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KSGphysio – Kinect Serious Game for Physiotherapy

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Abstract— **Serious games fall under a set of applications capable of improving recovery times by increasing the player's engagement. In this paper we focus on the possibility of joining thatcapacity to Microsoft Kinect sensors ability to collect data without the need of additional sensorsand present an application capable of giving proper feedback about the player's behavior during a rehabilitation session. Using an Android OS mobile platform as interface for the collected data,the proposed solution is a prototype that aims to facilitate the analysis of the patient'sprogress during rehabilitation sessions using serious games. Results associated with arm rehabilitation through serious gameare included in the present work.**

Keywords- *remote physical rehabilitation, serious games, pervasive computing, virtual reality, personalized medicine*

I. INTRODUCTION

In a world where it is increasingly common to integrate virtual environments in real-life situations rehabilitation is no exception. It is increasingly common to use video games to create greater engagement on the user increasing the physiotherapy efficiency. However, because they are adapted games and are not specifically designed for rehabilitation, many therapists prefer to just use them more as a complement to a physical therapy session rather than an integral part of the session. These games are very limited because they are not configurable or accessories are needed to interact with it, which sometimes makes it impossible to use in a rehabilitation session of a more impaired user. Do not allow tracking progress and in most cases there is a lack of feedback to the therapist and to the patients under rehabilitation process [1].

Research suggests that repeated execution of an exercise is sufficient to stimulate the brain to remodel and promote better motor control of the limbs [2]. However, the number of exercises performed during a rehabilitation session is not sufficient for this to happen which suggests the need for patients to practice these exercises at home. However 65% of patients self-reporting being non-adherent or partially adherent to their home programs [3], which in most cases represents a regression of the patient. Adherence embraces 2 elements: being compliant with the frequency of the suggested exercises and carrying out each exercise with the correct biomechanical alignment.

This study aims to produce an application that improves the quality of rehabilitation sessionsin the clinic or at home, while enabling data collection and communication so that we can track the patient physical rehabilitation progress.

II. RELATED WORK

Virtual reality is increasingly used in areas such as rehabilitation through motion-based games. This new generation of tools for rehabilitation has grown up rapidly in the past few years. However, many of these games require wearing a number of sensors attached to the body or use extra material to detect the movements of the patient [4, 5].

In [1], authors propose a rehabilitation tool based on Nintendo Wii complemented with a web-based application that allow motion capture and monitoring exercises to track patient's progression.

Applications based on Kinect sensors natural interaction without the need of additional sensors allow therapists to customize and adjust the physiotherapy training to be performed by the patientand give more freedom of movement.

In [2], after testing with Kinect-based applications in different situations and in patients with different levels of rehabilitation, the authors concluded that the accuracy rate in the detection of motion using a Microsoft Kinect sensor is more than 80%. Therapists rated the technology positively indicating that this kind of tool would reduce their labouring burden and improve rehabilitation efficiency, while patients indicated that this technology has helped to increase their motivation to participate in rehabilitation reducing the time affected by this process.

In [6], authors show their concern about the lack of arguments that validate rigorously the technical performance of Kinect sensor as a rehabilitation tool, although previous works prove the potential of Kinect sensor in this area. They studied the trajectories of the joints at the right hand, right elbow, and right shoulder when performing motor task External Rotation, Scapular Retraction and Shoulder Abduction and compared the results of a Kinect sensor with the results of a OptiTrack that is a marker-based system which requires users to wear reflective markers such that their movements can be tracked by an array of cameras. They also evaluate the timing performance of both systems.

In [7], authors present the results of Kinect applications used in physical rehabilitation tests and foresee that Kinectsensor technology will be widely applied in medical care fields.

