Monitoring Game-Based Motor Rehabilitation of Patients at Home for Better Plans of Care and Quality of Life*

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Abstract— **This paper describes the biomedical, remote monitoring infrastructure developed and currently tested in the EU REHAB@HOME project to support home rehabilitation of the upper extremity of persons post-stroke and in persons with other neurological disorders, such as Multiple Sclerosis patients, in order to track their progress over therapy and improve their Quality of Life. The paper will specifically focus on describing the initial testing of the tele-rehabilitation system's components for patients' biomedical monitoring over therapy, which support the delivery and monitoring of more personalized, engaging plans of care by rehabilitation centers and services.**

I. INTRODUCTION

Stroke is the second most common cause of death in Europe (EU Cardiovascular Disease statistics 2012) and it affects about 15 million people worldwide each year. Stroke survivors experience a broad range of problems that can impact their cognitive and motor systems, leading to chronic disability (e.g., hemiparesis) more often affecting the upper body (i.e., arms [1]). The goal of rehabilitation is to help survivors become as independent as possible and to attain the best possible quality of life. For over half of stroke patients, rehabilitation will be a long-term process requiring work supervised by therapists, supported by specialized equipment, lasting several months. Most persons with neurological disorders face this problem in receiving adequate intensity of therapy. However, increasing cost pressure on the healthcare system is leading to shorter periods of intensive rehabilitation at specialized facilities. Therefore the adoption of suitable technologies for in home rehabilitation, together with a proper training about the execution of a personalized program of exercises, can help reduce the patient's stay at the hospital, as well as the need and cost of reaching the rehabilitation facilities. In this work, we present early results from the REHAB@HOME European project where game-based, biomedical monitoring solutions for upper body rehabilitation were designed and tested in pilot studies conducted at two different rehabilitation centers, Fondazione Don Gnocchi Onlus (FDCGO, Italy) and Neurologische Therapiezentrum Gmundnerberg (NTGB, Austria).

Main innovative aspects of Rehab@Home project rely on:

- Simple low cost components.
- Tele monitoring of rehabilitation exercises and patient status by therapists and family.
- Plan of care adapted to each patient.

II. RELATED WORK

In the area of rehabilitation research and practice, there have been previous attempts to leverage on low cost gaming platforms, such as Wii [2] and PlayStation 2 EyeToy [3], to support therapy of neurological patients. However, these solutions are difficult to deploy with stroke patients in earlier stages of recovery when they have only limited range of motion and in more severely affected persons with other neurological disorders. For this type of patients, other more specific game-based solutions have been recently proposed. [4] and [5] developed haptic glove based games in which users scare away butterflies, play the piano, and squeeze virtual pistons to improve the player's finger flexion and extension. [6] built two webcam color tracked games similar to whack-a mole. In addition, they created a physics-based orange catching game and a whack-a-mouse game, both controlled with magnetic sensors and a vibraphone game, using a Wii remote as a pointing device. Game concepts and solutions more related to everyday tasks and activities of daily living have been explored to increase patients' motivation to play, by providing more meaningful settings. [7],[8] and [9] identified game design criteria that stem from stroke rehabilitation and elderly entertainment. [10] developed the Liftacube prototype for training of the upper extremities and tested it with four patients (affected by cerebrovascular accident or paraplegia) finding encouraging results and benefits regarding patients' motivation. In our work, instead of focusing on developing games for specific ranges of disability we aim to realize solutions that can be adapted for use by patients at different levels of recovery (a similar approach was proposed in [11]). By informing our design with requirements from therapists and patients, we have realize a rehabilitation platform enabling therapists to select and tailor games for individual patients' programs and for the subsequent remote monitoring.

III. BIOMEDICAL MONITORING OF PATIENTS

A. Patient Emotional Monitoring

The main objective of our project is to transform the patient's home in a place where physical and cognitive rehabilitation processes can be performed in a safe and comfortable way. The patient will not only be in contact with experts in the rehabilitation center providing guidance and feedback, but will also enjoy the participation in a sort of

*Research supported by EU Project REHAB@HOME N. 306113.

