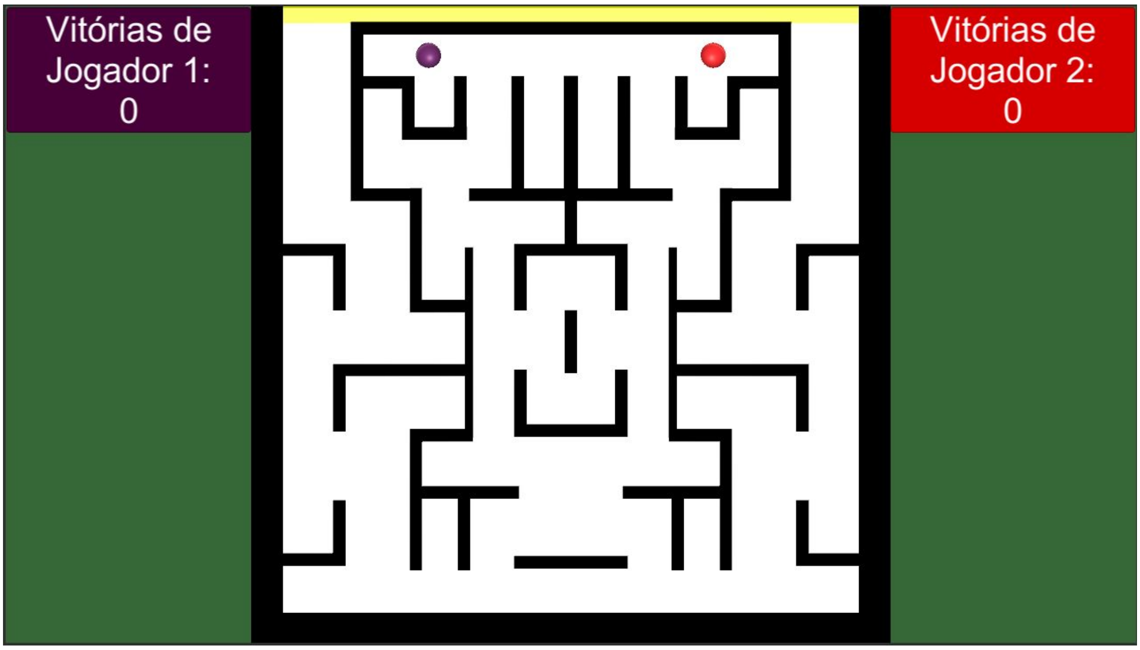

Figure F.5: Level 5 of the second version of the Competitive mode

Appendix G

G - Goniometer

G.1 Shoulder Flexion

Table G.1: Shoulder flexion measurements (in degrees)

	Microsoft Kinect v2		Goniometer	
	Right Side	Left Side	Right Side	Left Side
Subject ID	Measurement		Measurement	
1	116.20±0.59	35.66±0.59	120.00±1.00	47.00±1.00
2	98.22±0.84	97.34±0.38	107.00±1.00	107.00±1.00
3	89.68±0.51	93.31±1.15	94.00±1.00	96.00±1.00
4	89.38±0.23	94.27±0.32	98.00±1.00	96.00±1.00
5	59.87±0.39	40.13±0.98	68.00±1.00	48.00±1.00

