Serious Game for Physical Rehabilitation: Measuring the Effectiveness of Virtual and Real Training Environments

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***Abstract*— Recent advances in low-cost natural user interfaces such as Microsoft Kinect and Leap Motion controller allow the Virtual Reality implementation of 3D serious games for, posture, upper limb and lower limb rehabilitation purposes. However, it is very important to compare the results obtained by the users that train in virtual and real environments. This paper presents a virtual reality serious game for upper limb rehabilitation using a natural user interface expressed by Leap Motion controller. One of the developed virtual reality serious game for rehabilitation is converted to a real scenario with the same elements and rules and the same aims of physical rehabilitation. In order to extract appropriate information from the serious game based on real objects a RFID technology was used together with software components developed in LabVIEW. The evaluation of hand muscles' activity during the training session is based on the usage of thermography that permits to measure in an unobtrusive way the distribution of the temperature on the hands' level. Based on analysis of thermographic images obtained before and after serious game practice, the level of activity of specific muscles associated with training for virtual and real scenario is extracted. Experimental results that are also included in the paper underline the effectiveness of the proposed method for the comparison of the training in virtual and real scenarios.**

***Keywords*—**natural user interface, leap motion controller, serious game, RFID, thermography

I. INTRODUCTION

The physical rehabilitation for the patients that suffered accidents or stroke events requires intensive intervention aimed at mainly improving motor abilities. Moreover, the periods associated with rehabilitation are usually long and the costs are expensive. One of the possible solutions to minimize these drawbacks is to perform remotely supervised self-training at home or to use system based supervised self-training at home. This last solution can contribute to reduce significantly the rehabilitation costs and also to shorten the time of rehabilitation processes. Self-training based on classical equipment's always requires the clinical professional supervision taking into account the usage of classical rehabilitation equipment that not deliver any information about the rehabilitation process. However in the last decade the healthcare community has been demonstrating a great interest for IT in physical rehabilitation that include the usage of serious games (Therapeutic games or "Theragames"). The concept of Serious Games refers to the use of computer games without the main purpose of providing pure entertainment [1]. Healthcare rehabilitation is emerging as a leading target area for serious games, presenting new patient, health caregiver, and public expectations [2]. Several Theragames based projects have appeared which shows a wide general interest in improving and sustaining this technology. Among the Theragames, the Exergames [3] are a form of physical activity that requires the user to move at least a part of the body, the hands in our case, in order to interact and get the best experience the game, usually in virtual reality (VR) scenario.

The core idea of VR-based rehabilitation is to use sensing devices to capture and quantitatively assess the movements of patients under treatment to track their progress more accurately [4]. Two of the sensing devices that can be also considered as natural user interface (NUI) [5] are the Microsoft Kinect sensor and the Leap Motion Controller [6]. Referring Kinect there are several implementations that use Microsoft Kinect to control the games, providing feedback to patients, and even as a measuring tool [7][8]. According to the experience of Chang et al [4] for example, that integration of VR technology with exergames provides more motivation and engagement to patients while they are in rehabilitation activities. Important experience in the serious game for the rehabilitation is reported by our team [9][10][11]. The metrics values and the generated reports associated with implemented serious game are very useful for rehabilitation outcome evaluation. Nevertheless, the question of the usage of VR scenario instead the real scenario made the physiotherapist to question the VR efficiency in rehabilitation. In this context the present work provide a serious game based solution for physical rehabilitation, while the same serious game is implemented for VR and real scenario. A set of technologies including Leap Motion 3D camera, RFID are used to interact with two scenarios together the medical infrared thermography that permit to extract information in unobtrusive mode about the skin temperature on the hand level. The present approach is based on the usage of a thermography camera that provides non-intrusive procedure to measure the temperature without physical contact with the patient. Referring physical therapy, it can be mentioned that during training the skin temperature increases due to an increase in the blood flow. Thus, the measurement of the skin temperature, before and after the training sessions based on serious games, can give important information regarding the training session effectiveness.

The paper is organized as follows: section two presents the proposed serious game in two type of implementation including the main elements of the developed hardware and software components; section three is dedicated to the thermography as a method to measure the skin temperature on the hand level; section four is dedicated to the uncertainty sources; section five includes preliminary experimental results and the last section, section six, draws the conclusions.

