Development and Evaluation of a Kinect Based Motor Rehabilitation Game

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Abstract

The use of computational resources, such as virtual and augmented reality based systems has being commonly used to provide patient motivation in rehabilitation processes, great interaction, fun and challenges to therapy. This study presents a development and evaluation of a Kinect based motor rehabilitation system developed iteratively by gathering users' opinion. This systems is currently a prototype and consists of a physiotherapeutic game controlled by biomechanical movements that supports therapeutics exercises and a module that performs a biomechanical analysis, detecting postural compensation. The system development included two versions. A first system version was developed and evaluated by users. Based on this evaluation the system was upgraded and the new version was evaluated once again by the same users. By comparing these two tests it was possible to notice an improvement of the system in all evaluated aspects.

Keywords: rehabilitation, virtual reality, serious games, interface.

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1. Introduction

In the XXI century, it has been acknowledged that the efficacy of long time treatments is highly dependent on the engagement of the patient. Health professionals are always searching for a more effective treatment that focus not only at the elimination of the pathology symptoms but also hold the patient involved to it during the entire treatment in order to achieve the cure. The importance of taking into consideration related human factors, such as patient satisfaction and motivation is the key to ensure patient involvement and to achieve a successful treatment [Mendonça 2007].

These factors are even more important for the success of physiotherapy treatments due the fact that the patient's recovery is directly associated with his/her continuous effort, commitment and discipline during the entire rehabilitation process [Machado and Nogueira 2008; Sveistrup 2004]. This process consists in a series of sessions where the patient must perform therapeutic exercises. Such exercises have some aspects that are appointed as discouraging factors, making the patients leave the treatment without completion and causing a high rate of therapeutic failure [Burdea 2003; Loh Yong Joo et al. 2010]. Examples of such aspects are the repetitive nature of the exercises, the long time necessary for treatment, which can take several weeks, the need to avoid repetitive wrong movements, and also to avoid compensation movements. Another characteristic of these sessions is that they can be performed both in a clinic with physiotherapist supervision or at home. In the later case the responsibility for executing the correct movements relies solely on the patient. This increases the need of tools that motivate the patient, guide him/her to do the treatment correctly even without a professional assistance and also provide feedback for the therapist about the patient's performance.

Several approaches are being researched to tackle the problem of patient adherence to treatment. These approaches try to make the therapeutic process more attractive to the patient, increasing motivation and improving treatment efficacy [Aziproz et al. 2005; Weiss et al. 2004]. In general these approaches incorporate to the rehabilitation process an environment where the patient is able to interact with a playful application using therapeutic movements. Some approaches implement a therapeutic environment that supports interaction via the use of immersive video [Rand et al. 2008; Weiss et al. 2004]. The environment may also be capable of detecting incorrect movements and provide sensorial, auditory and visual feedback to the patient and/or physiotherapist. Based on these factors, this paper presents a development and evaluation of a Kinect based motor rehabilitation game developed interactively with user's opinion.

This paper is organized as follows. First, in Section 2, the major related work regarding systems and games for rehabilitation are presented. Section 3 describes the technical features of rehabilitation support system, including implementation details. Section 4 is dedicated to interface evolution, presenting the steps of interface decision and increments. Section 5 shows the evaluation process and the protocol for user tests. Finally, in Section 6 it is presented the results and discussion of the system´s development and evaluation. Lastly, some conclusions are drawn and future works are discussed.

2. Related Work

Technologies such as virtual reality, augmented reality and games are being applied for a long time in different health purposes. These include cognitive training, phobia treatment, medical training and motor rehabilitation [Richard et al. 2007; Standen and Brown 2006; Sveistrup 2004; Taylor et al. 2011]. More recently the emergence and popularization of interaction technologies that enable body movements to control systems and games has supported the increase use of this kind of technology on motor rehabilitation.

A motor rehabilitation system can be developed applying different tools for interaction such as haptic sensors, markers and cameras. The use of haptic sensors is common on upper limb rehabilitation, where it is used to interact with the system and also to enable feedback for the user [X Luo et al. 2005]. Techniques that apply markers are commonly used due its low cost and easiness of use. These markers are used as references to extract information about the scene orientation and the positioning of the objects in order to provide guidance to the treatment[J W Buker et al. 2010]. Another option is the use of accelerometers and gyroscopes provided by the Nintendo Wii remote. Despite being simple to implement, these approaches have the disadvantage that the patient needs to hold or attach objects to his/her body, which is not always applicable [Sparks et al. 2009]. Nevertheless, none body reference for interaction is used on them, turning difficult to analyze movement carefully, which is a powerful tool not only for the current patient evaluation but also for the storage and future analysis of his progress on the rehabilitation treatment [Da Gama et al. 2012a; Danny Rado et al. 2009].