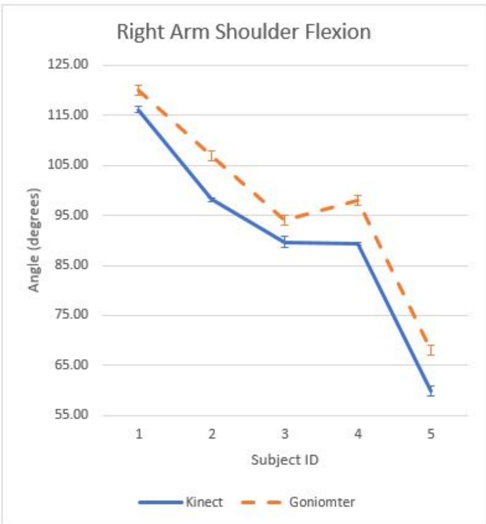

Figure G.1: Free Angle Right Arm Shoulder Flexion

Figure G.2: Free Angle Left Arm Shoulder Flexion

Table G.2: Shoulder flexion measurements to a 90° angle in a coronal view

	Microsoft Kinect v2		Goniometer	
	Right Side	Left Side	Right Side	Left Side
Subject ID	Measurement		Measurement	
1	81.53±0.41	76.16±0.56	90.00±1.00	90.00±1.00
2	89.19±0.29	94.55±0.99	90.00±1.00	90.00±1.00
3	89.96±0.79	90.56±0.56	90.00±1.00	90.00±1.00
4	73.05±1.75	83.42±0.27	90.00±1.00	90.00±1.00
5	80.15±0.84	90.34±0.88	90.00±1.00	90.00±1.00

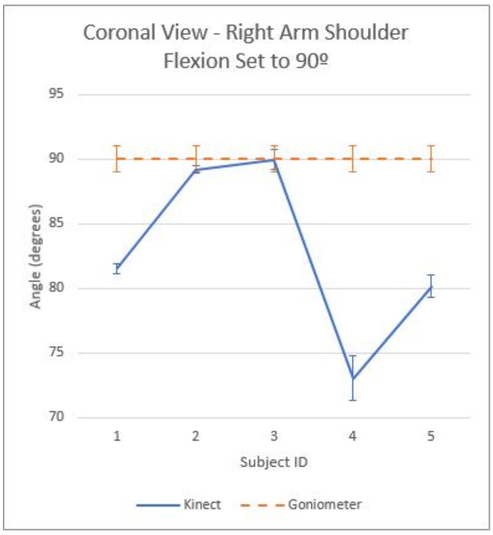

Figure G.3: Coronal View Set to 90° Right Arm Shoulder Flexion

Figure G.4: Coronal View Set to 90° Left Arm Shoulder Flexion

Table G.3: Shoulder flexion measurements to a 90° angle in a sagittal view

	Microsoft Kinect v2		Goniometer	
	Right Side	Left Side	Right Side	Left Side
Subject ID	Measurement		Measurement	
1	99.59±0.48	108.83±0.3	90.00±1.00	90.00±1.00
2	100.03±0.28	86.94±1.54	90.00±1.00	90.00±1.00
3	96.01±0.14	88.11±3.98	90.00±1.00	90.00±1.00
4	88.61±1.30	96.74±0.22	90.00±1.00	90.00±1.00
5	85.25±1.63	92.35±0.68	90.00±1.00	90.00±1.00