II. Serious Game for Physiotherapy Setup

The described serious game was developed for rehabilitation of the finger and hand motion and was designed and implemented for virtual reality (VR) scenario and for real scenario with real objects. In the case of VR scenario the interaction between the user under training and the game is performed using the Leap Motion natural user interface, while in the case of real scenario the user manipulates a set of colored cubes characterized by identification capabilities based on RFID technology.

A. Leap Motion Controller

The Leap Motion Controller (see Fig. 1) [12] can be connected to a computer using a USB cable. The heart of the device consists of two cameras and three infrared LEDs. This device can track the motion of both hands and all 10 fingers with up to 1/100 mm accuracy and no visible latency within its field of vision. The Leap Motion Controller's viewing range is 60 cm above the device and can reach 80 cm with the Orion beta software [13]

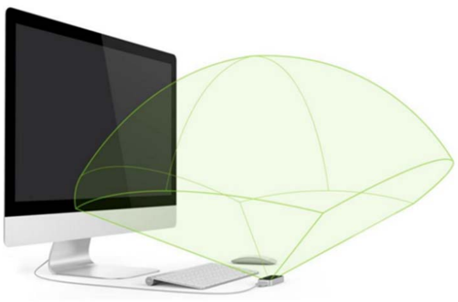

Fig. 1. Leap motion controller detection zone

This technology holds great promise for the rehabilitation field, since it does not require the patient to wear gloves (example, force glove feedback), which makes an important factor in patients who had gone through hand surgery. The device provides a new way to interact with user and the computer, with the ability to bring the real world to the digital domain.

B. Serious Game Setup: Virtual Reality Scenario

The game "Collect Color Cube" was developed by the authors using Unity and C# scripts the interface between the user and VR scenario is expressed by the Leap Motion controller connected by a computer that runs the VR serious game. The Leap Motion captures the movements of the user's hands and fingers, and represents them as part of the virtual game scenario for physical rehabilitation (Fig. 2). In the implemented serious game the goal is to place the colored cubes in the collecting box that presents the same color as the captured cubes in order to earn points. If the user associated the cubes with different color collecting box the player loses points. It has a certain established time and the boxes will change the color during the game. A common setup was 4s to 10s the period between color changes. At the same time the physiotherapist can impose the serious game duration according to the capabilities of the user under training.

The game has to be adaptable to the player needs to take better advantage of the gaming experience, to do so at the beginning of each game are set some parameters such as:

- Name;
- Age;
- Gender;
- What hands to use during the game (left, right, both);
- What is the rest time between two games?
- What is the duration of the game?

Depending on the parameters set, the game will adapt to the player, for example, along with Gender and Age will define how the hand will be represented during the game. A younger player will have a more robot aspect then an older player group. This group would have a closer representation of reality, and this representation is different in male and female genders.

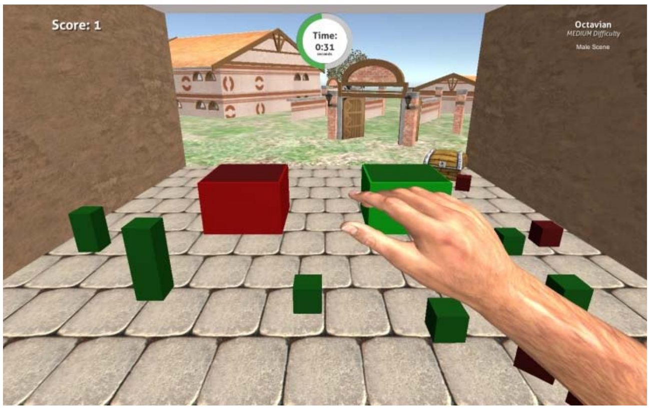

Fig. 2. "Collect Color Cube" Serious Game: Virtual Reality Scenario

C. Serious Game Setup in Real Scenario

The "Collect Color Cube" virtual reality serious game was translated into a real scenario where the virtual objects (cubes and boxes) are expressed by red and green cubes with RFID tags (125Hz disk tags) used for identification of individual cubes that can be red or green. The implemented technology may be used to extend the diversity of the object color in a next level of the implemented serious game. The cubes are disposed on a table and the user will catch and introduce in the red and green box the box color being signaled by red and green LEDs disposed on the box level (Fig. 3).