III. SYSTEM DESCRIPTION

The proposed system is divided in three parts, asare presented in Figure 1. The first one is a game that uses the Microsoft Kinect motion sensor to allow data collection during rehabilitation sessions. Every time a patient start his session, a particular game that was previously configured by the therapist who defined some aspects of the game as the speed, the angle that must be performed by a particular limb or the difficulty level of the game given the patient's condition. Using the Microsoft Kinect SDK and a C# wrapper for Unity 3D we can detect automatically the patient joints position and send that information frame-by-frame to the database. Each time a special event occurs, the patient joints positions also are sent to the database. It is understood as special event every time the patient accomplishes a game objective like catching a specific object. In that way we can relate the position of the picked up object and the position of patient’s joints and compute physical rehabilitation parameters such as velocity, angles or limbs rotations and compare them with those previously given by therapist through the game configuration interface. The Kinect sensor isconnected to a computer with an Intel core i5-4250U processor, an Intel HD Graphics 5000 and 8G of memory RAM. The computer characteristicsare important to guarantee that the performance of the game is not compromised.The second one is the server, which includes a database, an API and a data processing application to work over the collected data. The API allows every component of the system to communicate with the databasethrough a set of GET and POST methods. The other component held in the server is the data processing application that will translate the frame-by-frame the data collected during the session into metrics that can be easily interpreted by the therapist.

The third component is the mobile application developed for Android OS devicesthat behaves as a client. The application connected to the database and running on the deviceallows the therapist to consult patient’s recordsthrough charts, analyze the data collectedfrom previous sessions,do comparisons between session’s data, configure new sessions and add reports related to the patient evaluation.

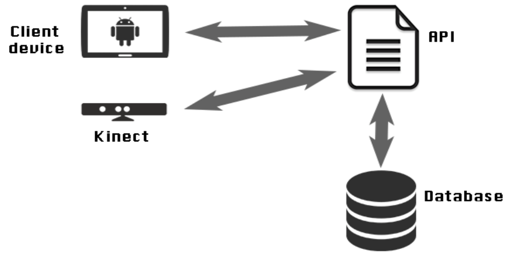


Figure 1 - System architecture

A. *Kinect Sensor*

Kinect is a motion-sensing device that was originally developed for Microsoft’s Xbox360 gaming console. The main feature that distinguishes it among others in this gender is that it is not a hand-controlled device, but rather detects your body position, motion and voice. It replaces the controller that was once the heart of a gaming device by your body.

The idea of developing the Kinect sensor began to take shape when Microsoft engineers realized that the traditional game controller was the main barrier to making video gaming into a mainstream activity.They quickly realized that the solution was getting a device to track users' bodies as they move.

The core of Microsoft Kinect sensor technology came from a Israeli startup named PrimeSense that figured out how to encode patterns in the light beams and then measuring the changes in those patterns it's possible to give a particularly accurate view of a room [8].

The Kinect sensor(has now outgrown its Xbox roots and is no longer limited to only gaming after Microsoft release Kinect for Windows, a version designed specifically for PC that helps developers to write their own code and develop real-life applications like serious games for rehabilitation purposes with human gestures and body motions.

The Kinect sensor includes a color sensor (Figure 2), an infrared (IR) emitter, a IR depth sensor, a set of microphones and a LED. Additionally has a small motor working as the base that enables the device to be tilted in a horizontal direction.The color camera is responsible for capturing and streaming the color video data. The Kinect color stream supports a speed of 30 frames per second (FPS) at a resolution of 640x480 pixels, and a maximum resolution of 1280x960 pixels at up to 12 FPS.

The IR emitter and the IR depth sensor work together to make things happen. The IR emitter constantly emits a infrared light in a “pseudo-random dot” pattern over everything in front of it, as seen in Figure 3, and the depth sensor reads the reflection of the dotted light in the objects and converts them into depth information by measuring the distance between the sensor and the object from the IR dot was read from [9].