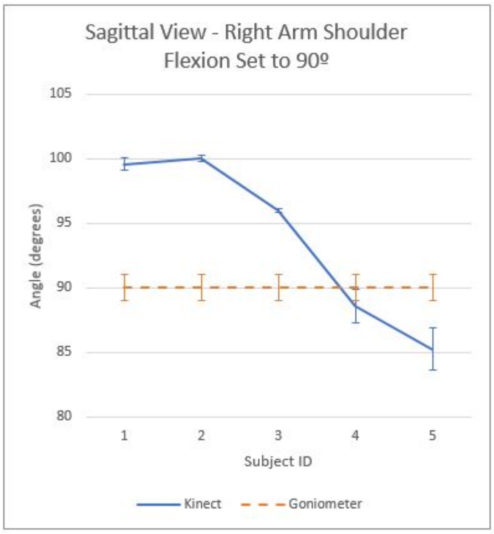

Figure G.5: Sagittal View Set to 90° Right Arm Shoulder Flexion

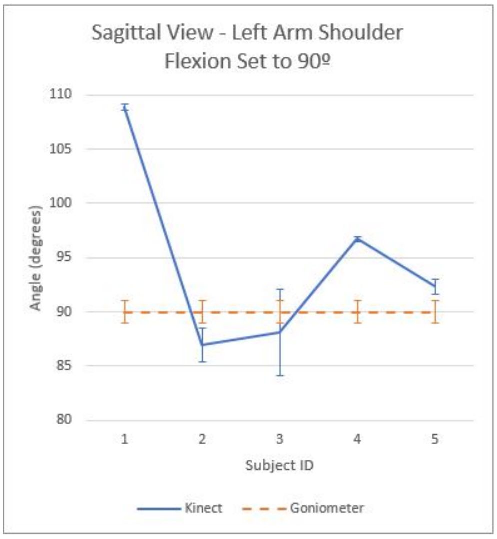

Figure G.6: Sagittal View Set to 90° Left Arm Shoulder Flexion

G.2 Shoulder Abduction

Table G.4: Shoulder abduction measurements (in degrees)

	Microsoft Kinect v2		Goniometer	
	Right Side	Left Side	Right Side	Left Side
Subject ID	Measurement		Measurement	
1	42.47±3.67	73.13±0.31	42.00±1.00	75.00±1.00
2	86.48±0.30	71.84±0.26	92.00±1.00	67.00±1.00
3	97.61±0.22	41.97±0.15	100.00±1.00	54.00±1.00
4	86.62±0.31	96.76±0.09	90.00±1.00	91.00±1.00
5	50.87±0.80	142.30±2.39	50.00±1.00	140.00±1.00

Figure G.7: Free Angle Right Arm Shoulder Abduction

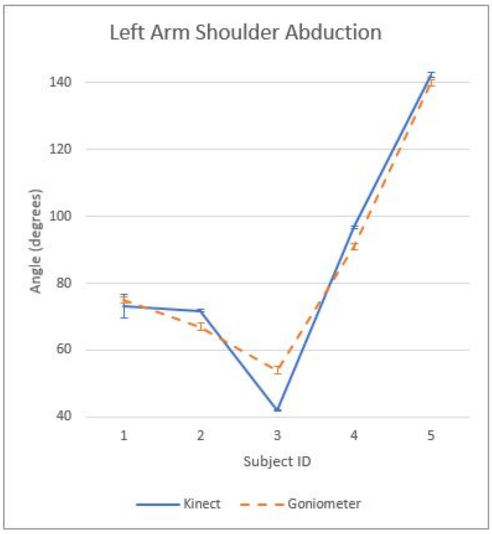

Figure G.8: Free Angle Left Arm Shoulder Abduction

Table G.5: Shoulder abduction measurements to a 90° angle in a coronal view

	Microsoft Kinect v2		Goniometer	
	Right Side	Left Side	Right Side	Left Side
Subject ID	Measurement		Measurement	
1	87.86±0.41	88.60±0.28	90.00±1.00	90.00±1.00
2	89.47±0.04	88.84±0.27	90.00±1.00	90.00±1.00
3	85.45±0.19	84.19±0.18	90.00±1.00	90.00±1.00
4	85.35±0.33	87.04±0.07	90.00±1.00	90.00±1.00
5	89.26±0.51	82.05±0.19	90.00±1.00	90.00±1.00