The color associated with boxes alternatively changes in order to impose the same challenges that characterize the virtual reality serious game. Thus in serious game real scenario from time to time (e.g. 5s time interval) the LEDs array are receiving the switch-on or switch-off commands from the LED driver that is a part of RFID LF reader unit (1024 Phidget Read-Write) characterized by 125kHz embedded antenna (Fig. 4).

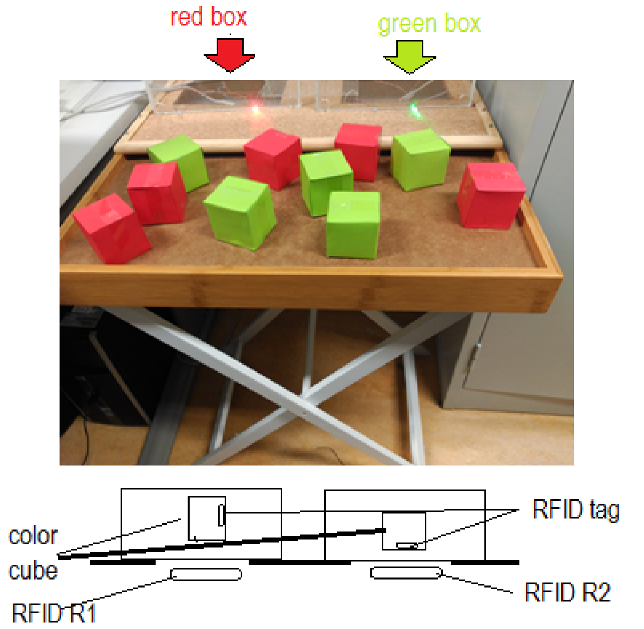

Fig. 3. Serious game setup for real scenario including 2 RFID readers associated with two boxes and RFID tags for each color cube

The PhidgetRFID supports the following protocols; EM4100, ISO11785 FDX-B, and PhidgetTag. The PhidgetTag protocol simply stores up to 24 ASCII characters to the tag, eliminating the necessity for a table of corresponding tag numbers and names.

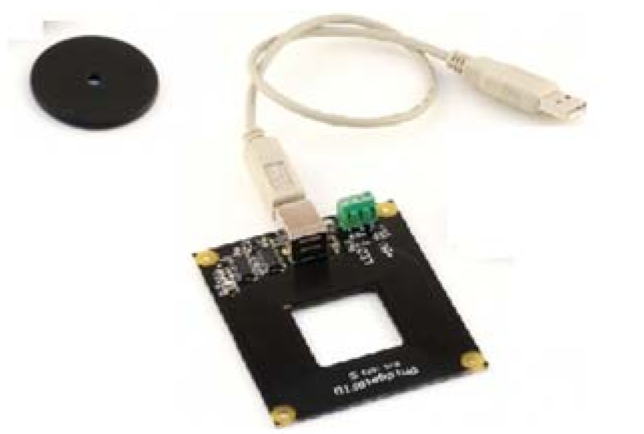

Fig. 4. LF RFID reader embedded in the box and LF tags embedded in the red and green color cubs for cubs ‘identification.

Taking into account that passive tags require a strong RF field to operate, their effective range is limited to a space volume in close proximity to the RFID reader (less than 7.5 cm). The distance over which the RFID tag is usable is affected by the orientation of the reader and tag in respect to each other. For this reason a freely motion, based on gravity, in the color cube can be assure less failure detection events of the cubes that are introduced by the user. Taking into account that the serious game implementation in real scenario implies limitations related with the number of objects and the game space, in the preliminary implementation of the game a set of 10 cubes (5 red and 5 green) were considered. Table 1 the RFID tags that were used for cubes identification. Table 1- Serious Game’ Cubes identification

No/	RED Cube Tag	GREEN Cube Tag
1	0107ee57be	0107ee579b
2	01068dbf16	0107ee66b2
3	0107ee5928	0107ee8bce
4	0107ee5691	0107ee56cf
5	01023c5297	0107ee8ca2

The control of the LEDs through the RFID LED driver and the RFID readers’ control (RFID R1, RFID R2 – Fig. 3) is carried out by a software developed in LabVIEW using RFID Phidget driver. The software GUI is presented in Fig.5 and is expressed by two TABs one for RFID Readers and LEDs control and one is associated with data storage and visualization.