One improvement on the efficacy of rehabilitation systems is the use of technologies that provide support for natural interaction. This eliminates the need to attach markers to the patient's body that could disturb the movements performance [Da Gama et al. 2012b]. One example of a device that applies such technology is the Kinect sensor that detects the user body and its joints using a RGB-D camera. The use of these apparatus for rehabilitation purposes is being widely applied and benefic [Deutsch et al. 2008; Lange et al. 2011].

Despite the interaction is a critical point in a rehabilitation system, it is also necessary to associate a visual entertainment able to motivate the patient during therapy [Burdea 2003]. To achieve this, the developed systems usually incorporate games based on virtual or augmented reality. In virtual reality, the patient interacts with a virtual environment, while in augmented one, the image from real world is incremented with virtual objects to induce, direct or correct movement performance [Sveistrup 2004].

The games developed for rehabilitation systems are commonly simple mini games where the movement or strength performed by the patient is mapped to actions in the game. Systems that track upper limb movements normally associate them with targets to be reached [Christian Schönauer et al. 2011]. These games can also simulate daily activities, such as the action of putting objects on a shelf [J W Buker et al. 2010].

The use of commercial games, such as Nintendo Wii, for rehabilitation proposes is also practiced on clinical routine. The commercial games have the advantages of a variety of games providing entertainment and giving more options for the patient to play. However these products present disadvantages that are mainly bounded to the fact that they are not developed for rehabilitation purposes [Griffiths 2004]. Most of these videogames require the patient to hold a remote, which is difficult for some pathologies. These games also cannot be adapted for specific patient limitations and no correction of compensations is given [Da Gama et al. 2012a; Sparks et al. 2009].

Based on this, it is possible to notice the importance of a directional development based on therapeutic and patient necessities [Griffiths 2004]. The games focused on motor rehabilitation have to be simple and fun, being capable of encouraging and motivating the patients [Sveistrup 2004]. They also need to have a good movement interaction and sensibility to promote a more useful therapy, and a precise movement recognition in order to avoid the execution of wrong exercises [Da Gama et al. 2012a].

3. System Description

This work presents a rehabilitation support system proposed and developed by an interdisciplinary group including computer science, computer engineering, physiotherapists and design professionals. The system allows the therapist to specify the treatment and implements a game controlled by therapeutic movements. It also performs a biomechanical analysis, in which the movement is interpreted and technically evaluated, detecting postural compensation and also providing a report for both patient and therapist.

During development, the system was submitted to a test, then it was improved based on the feedback received and then a retest was made to compare the evolution of the system as well as to collect new suggestions. These tests are described at Section 5.

The developed system is composed of four modules: i. body tracking module that recognizes the patient body and extracts body data such as information about the patient's joints; ii. biomechanical analysis module that is responsible for the analysis of the patients' movements from the perspective of biomechanical parameters based on planes and angles; iii. game module, which consists of an interactive game controlled by an input from the biomechanical analysis module, i.e., the control occurs through therapeutic movements, determined by the physiotherapist, which are traditional movements performed during motor rehabilitation according to joint anatomy and biomechanics; iv: report module that provides therapeutic information about the patient performance during the use of system, for example maximal angle of a biomechanical movement.

3.1 Body Tracking Module

In general, rehabilitation processes deal with different kinds of patient limitations and thereby explore different movements. For the proposed system it was specified the need to track the patients' natural movements without the use of markers or controllers. Aiming to fulfill the requirement of a full body tracking, the Microsoft Kinect sensor was used to extract body data. The sensor consists of a RGB-D camera, enabling an association of two-dimensional color image to its respective depth information. Thus achieving a tridimensional perception with the Z axis origin centered on the device. Its camera gives a 640x480 color image at 30 frames per second with depth resolution of a few centimeters [Shotton et al. 2011].

The Kinect sensor is capable of detecting patient body position without the need of any wearable device or calibration method. Moreover, the sensor works well in most light conditions (clarity or darkness), with the exception of outdoor environments on daylight, due to its infrared tracking method [PrimeSense 2011]. Since this work focuses on treatment scenarios that are typically performed indoor, this issue is not relevant. The sensor proved to be an effective tool towards a more natural interaction, providing some characteristics that this kind of interaction requires like patient freedom, low latency response and accuracy [Valli 2005].