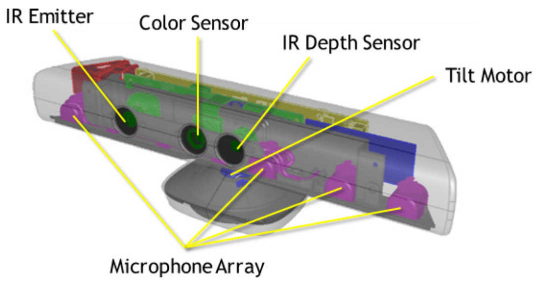


Figure 2 - Microsoft Kinect architecture

Figure 3 - Pseudo-random dot pattern

B. 3D Game

There are a variety of game engines that can be used to develop 3D games as RAGE (Rockstar Advanced Game Engine) or CryENGINE, this two have been used to create some of the best video games that exist nowadays [10].

To develop the game we used a game engine named Unity 3D that is a powerful rendering engine fully integrated with a complete set of tools and rapid workflows to create interactive 3D and 2D content that has C# as primary language [11]. Unity has a very simple, uncluttered interface for development that allows you to develop games quickly and have a very good integration with Microsoft Kinect sensor. It is also a game engine quite well documented with a strong Asset Store where you can buy scripts, tools and textures to use in the game. Has amazing third party solutions for Audio and Physics and the code is well architectured to reduce the amount of errors done by programmers.

The game environment is based on an orchard composed by rows of trees on both sidesand intends to simulate a harvesting of apples where the user must catch as many apples as possible a defined period of time, due to this fact the game focuses on the upper limbs of the patient. There aretwo different kinds of apples, the red ones and the green ones. Different kinds of objectsto choosefrom permits us to define different weights for those objects, whichallows the therapist to understand the cognitive capacities and the patient behavior in situations where he has to take decisions.In this case, the red apples add 100 points to the game score and the green ones add 50 points, as seen in Figure 4, so the patient has to decide if he prefers to catch the green apple that is easier to catch and get only 50 point or if he prefers to catch the red one and reach the goal defined by the therapist faster.

The main difference between this game and the other games mentioned in Related Work is that the parameters related to the rehabilitation process are configurable by the therapist. Using the mobile interface (D) the therapist can define rehabilitation parameters such as the speed, the angle that must be performed by a particular limb, session duration, if the user should execute rotation of the body or not, the difficulty level of the game given the patient's condition and the minimum number of points to do at a session setting up a goal for the patient to commit with.This last parameter is used to compare the performance of the patient between sessions. Every time the patient picks up and object some points are added to the patient's score, in the end of each session the score should be equal or bigger than the minimum defined by the therapist, a lower score may portray a regression of patient's condition.All of these aspects will contribute to help us mapping the patient's progress during the rehab time.