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978-1-4244-9270-1/15/$31.00 ©2015 IEEE

virtual gym, to increase inclusion and motivation. During the daily rehabilitation therapy, it is very important to monitor the emotional involvement of the patient, in order to properly inform the therapist on patients smooth progress with the plan of cares assigned [12][13].

Human engagement and emotions during therapy can be expressed through many channels such as facial expressions, voice, but also physiological responses like accelerations and decelerations of the heartbeat [14][15]. For this reason, the heart rate (HR) was chosen as a physiological signal to analyze and monitor relevant changes during different phases of a rehabilitation session [12]. Patient's heartbeat, with a pulse oximeter transmitting data via Bluetooth, was recorded and inter-beat was extracted from it. After saving a session's log, data are analyzed and processed with dedicated algorithms that extract the most important features. These data are also compared with game scores/data, to monitor progress with therapy and the involvement of the patient in the rehabilitation session [16].

B. Materials and Methods

Kinect Xbox 360 is a motion sensing input device by Microsoft, designed first for the Xbox 360 game console and then for Windows PCs. Based upon a RGB camera and a set of sensors it allows the user to interact with the gaming console or the PC by using only the body.

Figure 1: Kinect for Xbox 360 is linked to the PC through an adaptor for the USB port.

Pulse oximeter: this sensor is a classical fingertip pulse oximeter, but it has the advantage of transmitting data by Bluetooth. So the patient is not required to stay near the PC or the station that receives the signal. It provides oxygen saturation, pulse and inter beat value. Dedicated software was developed which enables to read and record the pulse signal.

Figure 2: Bluetooth pulse oximeter

C. Calibration

A personalized calibration needs to be conducted in order to get the normal range of biophysical parameters of each patient. This allows the bio-monitoring procedure to fit the characteristics of the patient and to avoid false alarms. The calibration procedure is expected to be carried out under the therapist control before a patient leaves the rehabilitation center. After the patient has worn the sensors, the calibration procedure is executed by going through three phases: a) patient is relaxed, b) patient normally active such as during a game session or its simulation, c) a few minutes after the game session is over. During the calibration phases, a patient's heartbeat is acquired by a sensor and saved to calculate the upper control limit by statistical methods to be applied in a control chart:

$$\text{Upper Control Limit (UCL)} = x_{mean} + 3\sigma \qquad (1)$$

The procedure is correctly completed if no problem occurred during the signal recording. The medical staff can evaluate the results and decide whether they are acceptable or not. The computed range will be stored and considered in all the subsequent phases of the rehabilitation at home.

D. Description of the rehabilitation set

The patient is sitting on a chair (without armrests) in front of a large screen and a Microsoft Kinect for Xbox 360, two meters away from the screen. Before starting the rehabilitation session, s/he wears the Bluetooth pulse oximeter on the second or third fingers of the non-rehabilitated hand, so as not to affect the signal. When the patient is ready, the calibration of the Kinect starts, and the range of movement is acquired for all the duration of the session.

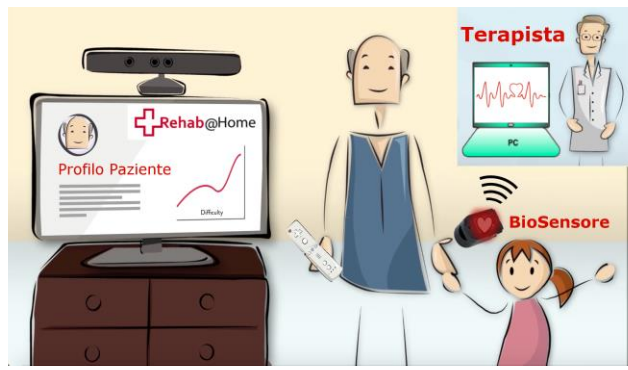

Figure 3: Example of the scenario of the patient's home during rehabilitation session.

E. Acquisition protocol

For the acquisition of the HR a standard protocol, divided into several parts, is set up.

