3D serious games for Parkinson's disease management

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ABSTRACT

The aim of the article is to show how off-the-shelve equipment can be used to develop serious games for an affordable tele-medicine solution for Parkinson's disease management. Two games have been developed aimed at assessing and training patient's reach of upper limbs (using Kinect v2) and fine motoric skills of fingers (using Leap motion). The games collect player data in terms of score achieved and full kinematics of movement during gameplay. The data is stored online and made available to therapists and doctors through a secure connection. The games have been tested with patients within the Soča rehabilitation institute as well as at their homes.

Categories and Subject Descriptors

Categories and subject descriptors: H.1.2 [**User/Machine Systems**]: Human factors; J.3 [**Life and Medical Sciences**]: Health;

General Terms

Measurement, Documentation, Performance, Design, Human Factors.

Keywords

3D interaction, serious games, Parkinson's disease, rehabilitation, tele medicine

1. INTRODUCTION

Parkinson's disease (PD) is a long-term disorder of the central nervous system that mainly affects the motor system. It belongs to a group of conditions called motor system disorders, which are the result of the loss of dopamine-producing brain cells. The four primary symptoms of PD are tremor, or trembling in hands, arms, legs, jaw, and face; rigidity, or stiffness of the limbs and trunk; bradykinesia, or slowness of movement; and postural instability, or impaired balance and coordination. As these symptoms become more pronounced, patients may have difficulty walking, talking, or completing other simple tasks [1]. There are 10 million patients worldwide (1.2 million in the EU [2]). Their lives are dependent on others and there is no cure, we can only postpone the onset of symptoms or treat their severity. "The combined direct and indirect cost of Parkinson's, including treatment, social security payments and lost income from inability to work, is estimated to be nearly $25 billion per year in the United States alone. Medication costs for an individual person with PD average $2,500 a year, and therapeutic surgery can cost up to $100,000 dollars per patient." [2]

Given the above, it is no surprise that several research projects have been funded to advance our knowledge of PD (Rempark[1], Sense-Park[2], Cupid[3], Neurotremor[4]). The work presented in this article is part of the PD_manager project, which aims to build and evaluate an innovative, mHealth, patient-centric ecosystem for Parkinson's disease management. More specifically the aim of PD_manager is to:

1. model the behaviors of intended users of PD_manager (patients, caregivers, neurologists and other health-care providers),
2. educate patients, caregivers and healthcare providers with the focus on occupational and speech therapies and
3. propose a set of unobtrusive, simple-in-use, co-operative, mobile devices that will be used for symptoms monitoring and collection of adherence data (smartphone, sensor insole, smart pillbox, wristband with sensors for acceleration, heart rate, etc.) [5].

The games presented form a small subset of the devices used within the project for monitoring of patients and their adherence to treatment. As their main purpose is not entertainment, the developed games fall in the category of serious games [7].

2. REQUIREMENTS

The basic idea behind the presented systems is to (1) encourage patients with Parkinson's disease to put more time into rehabilitation through the use of gamification concepts, and (2) allow tracking the performance of individual patients that use the system. Performance tracking is created by recording of patient's activity both, at the rehabilitation center as well as at the patient's home.

The recorded performance track is also available to the doctors who have the possibility of tracking the progress of all patients that use the system via a web-based application. The web-based application is intended for doctors' use to asses and track individual patient's performance and plan his/hers rehabilitation remotely.

The system therefore consists of three parts: a client part application for patients, a server for gathering data and settings and a web-based client for doctors and caregivers. The client part

[1] http://www.rempark.eu/

[2] http://www.sense-park.eu/

[3] http://www.cupid-project.eu/

[4] http://www.car.upm-csic.es/bioingenieria/neurotremor/

is the most demanding in terms of system requirements, as it has to enable the smooth and comfortable use by the user as well as allow undisturbed capture of the data about patients' performance. The systems used in the presented work have the following specifications: Intel i7 – 4770R processor. 8 GB RAM, 120 GB SSD Hard Drive, Microsoft Windows 8.1, Microsoft Kinect V2, Leap motion, Mini PC form factor (GigaByte Brix and Zotac ZBOX used), mouse and keyboard for standard input at system boot. The system connects to any modern television with an HDMI input.

3. IMPLEMENTATION

The games have been developed with the Unity 3D[5] game engine, the choice of sensors to use was done according user specifications from Table 1.