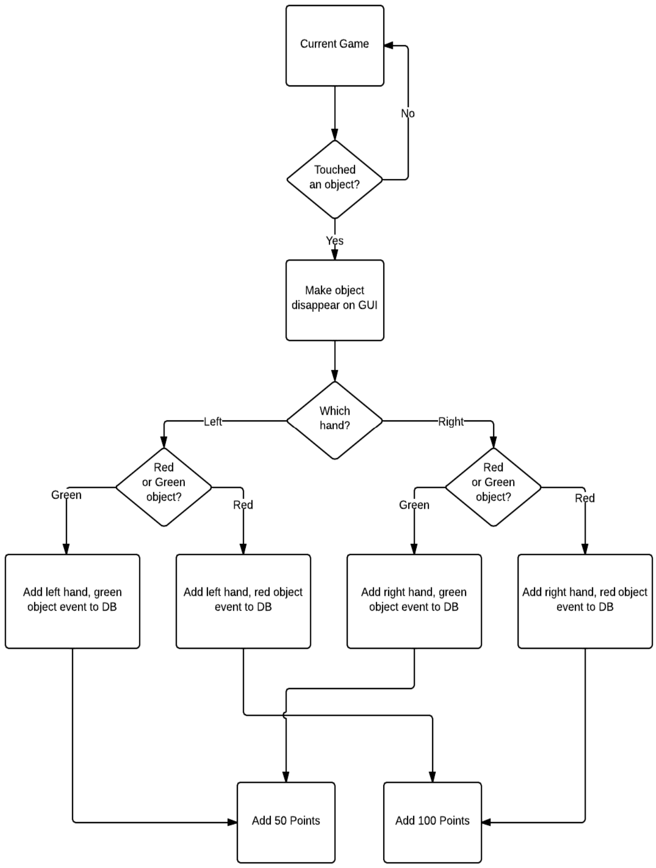


Figure 4 - Pick up object flowchart

C. Database model

For database we used a relational database management system (RDBMS) named MySQL [12] that has no GUI tools to administer databases or manage data contained within the databases. For that reason a front-

end tool named MySQL Workbench [14] was used to enable us to graphically create and manage the tables of our database.
We can divide de data stored in the database in two main data types. The first type is the one that can be added to database using the mobile application interface: patient's personal data, notes written by the therapist, prescribed plans and game configurations. The second type is the data collected by the Kinect sensor like limbs positions.

The system users identificationsare stored in the database grouped in two types:therapists and patients. Each therapist has a set of patients that he can manage through the mobile application.Each patient can have a set of plans associated to his profile that are defined by their therapist. These plans have an associated configuration defined by the therapist during the creation the plan that will be used in the construction of the 3D game scene when the user starts a session in the game. Each plan consists in a set of sessions organized in time, which in turn consist of a collection of scenes.

Each frame collected by Kinect sensor represents a scene and consists in a group of three-dimensional vectors (x, y, z) corresponding to the position of each member during that scene. In addition to the data collected by the sensor frame by frame, there are special events like picking up an apple, that are saved so that we can map the evolution of the patient,by comparing the number of picked up apples between a set of sessions performed by the patient. If the number of picked up apples increase, that could mean that the patient is improving.

D. *Physiotherapist's Mobile Interface*

The Android OS is one of the most used operating systems on mobile devices by virtue of being open-source and still growing. Well positioned on the market Android achieved the 81.1% market share in the first quarter of 2014 [13].The mobile application was designed to permit the interaction between physiotherapist and the data provided the client and stored on the serverside. It is important that the application can display the data in a clear, synthesized and objective way so that the therapist can easily understand them. To achieve that we use a set of different types of charts as line charts, pie charts, bar charts and radar charts to display the data graphically.To create the charts we useHoloGraphLibrarylibrary was used [15] that is simple to use and to integrate with the application. It uses Android Canvas, which works as an interface to the actual surface upon which the graphics will be draw. It's the best choice when the application needs to regularly re-draw itself.

The communication between the mobile application deployed in Android device and the server is done using a networking library named Volley [16] that speeds up and facilitates that communication by allowing asynchronous HTTP requests and dealing with cache.

The interface splits the data in two types: data concerning to the game goals and data concerning to the limbs behave. The first type is important to understand the evolution of the cognitive capacities of the patient by showing to therapist statistics like the percentage of green and red apples picked up during a session, comparison between the number of picked up apples in the last 5 sessions, score progression, percentage of sessions where the patient achieved the minimum score defined. Data are presented in a generic way by making an overview of the patient's progress, but the therapist can also select a specific session and analyse every session individually. The second type represents the behaviour of the patient's limbs, using the data collected by the Kinect sensor we can compare the limbs performance, understand which limb is more frequently used to pick up apples, the progression of each member, correctly execution of an angle, the average velocity of the session and distinguish if the patient did more points with his left hand or his right hand.
The mobile software, which flowchart is presented in Figure 5, permits to the therapist to execute other tasks as add new patients, to create plans related to a patient's profile and configure them, this configuration will allow the system to adapt the game according to the patient's needs, add general notes or notes related to a specific session.