The Kinect device along with the Microsoft Kinect Software Development Kit (SDK) [Microsoft Corporation 2012] were used in order to gather the information about the patient in the form of a virtual skeleton, which is composed by the tridimensional coordinates of each joint. The Kinect data is provided from a training method based on captured depth data [Shotton et al. 2011]. Using the SDK the x, y and z position of each joint is extracted for each frame. These positions are provided to the biomechanical analysis module for movement analysis.

3.2 Biomechanical Analysis Module

In this section is described the biomechanical analysis module that is responsible for detecting the correct execution of biomechanical movements performed by the patient in accordance to the specified therapist´s prescription (therapeutic movements). In order to identify and biomechanically analyze the movements, the data obtained from the Kinect sensor must be processed, creating a representation for the body that suits better the needs for the recognition of movements. In order to achieve this, a vector representation is created and also the body normal planes are computed. From these data, the range of motion can be calculated and the movement classified. Also, a postural analysis is done to avoid compensations making the rehabilitation process more effective. These steps are better explained on the following subsections. The flowchart depicted in Figure 1 shows this sequence of activities.

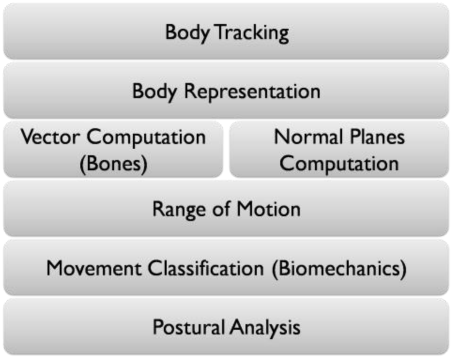

Figure 1. Biomechanical Analysis Module Activities.

3.2.1 Biomechanical Movements Concepts

In order to implement an interactive virtual therapy with maximal similarity with the traditional procedures, a biomechanical analysis is performed in order to classify biomechanical movements according to its therapeutic use. Biomechanical movements are described according to the plane and axis where it is being performed. Each human joint has an associated degree of freedom that indicates, according to its anatomy, the number of planes where it is able to move. A single movement of a joint at one plane is called a biomechanical movement and its associated angle is named Range of Motion (ROM). In the rehabilitation process, biomechanical movements are commonly executed and used for evaluation and treatment.

Another important concept is the anatomic position. It is a reference pose associated to the initial human body position used in movement classification, which is a stand position with hand palm facing forward and toes pointed to front. A median line is used as reference, crossed from the head to the feet, passing through the gravitational center dividing the body into right and left sides [Clarkson 2005]. Additional reference is given through planes. This way, the anatomic position is superimposed by tridimensional planes, upon which the biomechanical movements can be executed. The frontal or coronal plane (XY) is one which divides the body into front and back, the sagittal or vertical plane (YZ) splits the body into right and left sides and the last one, called horizontal or transversal plane (XZ), divides the body into up and down portions [Wu and Cavanagh 1995]. These planes are presented in Figure 2.

By using these references it is possible to classify biomechanical movements. The movements which occur on the sagittal plane are classified mainly as flexion, when approaching bones, and extension, when they are moving away. At the frontal plane the movements are described in relation to the median line, if the bone is moving towards the median line, it is an adduction movement, and if it is in the opposite direction it is classified as abduction [Clarkson 2005].

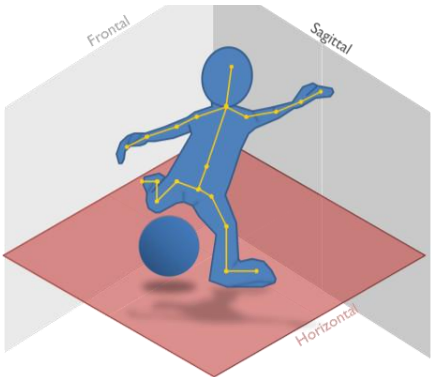

Figure 2. Joints points extracted from Kinect sensor, vectors composed between successive joints and references planes.

3.2.2 Body Representation

The human body representation was developed based on data extracted from the Kinect device. This data is processed in order to facilitate the biomechanical analysis. As previously mentioned, this sensor gives tridimensional joint positions (X,Y and Z coordinates). From these joints vectors can be extracted with two successive joints representing bones of body segments, e.g., elbow to wrist segment to represent forearm.

In order to enable patient mobility in relation to the sensor, tridimensional coordinates were centered in relation to the body position. This way, the movement recognition works the same way regardless whether the patient is positioned frontally or laterally to the sensor. In order to represent the previously described planes, a normal vector for each plane is computed using the cross product. The trunk vectors are used to calculate the normal of the frontal plane as demonstrated in Figure 3A; to represent the normal vector of the horizontal plane the unitary Y vector is used (Figure 3B); and finally to obtain the sagittal plane normal it is calculated the cross product between the other two normal vectors (Figure 3C).