Table 1: Sensor selection based on game requirements

Task	Reach	Fine motor skills
Requirements	Stimulate user to move hands above shoulder blades up and outwards	Stimulate user to use fine motoric skills of fingers
Sensor selected	Kinect v2	Leap motion
Relevant sensor specifications	3D tracking of 26 skeletal joints @30 Hz, seated mode, hand pose tracking (open, closed palm)	detailed 3D tracking of fingers@115 Hz

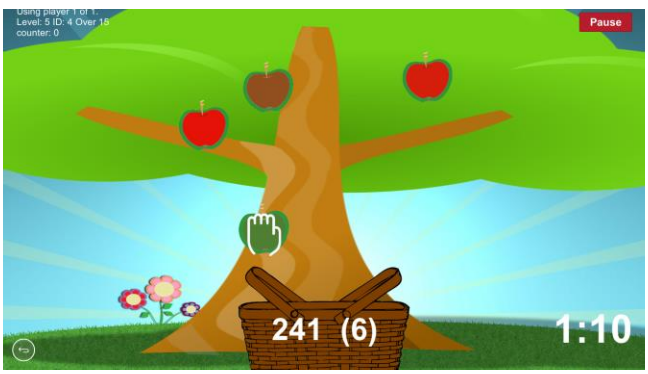

Figure 1: 'Fruit picking' game for exercising the reach above shoulder level.

The first game, aimed at preserving the range of movement of the patient's arms was developed with Microsoft's Kinect V2 sensor. The game consists of one scene in which the patient collects apples growing on a tree and puts them in a basket (Figure 1). Despite the game's simplicity its' development was not so straightforward. One of the most important aspects of such a game is the 'feeling' the user has when interacting, how smooth the interaction is, and the fidelity with which his movements are translated in the game. From a technical standpoint, this means filtering the raw input signal from the Kinect sensor and fine-tuning the filtering parameters. Additionally, with the health practitioners involved in the project we defined the physical interaction zone (PHIZ) of the game so it reflects the constraints that the domains of use imposes, i.e. mapping user movements relative to the users coordinate space (originating in the center of the user's torso) and translating the PHIZ above shoulder height (Figure 2). Difficulty levels were then defined based on how far the user needs to stretch to reach an apple; the higher the level, the more apart the apples are. The game progresses to the next level when a patient successfully collects 15 apples 3 times in a row. This protocol was defined after initial user tests. These test also revealed the possibility to cheat. The users could wait for an apple to fall near the basket, grab it then and put it in the basket, which defeats the purpose of the game (to reach out with the hands). This was corrected by making the apples not draggable once they start falling of the tree. Another issue raised from user testing was selecting the proper player as the sensor used can track 6 bodies simultaneously.

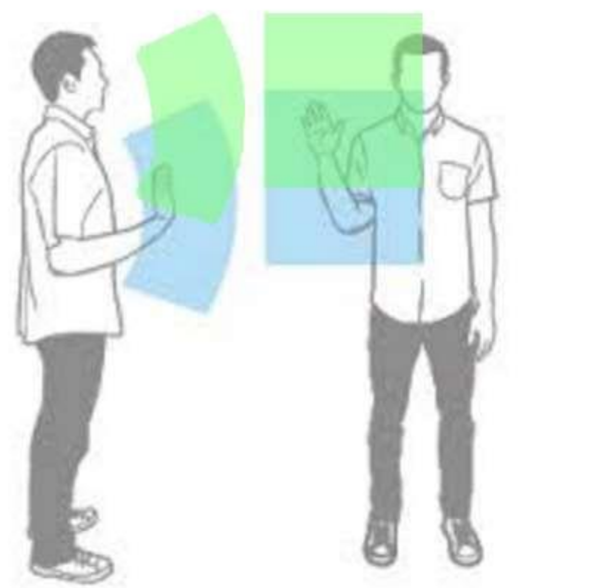

Figure 2: Original PHIZ (blue) and PD adjusted PHIZ (green) originating at the player's shoulder to stimulate proper exercising of upper limbs.

For the second game, focused on preserving the user's fine motoric skills, we decided to switch to the Leap Motion hardware as it would not be possible to achieve the desired accuracy with the Kinect sensor (some recent literature exist on how to process Kinect data to achieve accurate finger tracking [10], but the current available solutions proved to be too inaccurate for the task). The task of the user in the second game is to pick small cubes with his fingers and put them in a box (Figure 3). The result is the amount of blocks collected in two minutes and the time left in case he collects all boxes. Both games communicate with the server using secure SSL communication with self-signed certificates. Games settings, i.e. difficulty level, are retrieved from the server and controlled by the medical personnel remotely (Figure 4), while game results (score achieved and number of apples collected) and kinematic data of the user (rotation in Euler angles and quaternions and position of tracked joints) are anonymously stored online. The game also stores these data locally in case of problems with the internet connection at the patient's home.