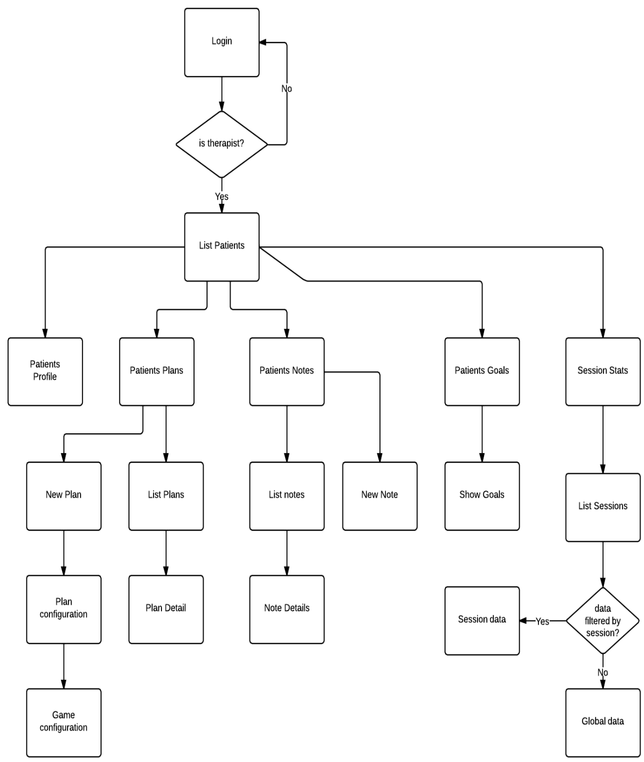


Figure 5 - Mobile application flowchart

IV. RESULTS AND DISCUSSIONS

In this section, are presented the results associated with the tests made using the Kinect based systemand the developed rehabilitation game for different users. Was tested the capacity of the designed and implemented system to collect data related to range, as it seen in Figures 6 and 7, and velocity, as seen in Figures 8 and 9,while patientsplayed the game. The represented data was normalized.The developed mobile interface is also presented with some results concerning the EHR and physiotherapy training data visualization.

We carried out this study with two male participants. Each participant played the pick up apples game during two minutes. We choose eighty-seven seconds of the collected data to evaluate the performance of the system regarding to patient's hands range and velocity.To perform the test, each participant was standing up three meters away in front of the Kinect sensor.