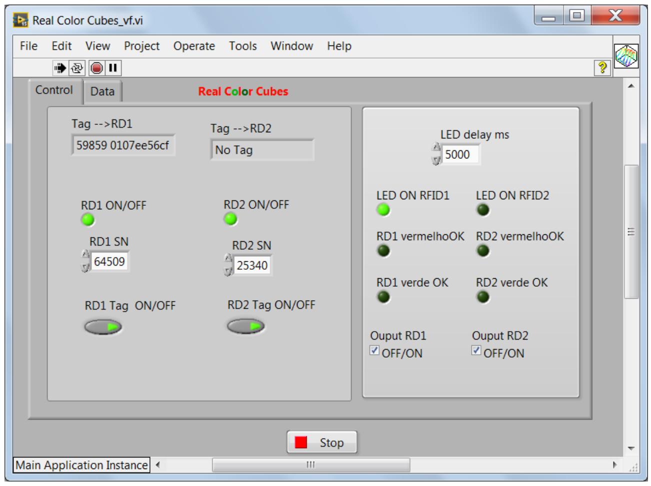

Fig. 5. Read Color Cubes – GUI including RFID reader controls and LEDs control associated with the implemented serious game for real scenario.

Similarly to the “Collect Color Cube” for virtual scenario, in the real scenario case a time delay between the “box color change” events was implemented, being this time interval defined by the physiotherapist in the serious game configuration phase. The values of “LED delay” control that appears on the GUI level were considered between 4s and 10s. Considering the LEDs color associated with the box and the cube color detected through the embedded RFID tag, the correct and incorrect actions of the user are signaled and stored in a file of training. The physiotherapist may perform an objective evaluation of the rehabilitation process creating new scenarios for the rehabilitation sessions by modifying cubes size, color, texture, weight, and can also perform modification for cognitive rehabilitation sessions [14].

The physical activity developed during serious game based physical rehabilitation can be evaluated in unobtrusive way using thermography.

III. THERMOGRAPHY

Thermography is a non-radiating and contact-free technology to monitor physiological functions related to skin temperature control that made this technology efficient in the case of muscular activity assessment during the rehabilitation period. One of the currently application of medical infrared thermography is for athletes that are exposed to physical stress during training that can originate “minor traumas”. Thus, the usage of medical infrared thermography can avoid injuries [15] and also make an evaluation of the rehabilitation program outcome through the evolution in time of the injuries’ region temperature [16].

The novelty of the present approach is related to the usage of thermography for unobtrusive evaluation of muscle activity during serious game. Thus a comparison between the user results obtained for a serious game performed in virtual scenario, or when the user perform the same serious game in real scenario. At the same time the evaluation of muscular activity, that originate variation of the temperature on the skin level, during successive sessions characterized by different duration is considered.

To evaluate the effectiveness of the training for specific *Theragames* a thermographic camera FLIR E60 is used to capture the skin thermographic images of the hand and finger regions that can be associated with the localization of the muscles that perform intensive activity during the considered serious game as the muscles that are presented in Fig. 6. Referring to the thermographic camera specifications it can provide 320x240 thermographic images for a frame rate of 60Hz. The thermographic sensitivity is better than 0.05ºC and the accuracy is 2% of reading for an extended measurement range between -20°C and 650°C.