Figure G.9: Coronal View Set to 90° Right Arm Shoulder Flexion

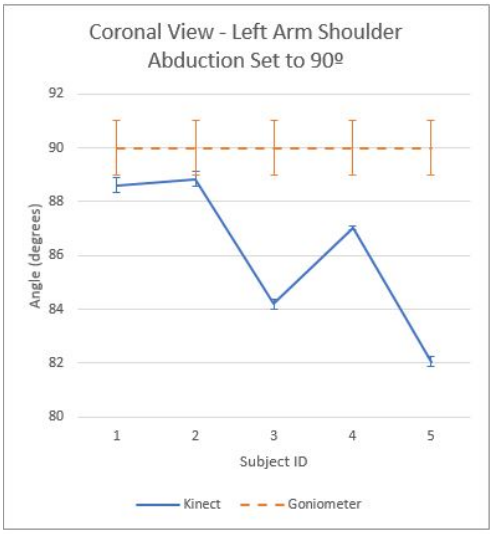

Figure G.10: Coronal View Set to 90° Left Arm Shoulder Flexion

Table G.6: Shoulder abduction measurements to a 90° angle in a sagittal view

	Microsoft Kinect v2		Goniometer	
	Right Side	Left Side	Right Side	Left Side
Subject ID	Measurement		Measurement	
1	86.27±3.22	98.95±0.76	90.00±1.00	90.00±1.00
2	99.47±0.77	90.00±1.56	90.00±1.00	90.00±1.00
3	104.15±1.74	95.40±1.61	90.00±1.00	90.00±1.00
4	94.14±0.80	94.72±0.89	90.00±1.00	90.00±1.00
5	95.98±1.52	92.05±6.70	90.00±1.00	90.00±1.00

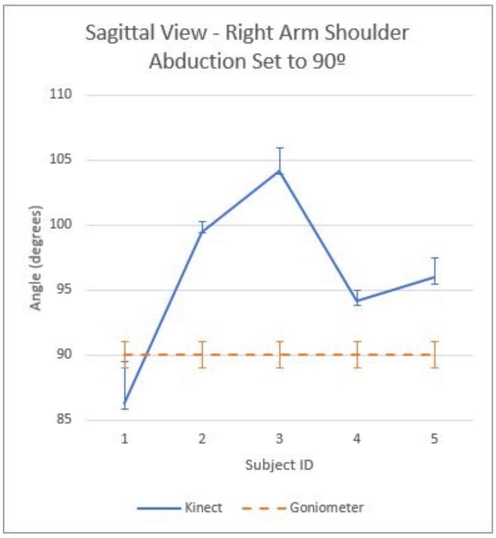

Figure G.11: Sagittal View Set to 90° Right Arm Shoulder Flexion

Figure G.12: Sagittal View Set to 90° Left Arm Shoulder Flexion

G.3 Elbow Rotation

Table G.7: Shoulder abduction measurements (in degrees)

	Microsoft Kinect v2		Goniometer	
	Right Side	Left Side	Right Side	Left Side
Subject ID	Measurement		Measurement	
1	105.01±6.96	45.80±1.72	98.00±1.00	40.00±1.00
2	61.78±0.82	83.24±0.54	71.00±1.00	70.00±1.00
3	143.54±6.05	106.84±1.69	138.00±1.00	110.00±1.00
4	97.04±2.54	84.16±3.00	80.00±1.00	79.00±1.00
5	160.04±0.85	123.07±3.84	158.00±1.00	126.00±1.00

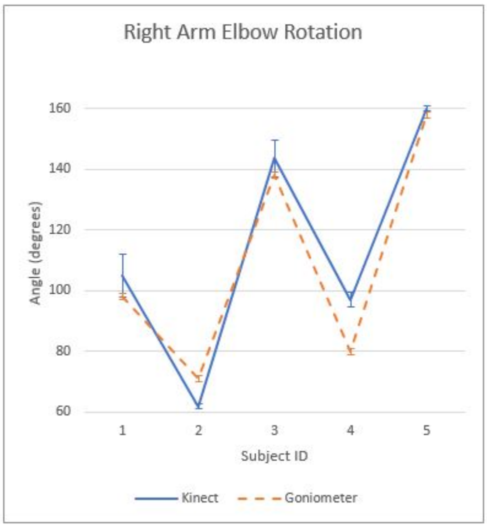

Figure G.13: Free Angle Right Arm Elbow Rotation

Figure G.14: Free Angle Left Arm Elbow Rotation