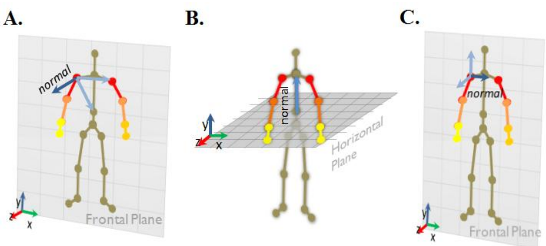

Figure 3. Normal vector computation for frontal, horizontal and sagittal planes definition

In sequence, the joints are categorized in accordance with the body position. First-degree joints are directly connected to the trunk, second-degree ones are attached to the first's joints, and so forth. By applying these categories to upper limb joints, the shoulder is classified as a first degree joint (red joints in Figure 3), followed by the elbow as a second (orange joints in Figure 3) and the wrist as a third degree joint (yellow joints in Figure 3).

3.2.3 Range of Motion Computation

Usually therapeutic movements are measured using the ROM, i.e., the angles computations of each joint in each plane [Clarkson 2005]. The joint angles are obtained from the arc cosine of the dot product between vectors connected to the joint that is being analyzed. For example, the elbow angle is calculated using arm and forearm vectors, as presented in Equation 1 and Equation 2, respectively.

$$elbowAngle = \arccos\left(\frac{forearm \cdot arm}{\|forearm\| \, \|arm\|}\right) \qquad (1)$$

It is important to notice that the same angle is computed independently of the movement plane. So, it is necessary to gather additional information in order to define in which plane the movement is being executed. This way, the angle between the moving vector and the normal vector (explained in subsection 3.2.2), is calculated. In order to be classified as a biomechanical movement in a certain plane, the angle between the moving vector and normal vector of this plane should be 90 degrees, giving a tolerance error margin that can be specified by the physiotherapist. Using this configurable error margin makes it possible to define how far away from the plane it is acceptable to classify the movement as a biomechanical movement. The range used to define the error margin on the present work is 15 degrees, which represents the most common used variation during a arm biomechanical movement [Doorenbosch et al. 2003].

3.2.4 Biomechanical Movements Classification

The biomechanical movements are computed and classified according to the planes and axis where the joint anatomy enables it to move [Clarkson 2005]. The classified biomechanical movements for the upper members are shown in Table 1. The first column lists the supported shoulder movements. The following column contains the points used as reference for the vectors that are the base for the joint angle computation. The third column shows the normal plane used to categorize and identify the movement plane. Due to the single movement possibility for the elbow, there is no need of a normal plane reference.

Table 1. Biomechanical Movements classified with respective points for vectors used for joint angle computation and normal reference for plane definition

Movement	Vector (Points-Tuple)	Normal Plane
Shoulder Flexion	Shoulder-Elbow Shoulder-Hip	Sagittal (YZ)
Shoulder Abduction	Shoulder-Elbow Shoulder-Hip	Frontal (XY)
Shoulder Horizontal Abduction	Shoulder-Elbow Shoulder-Other Shoulder	Horizontal (XZ)
Elbow Flexion	Shoulder-Elbow Elbow-Wrist	Not Necessary

As can be noticed the presented prototype is supports the tracking and recognition of upper member's movements, however it can be extended for lower limbs as well.

3.2.5. Postural Analysis

During movement execution, often the user commits postural compensations to make the exercise task easier. This practice can reduce motor ability and, if continually executed can promote pain [J Rainville 1997]. In order to minimize this practice during the treatment, the system is programmed to recognize compensations and then warn the patient, leading him/her to perform the movement correctly. Furthermore, the biomechanical movement is not considered valid while the patient is in a compensation posture, preventing the patient to continue playing while compensating.

In order to prevent trunk compensations, the angle between the vector going from right to left shoulder and the right to left hip vector are computed and then analyzed. This angle is accepted until a maximum tolerance value is reached. Therefore, the tolerance can be controlled through a range of acceptability and can be set according to rehabilitation needs or patient limitations (e.g. healthy subjects can use a range of 10° while scoliosis patients, whose trunk is naturally inclined, will need a larger range, like 20° depending of scoliosis degree).

3.3 Physiotherapeutic Game

Patient interaction is made through a physiotherapeutic game. In this game the patient controls the main character of the game using therapeutic movements. These are the same used during traditional therapy, a biomechanical movement. The game´s mechanic has been developed to induce the therapeutic sequence of movements and repetitions.