The entire protocol takes place in the patient's home and has a duration, which varies according to the patient's needs and plan of care assigned. The session key rehabilitation phases are the following:

I. Patient at rest for 3 minutes. The signal is acquired only during the third minute.

II. Three minutes of relaxation in which the patient watches a video consisting of a series of images depicting relaxing landscapes, with a music in the background that reproduces sounds of nature.

III. Game session: the patient plays with Kinect games that have been developed by imaginary srl [19], following the plan of care assigned. The type of games played are:

a. *Bees and Flowers*: Patient has to touch flowers falling from the sky, and avoid the bees.

b. *Popping Flowers*: Patient has to touch the flowers (right items) and to avoid the bees (wrong items). Items appear all over the screen's area.

c. *Colored Cans:* Patient has to put the can located on the kitchen counter in the right compartment, matching the right color.

d. *Grab your can*: Like the game in c, but the patient has also to grab the can.

e. *Blackboard*: Shapes on the left side have to be moved to colored spots on the right side, by following a random path. Random pairings are proposed (e.g. star-blue, square-red). Red dots that appear along the path should be collected.

f. *Mad Fridge* [this game is played with the Leap Motion device] [21]: the fridge "throws" eggs (right items) and gear (wrong items). The objective is to collect the eggs with a basket and to avoid the gear.

IV. Patient stays three minutes at rest without doing anything.

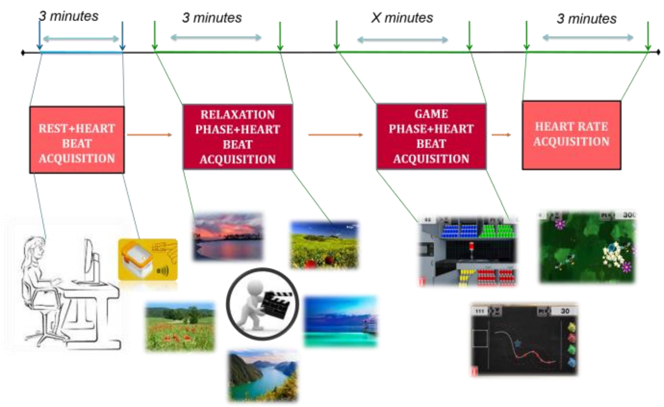

Figure 4: This figure explains the four steps of the protocol of the rehabilitation session

F. Data processing

Data are processed and analyzed with a Matlab program extracting the most significant features from the different phases of the rehabilitation session. The principal features extracted from the HR are:

- Average
- Standard deviation (σ^2)
- Maximum value
- Minimum value
- Difference between maximum and minimum value

From the game session, a report file is generated, including:

- Final score
- Score over time
- Spatial feedback
- Correct and incorrect items

For the rest phase, a linear regression is computed to extract the parameters related to the emotional and physiological condition of the patient. On the rest phase window, the straight line that best approximates the signal is computed and the following parameters were extracted:

- Angular coefficient: α
- Coefficient of determination: r^2
- Bravais-Pearson coefficient: r

G. Patients recruitment

Rehab@Home system is conceived for all those people who are affected by an impairment of the upper limb as hemiplegic, multiple sclerosis and Parkinson's patients.

To carry out the first trials of the prototype system it was decided to choose only the patients which will collect established scores in three screening test specially selected by the therapists.

The three tests chosen for the screening are:

- Beck's Fast Screening (Score<4)
- Mini Mental State Examination (Score>20)
- Active ROM (shoulder flexion>45°; elbow flexion>45°)

IV. Preliminary Testing Results

The system has been initially tested with four persons of respectively 84, 79, 49 and 66 years old, that all signed an informed consent form.

As it can be seen from Table I, the angular coefficient for all four participants is negative meaning that the rest phase was successful. The low values of the patient 3 and 4 point out that there was no significant changes during the relaxing phase. From the coefficient of determination, it is possible to see that the first two patients have good regression and fitting.

The results of the patient N.1 are shown in Table II. Analyzing standard deviation values, the higher one corresponds to the "Grab your Can" game, that, from patient's opinion and experience, appears to be the most tiring.