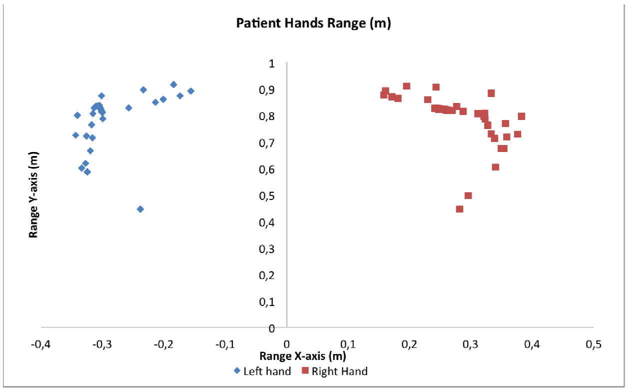


Figure 6–Left Hand/ Right Hand range test patient 1

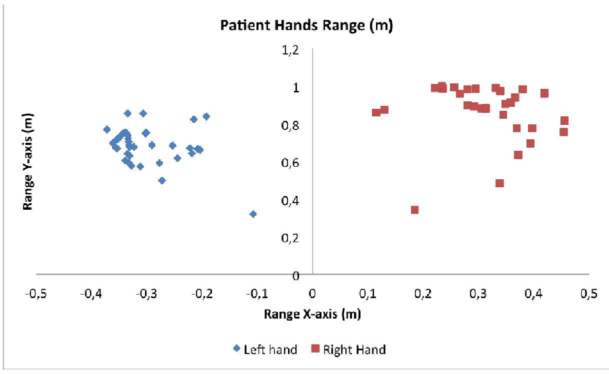
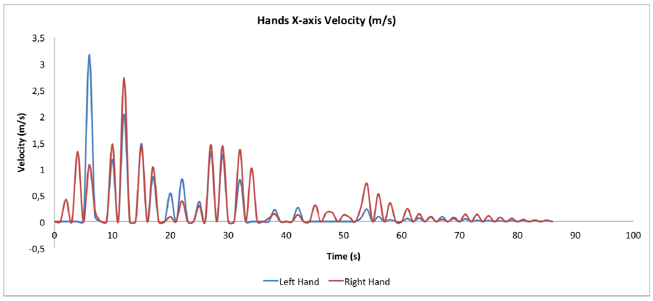
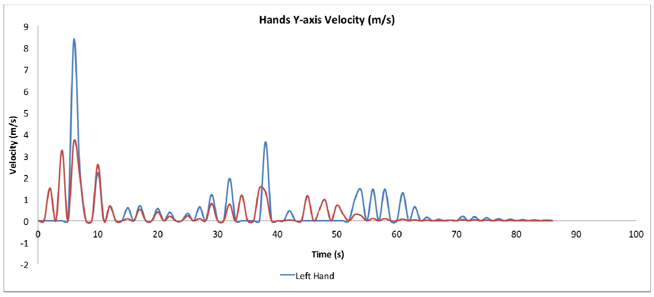


Figure 7 - Left Hand/ Right Hand range test patient2

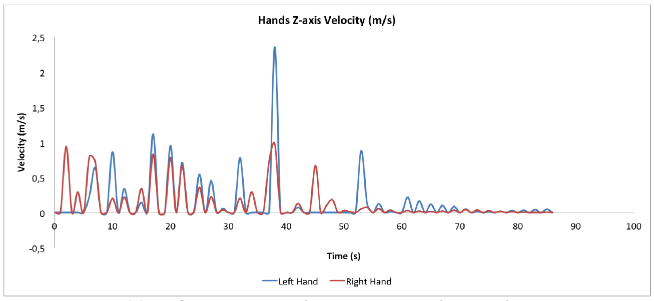
Figures 6 and 7 represents the ranges associated to left hand and right handmotion performed during a rehabilitation session showing that Kinect sensor has the capacity to collect sufficient data that can be used to track the evolution of the patient’s hands range.Acquiring data from consecutive sessions performed by the same patient may help to analyze the values of the measured ranges during different physiotherapy sessions of the range and evaluate the rehabilitation evolution process.