In the dynamic of the game the patient’s movements control the vertical motion of the main character. The patient has to make the main character catch some elements and avoid others, both coming from the opposite direction of the screen. Positive and negative feedbacks will be given depending on the success of the user on performing these tasks. This way the user has a real motivation for performing the necessary moves.

The main characteristic of the system is that the movement that controls the character can be scaled and graduated according to patient limitations. This way the maximal patient mobility will correspond to the maximal motion of the character. For example, the physiotherapist configures the game for shoulder abduction, which occurs at frontal plane as explained before, and determines that the maximum ROM for the patient is 90 degrees. Using this configuration, the game will interpret and respond accordingly as a full movement when patient abduction is at 90 degrees.

The therapy configuration is done through a text file which can be viewed in Figure 4. In this file the physiotherapist can choose one of a list of biomechanical movements to control the character. He/she is also able to define the side member, left or right arm, and the maximal angle that will correspond to the maximum character motion range. The therapist also specifies the game duration in minutes.

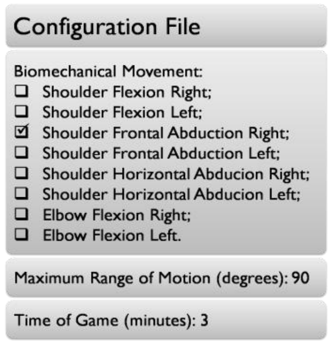

Figure 4. Configurations file options for game.

3.4 Report Module

The Report module is responsible to present the biomechanical analysis results captured during the game execution in an accessible and documented way. The report provides therapeutic information about the patient´s performance during the use of the system.

While the game is running, this module is continuously receiving data from the biomechanical analysis and at the end of the game the statistics measurements are computed including: maximal angle, percentage of time which the movement was executed incorrectly, if the movement was performed with postural compensation. Figure 5 shows the information provided by a game report after a patient playing for three minutes with shoulder frontal abduction of the right side.

Figure 5. Report file output information from user performance during game.

4. Interface Evolution

The interface of the system was designed in two phases. Firstly, a prototype was developed and then, after the system and this interface passed through user tests, the second version was made.

The first version of the game was focused on testing the hypothesis that a game specifically designed for physiotherapy rehabilitation with feedback for the patient would be valid. It was defined a simple game and set of requirements, thereupon it was necessary to test if this concept had value to the patients and to the physiotherapist. With this goal the first version of the game was created, the Dolphin's Adventure. As the focus of this version wasn't specifically on the user's satisfaction with the graphics, the effort on creating high quality graphics, meaningful story and characters and other well known characteristics accepted by the games market wasn't necessary.

With this prototype developed, tests were made to evaluate it, in which all the characteristics of the system (technology and interface) were considered. After the results of these tests and all the user feedbacks being collected, synthesized and studied, the development of the final version was initiated and then tested to measure the improvements made in the system compared with the first version. In this section will be described how these project steps were conducted, focusing on the graphic features and interface of the system. The tests and results will be described at the next section.

4.1 First Version: Dolphin´s Adventure

The theme of the first version of the game was chosen based on the concepts of mental mappings and affordances [Norman 2002]. These mental mappings point to the necessity of designing based on the spatial concepts already established in the mind of the user and on the active inherent meaning of the objects formal characteristics (virtual objects, in this case). As most of the moves to be made by the system's user should follow trajectories on the vertical axis, it was necessary that the character controlled by the user had its main moves on this axis too, making the system more intuitive. Thus, an aquatic environment was designed for the game, knowing that in the water the elements could have a two-axis movement freedom. All the graphic elements created to represent this theme and the game mechanics are presented in Figure 8.

4.1.1 Main Character and Scenario

Knowing that the game will be based on an underwater scenario, the main character was defined to be a dolphin, an easily accepted as a friendly icon of this environment. Figure 6 shows this character and the scenario, which will help the user to feel immersed at the game and be convinced that he is playing in an underwater scene.

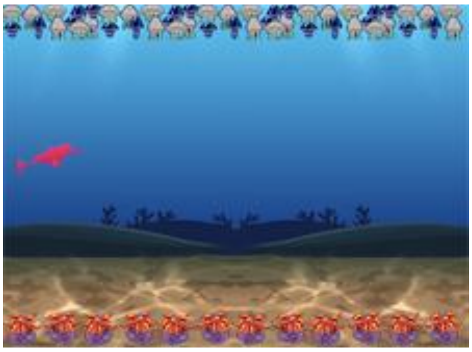

Figure 6. Main character and scenario

4.1.2 Bonus and Onus Elements

As explained in the game mechanics, the user will be induced to catch some elements at the screen. The characters chosen for this purpose were fish coins. Also to improve the interaction with the system, the element the user will have to avoid is a submarine and a piranha. These elements are shown in figure 7.