TABLE I. RESULTS OF THE REST PHASE FOR ALL PATIENTS

Subjects	Parameters		
	α	r^2	r
Patient 1	- 0.0273	0.7455	0.8634
Patient 2	- 0.0360	0.4936	0.7026
Patient 3	- 0.0090	0.0419	0.2046
Patient 4	- 0.0053	0.0697	0.2639

TABLE II. RESULTS OF THE FIRST PATIENT

Patient 1	Parameters				
	Average	σ^2	*MAX*	*MIN*	*MAX-MIN*
Bees and Flowers	86	1.3	89	84	5
Popping Flowers	88	1.2	91	85	6
Coloured Cans	87	1.1	89	85	4
Grab Your can	89	2.2	93	85	8
Blackboard	90	1.3	92	86	6

V. Other Monitoring Features

A Web prototype of the Therapist Client was developed during the project to enable therapists to supervise rehabilitation programs and progress of patients exercising at home over the long term. The prototype features implemented were based on results of the requirements elicitation phase conducted during the first year of the project. A pilot study was conducted to assess with therapists at FDCGO and NTGB if the implemented features of this client were appropriate and easy to use to support their work in the assignment and monitoring of plans of care. The main functionalities prototyped and evaluated during the pilot were:

- Login and Home screens to access the main features
- Tools for Communication with patients
- Patient search
- Plan of care assignment and review (including calendar)
- Graphic visualizations of patient progress over therapy
- Therapist profile information
- Access to catalogues of Games and Equipment

Prototype walkthrough and interviews were conducted with five therapists at FDCGO and NTGB to evaluate the prototype usability and effectiveness as a monitoring tool for clinics to support home rehabilitation of patients. The therapists involved had 1 to 6 years of work experience in the rehabilitation field. All of them were familiar with gaming platforms like Wii or Kinect, for private use or professional deployment.

A. Main feedback received from Therapists

Most of the therapists' comments and suggestions for improvement concerned the following features of the Therapist Client:

1) *Plan of care exercise assignment*: many suggestions were provided to improve the usability of the interface in setting options and parameters for plans of care. Therapists asked to have default values preset for parameters once they choose a certain level of difficulty of games, so as to speed up the completion and assignment of the rehabilitation program to patients.

2) *Communication with patients*: therapists liked the chance to receive preset notifications from patients, as well as the possibility of editing text messages to be sent to the Patient Station and displayed before the start of each rehabilitation session.

3) *Calendar:* all therapists agreed about having the possibility of adding notes to the calendar as reminders of specific issues with a patient plan of care.

4) *Games and Equipment Catalogs:* this feature was presented as a client section including videos and guidelines regarding device/games usage. All therapists found useful to have a catalog of games and devices where to find additional information on how to set up and use the REHAB@HOME solutions available.

5) *Visualization options for monitoring rehabilitation programs of patients:* different visualization options were presented to therapists to check their level of intuitiveness and usefulness to monitor progress of patient with the rehabilitation program. Therapists provided interesting feedback on each visualization proposed and helped the client designers to take future steps for the final implementation and deployment of these visualization in the final Therapist Client prototype.

VI. Conclusion and Future Work

The feedback collected from patients and therapists during the pilot studies presented has been fed into the final integration and implementation steps of our project. Over the summer 2015 the REHAB@HOME platform will be tested by means of a longitudinal trial involving 20 patients in Italy and Austria, using the system for at least 12 rehabilitation sessions. The qualitative and quantitative data collected during the trial will be analyzed to assess the quality of the final solution in terms of usability, patient motivation and compliance with the plans of care assigned, effectiveness of the realized solution for motor-cognitive rehabilitation of the upper body.

Acknowledgment

This work has been supported by the FP7 STREP Project REHAB@HOME N. 306113.

References

[1] Dobkin, B.H. (2005), Rehabilitation after Stroke. N Engl J Med, 352. 1677-1684 April 21, DOI: 10.1056/NEJMcp043511

[2] Deutsch, J.E. et al. 2008. Use of a low-cost, commercially available gaming console (Wii) for rehabilitation of an adolescent with cerebral palsy. *Physical Therapy*. 88, 10 (Oct. 2008), 1196-1207.