[5] http://www.unity3d.com/

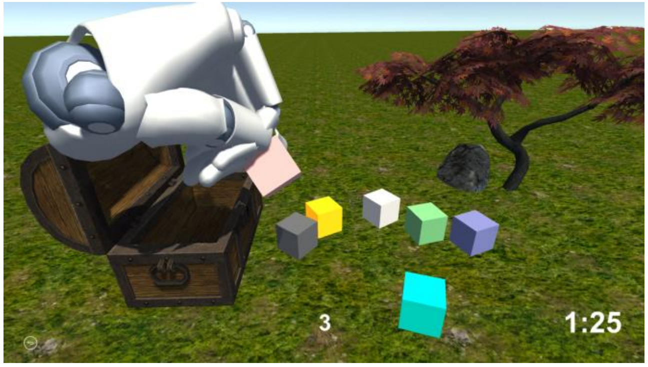

Figure 3: '10 cubes' game for exercising fine motoric skills.

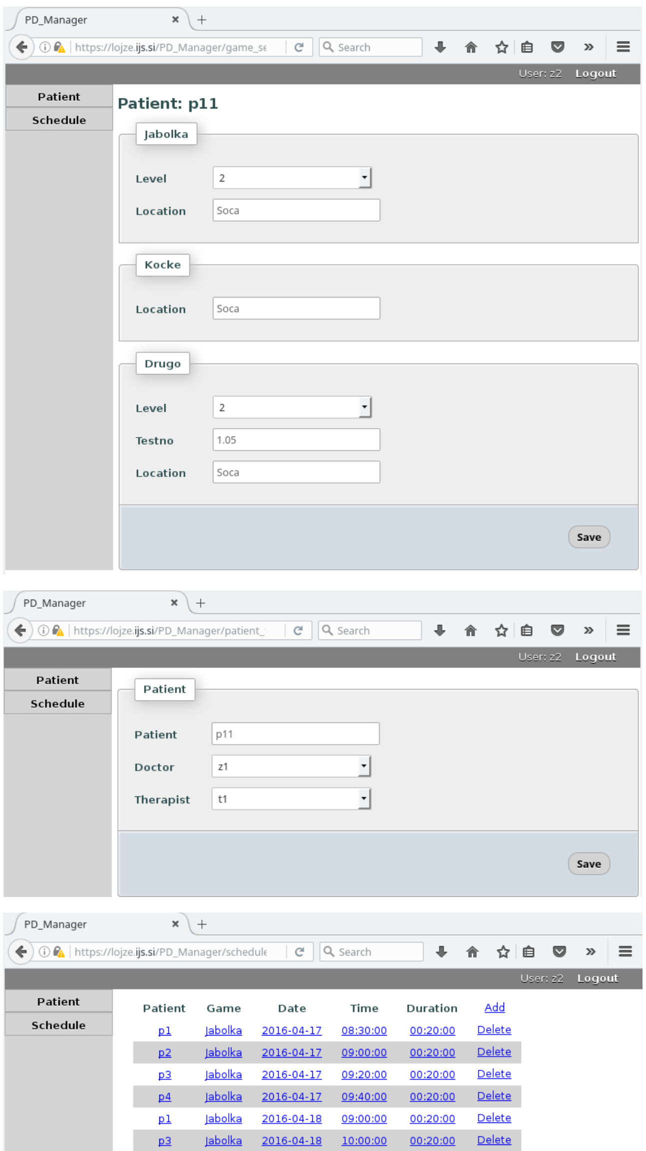

Figure 4: The interface for doctors and caregivers: patient-specific game settings (top), patient data (middle), exercises schedule (bottom).

3.1 PHIZ

While we could use the Leap motion SDK out of the box, we needed to make some adjustments when using the Kinect v2 sensor. The physical interaction zone (PHIZ) of the Kinect intended for normal use is defined as a cube originating in the player's torso as shown in Figure 2 left, while the constraints that the domains of use imposes, imply a different PHIZ. The change demands the mapping of user movements in the original PHIZ to one translated above shoulder height as shown in Figure 2 right. Figure 5 shows the PD adjusted PHIZ in action during testing.

Figure 5 Testing with 'Fruit picking' game.