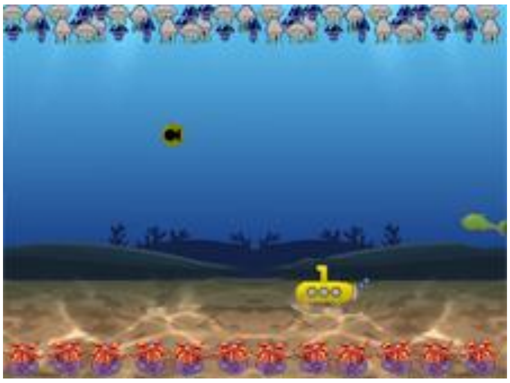

Figure 7. Bonus and onus elements

4.1.3 Feedback Elements

The score, game time, user's movement angle and a virtual mirror were added above all the elements to help the user understand and feel comfortable with the game mechanics, as illustrated in Figure 8.

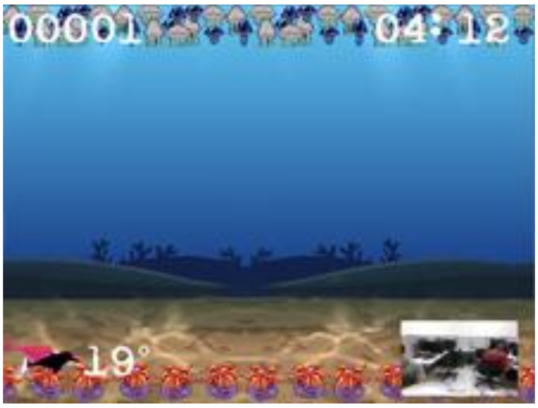

Figure 8. Feedback elements

4.2. Second Version: reAIRabilitation

After the tests with the first version of the game, it was found some issues regarding the feedbacks provided by the system, graphic elements presentation and positioning, and with the user´s satisfaction in general. These issues are detailed in the Section 6. Given the need to improvements, the game was redesigned, now with focus on the user's satisfaction and needs.

4.2.1. Main Character and Scenario

After a brainstorming session, a plane was defined as the new main character, keeping the same restriction on vertical movement's freedom. The scenario has been made cleaner than the previous version and provides more space to the other elements (Figure 9).

Figure 9. Main character and scenario

The creation of the other elements was given with the same necessities pointed at the initial version of the project and with the same methodology used to define the new main character: brainstorming, sketching and refining the chosen alternative. Bellow is shown these final versions of the elements as well as some of its animation characteristics.

4.2.2 Bonus and Onus Elements

Rings were defined as the main must do steps for the patient. The physiotherapist can set the positioning and timing of these rings in order to make the patient do the correct movements. Stormy clouds are now the elements to avoid. To improve the dynamics of the game, fuel boxes must be picked up in order to make the plane keep flying. All these elements (Figure 10) were chosen to make the user easily understand what to do without having to follow any instructions.

Figure 10. Bonus and onus elements

4.2.3. Feedback Elements

As seen on the first tests, there was a lack of feedbacks on the game and the user could not understand when he was doing the movements in a wrong way. To rectify this problem, visual and sonorous feedbacks were added to the game, both triggered when the patient does anything different than what has been planned by the physiotherapist. These elements can be seen on Figure 11.

Figure 11. Feedback elements

5. System Evaluation

In order to improve the development of the system, it was submitted to user evaluation to receive feedback from them and, this way, improve the system's characteristics and usability. The system was applied to three different population groups where each person's opinion and suggestions on how to improve it were collected. First, tests were applied with the primary prototype version, which was upgraded according to evaluation and necessities. Followed by a second test done with the new system's version.

The required population was composed of subjects from physiotherapy area, computing area and general population. The therapists were included to enable suggestions about system therapeutic effect and application, while computer specialists could give a more technical opinion. General population was add to evaluated general aspects of usability and motivation of system applicability.

All users participated of two encounters, dedicating one for each version of the system. In each encounter, all the users answered a survey consisting of eighteen questions from which a subset of nine are considered and analyzed in this work. The selected questions can be split among four major aspects, being each question related to one of the following core subjects: control sensibility (question 1), therapeutic domain (questions 2 and 3), welfare (questions 4 and 5) and ludic value (remaining questions 6, 7, 8 and 9). At the questionnaire end a space for suggestion were available.