[3] Flynn, S. et al. 2007. Feasibility of using the Sony PlayStation 2 gaming platform for an individual poststroke: a case report. *Journal of Neurologic Physical Therapy: JNPT*. 31, 4 (Dec. 2007), 180-189.

[4] Huber, M. et al. 2008. PlayStation 3-based tele-rehabilitation for children with hemiplegia. (2008), 105-112.

[5] Jack, D. et al.,2001. Virtual reality-enhanced stroke rehabilitation. *Neural Sys. And Rehab. Engr., IEEE Trans. 9, 3 (Sep. 2001),* 308-318.

[6] Burke, J.W. et al. 2009. Serious Games for Upper Limb Rehabilitation Following Stroke. (2009), 103-110.

[7] Sanchez, R.J. et al. 2006. Automating Arm Movement Training Following Severe Stroke: Functional Exercises With Quantitative Feedback in a Gravity-Reduced Environment. *Neur. Sys. and Rehab. Engr.,* IEEE Tr. on. 14, 3 (2006), 378-389.

[8] Burke, J. et al. 2009. Optimising engagement for stroke rehabilitation using serious games. *The Visual Computer*. 25, 12 (2009), 1085-1099.

[9] Flores, E., Tobon, G., Cavallaro, E., Cavallaro, F.I., Perry, J. and Keller, T. (2008). Improving patient motivation in game development for motor deficit rehabilitation. Proceedings of the 2008 International Conference on Advances in Computer Entertainment Technology, Yokohama, Japan, 2008, 381-384.

[10] Vandermaesen, M. et al., 2013. Liftacube: a pervasive prototype for rehabilitation in a residential setting, In *Proceedings of The 6th International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '13)*.

[11] Alankus, G. 2011. Motion-Based Video Games for Stroke Rehabilitation with Reduced Compensatory Motions, Doctoral Dissertation, *Department of Computer Science and Engineering, Washington University in St. Louis*, 2011.

[12] Drachen, A., Nacke, L. E., Yannakakis, G., & Pedersen, A. L. (2010, July). Correlation between heart rate, electrodermal activity and player experience in first-person shooter games. In Proceedings of the 5th ACM SIGGRAPH Symposium on Video Games (pp. 49-54). ACM.

[13] Martinez, H. P., Jhala, A., & Yannakakis, G. N. (2009, September). Analyzing the impact of camera viewpoint on player psychophysiology. In Affective Computing and Intelligent Interaction and Workshops, 2009. ACII 2009. 3rd International Conference on (pp. 1-6). IEEE.

[14] Nacke, L. E., Kalyn, M., Lough, C., & Mandryk, R. L. (2011, May). Biofeedback game design: using direct and indirect physiological control to enhance game interaction. In Proceedings of the SIGCHI conference on human factors in computing systems (pp. 103-112). ACM.

[15] Nacke, L. E., & Lindley, C. A. (2010). Affective ludology, flow and immersion in a first-person shooter: Measurement of player experience. arXiv preprint arXiv:1004.0248.

[16] Nacke, L. (2009). Affective ludology: Scientific measurement of user experience in interactive entertainment.

[17] Mandryk, R. L., Inkpen, K. M., & Calvert, T. W. (2006). Using psychophysiological techniques to measure user experience with entertainment technologies. Behaviour & Information Technology, 25(2), 141-158.

[18] Gabrielli, S. et al. (2014)Designing a Game-Based Solution for In-Home Rehabilitation. Proc. Neurotechnix 2014. Rome, Italy, 2014.

[19] E. Ferrara, S. Nardotto, S. Ponte, SG. Dellepiane. (2014) Infrastructure for data management and user centered rehabilitation in Rehab@Home project. PETRA'14, May 27-30, 2014, Island of Rhodes, Greece. ISBN: 978-14503-2746-6 doi>10.1145/2674396.26744.

[20] Imaginary srl, www.i-maginary.it

[21] Leap Motion, www.leapmotion.com