(a) Left hand and Right hand X-axis velocity

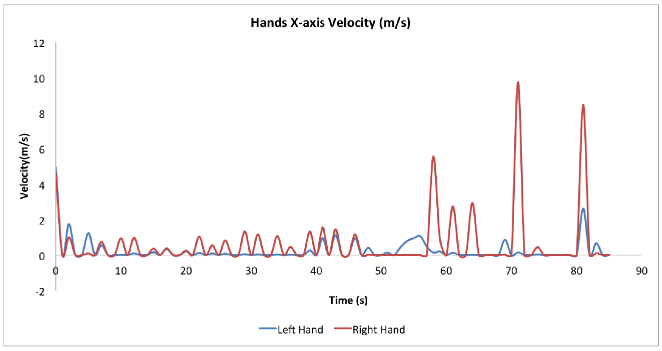


(b) Left hand and Right hand Y-axis velocity

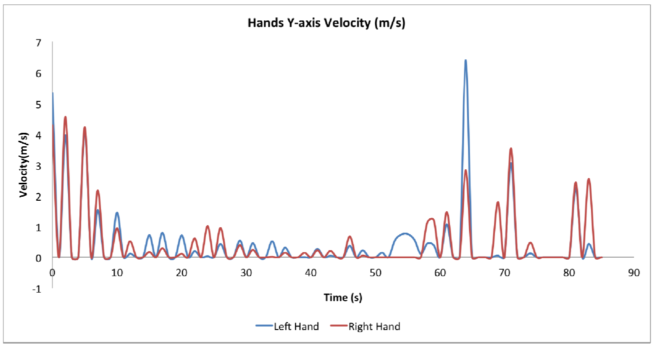


(c) Left hand and Right hand Z-axis velocity

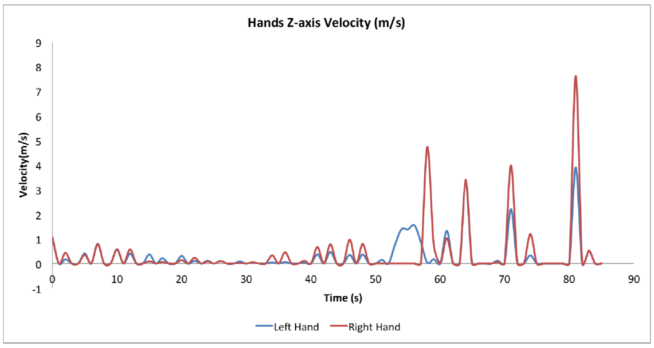
Figure 8 - X-axis, Y-axis, Z-axis patient 1 hands velocity performing a game session



(a) Left hand and Right hand X-axis velocity



(b) Left and Right hand Y-axis velocity



(c) Left hand and Right hand Z-axis velocity

Figure 9 – X-axis, Y-axis, Z-axis patient 2 hands velocity performing a game session

In a similar manner, using the Kinect sensor we can calculate the velocity of the left and right hands regarding to X-axis, Y-axis and Z-axis. Given the velocity values in different axis may help to understand the mobility of a patient's arm in different orientations.

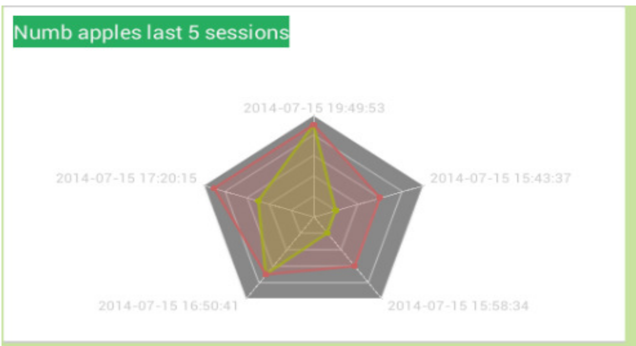


Figure 10–Mobile application graphic comparing the number of red apples and green apples picked up between patient's last 5 sessions

Figure 11 - Mobile application showing patient's progression in last 5 sessions

Using the mobile application the therapist has the access to statistics regarding patient's rehabilitation sessions.Figure 10 and 11 illustrate some of that statistics, in Figure 10 we can see the comparison between the number of objects picked up by the patient in the last five sessions sorted by colors, so the therapistcan compare the patient performance and cognitive capacity. In Figure 11 we can see the user interface showingan overview of the patient's progression in the last five sessions,in terms ofpoints obtained in each session, and the number of red and green apples caught.

V. CONCLUSIONS

Microsoft Kinect sensor is an appropriate tool for data collection because it enables an appropriate analysis of patient's behaviour during a rehabilitation session.The advantagesof combining the Kinect sensor with the rendering engine Unity3D and mobile applications to create 3D serious games capable of being configurable and adapted to the patient's needs are undeniable. Using Unity3D allows us to replicate real life situations, which facilitates the transition between virtual and real world. The mobile application brings mobility to data analysis allowing the therapist to see relevant statistics of a patient session, enables a single therapist to monitor several patients at the same time and allows him to configure specific parameters as velocity or angles of a session according to the patient's needs. Both, game and mobile applicationwere presented during demonstration workshops and proved to have a good acceptance in the therapist community.

The ongoing work is focused on an evaluation of the effectiveness and usefulness of the system, using two control groups: a group of therapists to test the mobile application and a group of patients to test the game represents.

ACKNOWLEDGMENT

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