Here follows the applied questions: 1) Did you feel that you could control the game? 2) Do you perceive the therapeutic function of the system? 3) Did you feel that the game helped you to correctly perform the movements? 4) Did you feel comfortable during the playing experience? 5) Did you find that the game is easy to play? 6) Do you think the game was fun? 7) Would the game improve your motivation to perform exercises? 8) Did you enjoyed the game scenario? 9) Did you feel challenged?

Each question could be answered, rating, according to a 1-5 Likert scale. In addition, a score was assigned for each question by considering the sum of all ratings of the respective question. This score allows a fast overview of the total of answers, considering all users. This measure also helps to achieve a fast comparison between two stages in which the same question was answered, this way giving a fast overview of the impact of the second tested version over the first one.

To validate differences a statics analysis was performed with the Graph Prisma 5.0 software. It has been used to verify the data distribution according to the kolmogorov-smirnov test. No normal distributions were found. Due to this fact, a comparison performed with the wilcoxon test for paired non-parametric data. The tests were considered with 95% of significance level and expressed through probability (p) value, where a p value lower than 0.005 means that the difference was significant.

6. Results and Discussion

As presented before, both versions of the game were tested and evaluated by a set of users. In total 55 users participated of the two encounters, one for each version of the system, with a 30 days time interval between the encounters dedicated to implement the pointed improvements. In each encounter they answered the previous described questionnaire.

In Figure 12 it is shown a chart for each one of the four aspects (grouping the respective questions of each aspect) and a final chart representing all questions together. Each chart presents the number of occurrences (vertical axis) of each rating (horizontal axis), presenting both the first and the second encounter results (labeled as 1^{st} and 2^{nd} time).

In addition to the results presented in Figure 12, Table 2 shows the scores obtained on the first and second encounters for each specific question as well as for the grouped aspects and for the overall results. This way, it is possible to understand the influence of each question in the results presented in Figure 12 as well as perform a fast analysis of which topics are well evaluated by the users by comparing the obtained score to the reference score measures (maximum, intermediate and low score of respectively 275, 165 and 110). Besides, it is also possible to acquire a first notion of the improvement the system experienced by correlating the scores of the 2^{nd} and the 1^{st} encounter as shown in the last column in Table 2.

As an initial overview, it is noticed in Table 2 that the users on the second encounter better evaluated all topics presented on the questions. It also can be seen in Figure 12 that great part of the users migrated their ratings from a lower value to 5, in fact in the overall results the number of 5 ratings is 125 greater in the second encounter. Independently of the first tested version, in a more absolute analysis, by considering that the total of answers of all questions is 495 and 445 of those, i.e. 89.9%, were a 4 or 5 rating (Figure 12), revealing a significant satisfaction from the users with the second version of the system.

Table 2. Score of each topic in the 1st and 2nd encounter.

Aspect or Question	1^{st} Time Score	2^{nd} Time Score	2^{nd} / 1^{st} Score	p value
Question 1	207	253	122%	0.0002
Question 2	238	246	103%	0.3133
Question 3	187	243	130%	0.0001
Question 4	180	241	134%	0.0001
Question 5	234	266	114%	0.0005
Question 6	189	235	124%	0.0001
Question 7	223	253	113%	0.0006
Question 8	222	256	115%	0.0001
Question 9	198	205	104%	0.4049
Control Sensibility	207	253	122%	-
Therapeutic Domain	425	489	115%	-
Welfare	414	507	122%	-
Ludic Value	832	949	114%	-
Overall Results	1878	2198	117%	-

Specifically, the questions 2 and 9 did not reach a significant growth in the second evaluation and so the second evaluation does not provide enough statistics data to declare that the second version of the system presents a better resolution for these topics. However, the question 2 already presented a high score of 238 in the first evaluation thus, being understandable its low growth since the maximum limit were already too near. On the other hand question 9 reveals that game aspect of challenge still have a significant space for improvements since both evaluations of the users showed an intermediate score near 200.

Furthermore, questions 3, 4 and 6 revealed the lowest result in the first evaluation and so, a major need for improvements compared to the other topics. Question 3 revealed the need of a feedback system that was implemented for the second version of the system, providing audio and visual information directed to assist the user during the execution. Question 4 by its turn revealed that the random criteria used to define whether or not an obstacle or a bonus coin should appear forced the users to perform too much isometric movements, e.g. keeping the arm raised for too much time. The second version of the system was prepared in a way which all positive and negative elements (e.g.: thunder clouds, gas and golden hoops) appears in game inducing the user to switch the exercise mode between slow and fast movements as well as some rest time. One advantage of the new design of these elements is that it helped the user to visually recognize more quickly which elements he should avoid, which he should pick and which he should pass through its center. At last, question 6 revealed a space for improvement about the fun during the playing experience. As can be seen in Table 2 the interface improvements, plus some adjustments for the second version of the game solved partially this problem.