3.2 Kinematic data collected

In the first game, the data collected by the Kinect sensor is collected at 30 FPS and consists of the position vector (x,y,z) and quaternion orientation (w,x,y,z) of all joints of all detected players (layer). The recorded joints are: left ankle, right ankle. left elbow, right elbow, left foot, right foot, left hand, right hand, tip of the left hand, tip of the right hand, head, left hip, right hip, left knee, right knee, neck, left shoulder, right shoulder, base of the spine, middle of the spine, spine at the shoulder, left thumb, right thumb, left wrist, right wrist. See [6] for details.

The second game records kinematic data from the Leap motion controller data at 115 FPS. The data is described as follows: in each frame, there can be one or more hand objects. The hand object reports the physical characteristics of a detected hand. It includes a palm position and velocity; vectors for the palm normal and direction to the fingers; properties of a sphere fit to the hand; and lists of up to five attached fingers (identified by number, from 0 for thumb to 4 for pinky finger). The anatomy of each finger is further described with four bones ordered from base to tip, indexed from 0 to 3: 0 for metacarpal, 1 for proximal, 2 for intermediate, 3 for distal). Finally, each bone is described with its length, width, center position, orientation, next and previous joint [4].

For two minutes of gameplay, the data gathered amounts to approximately 5 MB and 100 MB for game 1 and 2 respectively.

4. DISCCUSION AND CONCLUSION

According to the review and the proposed classification of serious games for health presented in [8], our games can be classified as follows: *purpose* – for health, *application area* - motor, *interactive tool* – 3D cameras, *interface* – 2D/3D, *players* – single, *genre* - exergame, *adaptability* – yes, *progress monitoring*

– yes, *feedback* – yes, *portability* – yes, *engine* – Unity3D, *platform* – PC, *connectivity* – on. There were two other games mentioned in the review dealing with PD. One aimed at cognitive capabilities and the second for motor skills. The latter is comparable to our games with the exception that it does not provide feedback nor connectivity. Additionally, we can compare our games against the guidelines for serious games for PD described in [9]. We can see that most were met:

- *accuracy* – yes, the sensors used provide data that is accurate enough to be analyzed to evaluate the performance and progress of the patient,
- *home-based solution* – yes, the system is commercially available and affordable,
- *real-time biofeedback* – yes, the system gives feedback about how the patient is doing to therapists as soon as a session is finished (if connection is available),
- *customized games* – the games enable visual cues, and adjustable level of difficulty that can monitored remotely by the therapist,
- *PD rehabilitation protocol* – yes, the addition of new mini-games is possible,
- *automated system calibration* – yes, the Kinect sensor's skeleton tracking with the modified PHIZ acts as an automatic calibration system that matches the range of movement of the patient with the range of movement required by the virtual game player,
- *feedback/reward system* – yes, the games stimulate the user by constantly giving feedback on the progress of the game and after the game is finished to increase the engagement and involvement of the player with the game and reduce the risk of abandonment of the game and physiotherapeutic treatment.

4.1 Lessons learned

Connectivity is often overlooked. Two examples: first, the GigaByte Brix has no external WiFi antenna, which proved to be a problem when operating in the hospital as the room in which the therapy takes place has poor signal and second, PD patients are elderly people with often-outdated TV sets without HDMI input.

Other players of the system such as grandchildren must be taken in consideration. On the one hand, they make the whole tele-medicine experience nicer for the patients and can help with system adoption and troubleshooting but on the other hand can bring noise in the data collected if the system has no option to discriminate between patient and other player. This is why we introduced the warm-up mode of gameplay, where data is not recorded online.

Ease of use for both patients and therapists is equally important as both spend a lot of time with the system, but from a different perspective. For the patient, the ease of use is determined by how the game feels while playing, while for the therapist use of use is about the simplicity to set up the system, to switch between patients using the game and how much help the patients need when using the system at home.

Giving feedback is not always positive as some patients suggested that knowing that they are near the goal makes them anxious, which in turn makes it harder for them to actually reach the goal.

4.2 Future work – trials, evaluation

The virtual reality supported physiotherapy starts with inpatients and lasts for 4 weeks and each individual continues at home for additional 2 weeks. 18 inpatients, aged between 54 and 80, were recruited for testing and validation, 5 patients tested the system also in their homes after admission. Physiotherapists assess the patients' condition at the time of recruitment at the time of admission and at the end of home therapy. Although testing with additional patients and validation in a bigger pilot with 200 patients is subject of ongoing work, we can say that in general, the system is well accepted by patients.

5. ACKNOWLEDGMENTS

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