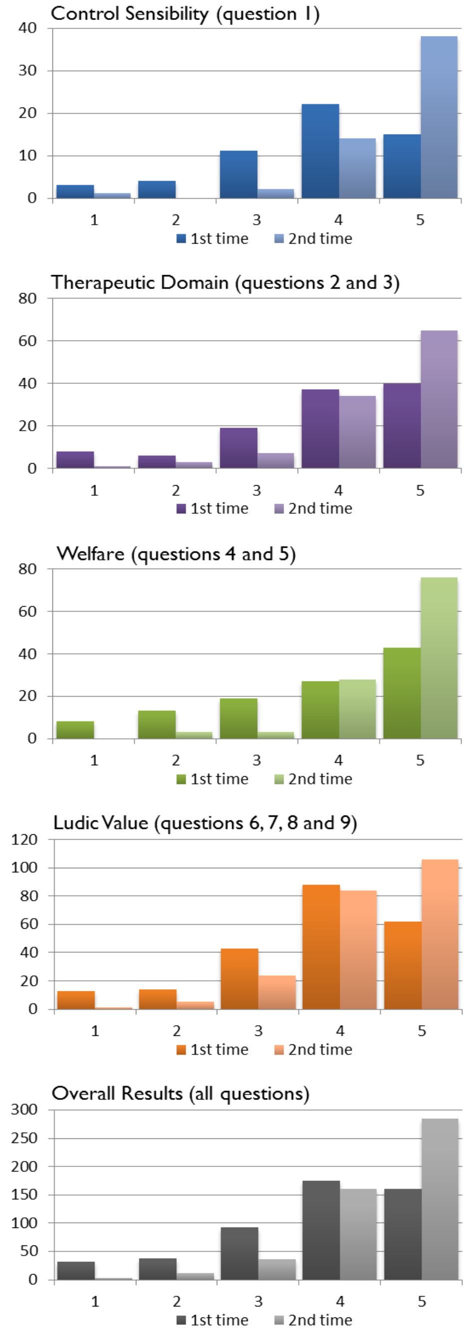

Figure 12. Ratings of each aspect plus the overall results.

One of the reasons that may be responsible for the better results related to question 1 is that the version of the used Microsoft Kinect SDK was updated, and so, the precision of the tracking algorithm was increased. Besides that, the new design of the main character may favored a better visual idea of control. Before, in the first version, the player controlled a pink dolphin which was animated constantly moving in its own space and so, its movement should confuse the user whether the movement was obeying his commands or just being performed by the game itself. The remaining questions (questions 5, 7 and 8) also revealed that the redesigned graphical interface had a good impact on users about the easiness of play, the motivation to play during the practice of therapeutic exercises and the visual aspect of the presented scenario.

7. Conclusions

This work presented a rehabilitation system based on markerless interaction in a virtual reality environment. This system uses the Kinect device for interaction and it is based on a game controlled by therapeutic movements, which is set by physiotherapists, inducing the user to do exercises correctly. It is capable of identifying whenever the patient is doing it correctly, warning him/her otherwise and also saving the statistics in a report for a further professional analysis. This way, it is presented the development of a rehabilitation game as well as its use evaluation.

The first test showed that the system attended the requirements at least minimally, but needing to be improved in some points. These issues were tackled resulting in a second version of the prototype, which had improvements mainly on its interface. This new interface is cleaner and friendlier, making the user understand better what to do and being funnier as well. It also had the improvement on the feedback given to the patient when he/she is doing a wrong movement. This is an important feature since the system main purpose is to assure the correct execution of physiotherapeutic exercises. All these improvements reflected on the second round of test, where the second prototype had higher grades in all evaluated aspects. These results show the importance of a user centered design approach on the development of this kind of applications, putting the patient needs as guidelines of the product's development. The improvements made on the second version of the system proved to be an effective way to enhance the user's experience and, by this way, increasing the chances of an successful physiotherapeutic treatment.

As future works, the system shall be used and studied in a real case scenario, aiding patients in their recovery process and evaluated by both patients and physiotherapists.

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Acknowledgements

The authors would like to thank FACEPE (APQ-0868-1.03/10; PBPG-0024-1.03/11; PBPG-0547-1.03/11; BIC-0876-1.03/11; BIC-0814-1.03/11) for partially funding this research project. Also thank Igor Cardoso for helping with the sprites.

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