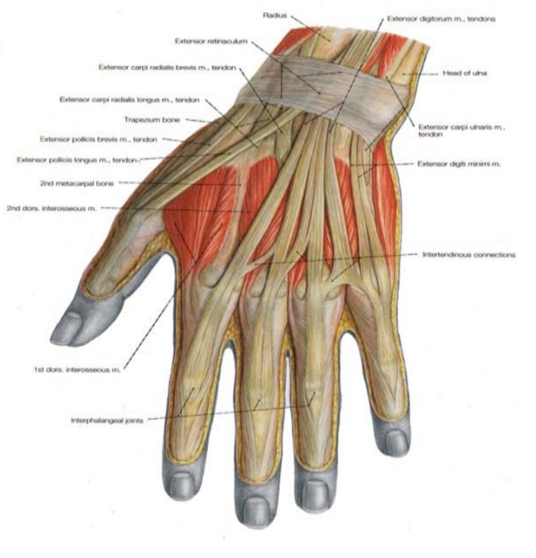

Fig. 6. Hand muscle that are used during the “Collect Color Cubes” serious game in VR and real scenario

Using the acquired thermographic images that provide information about skin temperature distribution caused by the muscle activity, o the temperature before and after training was extracted. The temperature measurement is based on the region selection of the thermographic image (Fig. 7). The temperatures for the selected region (minimum, maximum and average temperature) are obtained using the FLIR Tools+ thermography image analysis toolkit [17].

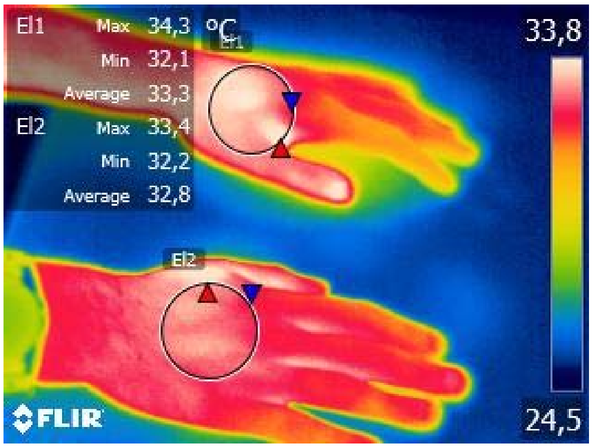

Fig. 7. Thermographic images associated with temperature distribution after 1 min game training using “Colored Cubes” serious game for virtual scenario.

IV. Uncertainty Sources

The usage, in the present work, of different technologies such as infrared emitters and detectors associated with Leap Motion Controller, RFID for real game objects identification and the thermography for unobtrusive measurement of hand skin temperature requires a discussion about the involved sources of uncertainties and about the possibilities to evaluate the uncertainties values.

The usage of RFID in real serious game cube identification implies the introducing in the system of uncertainties that are proper of this type of technology. One of the uncertainty sources is represented by tag-reader location. In the present case, the position of the LF RFID was established in order to assure optimal reading of the tags however the usage of a single RFID tag on the level of the cube made relative position tag – RFID reader antenna difficult to predict during the game. One of the solutions, and the cheaper one, is to use cubes with geometrical characteristics that made maximum distance between tag and reader antenna small enough for successful reading.

Referring to the thermographic camera that is essential for physical training effectiveness evaluation the sources of uncertainties according with FLIR thermographic camera manufacturer [18] are: emissivity, reflected ambient temperature, transmittance, atmosphere temperature, camera response and calibrator (blackbody) temperature accuracy. Taking into account the laboratory requirements to extract the quantitative values of all of the above mentioned sources of uncertainties in the present work was not considered this kind of approach, however the FLIR E60 calibration procedures was followed for the used thermographic camera in order to guarantee the specified accuracy values. At the same time for objective evaluation of real and virtual game effectiveness it is important to figure out the differences between the measured temperature for VR gaming scenario and for Real gaming scenario, and not the absolute values of temperatures for each of the considered cases.

V. Results and Discussions

Several laboratory testing sessions were carried out with a number of four volunteers: three males and one female to evaluate the performance of the serious games for virtual reality and real scenarios. The healthy volunteers were participated in two game training sessions. The first session was focused on the serious game characterized by the virtual reality scenario. The experimental procedure is essentially based on the temperature measurement of the hands' skin before and after the game session. The volunteers played sessions of 30s, 1min, 1.5min and 2 min and a set of thermographic images were acquired and off-line analyzed using the FLIR Tools+ and a circular temperature estimation region as it is presented in Fig. 7. At the same time in order to extract the correlation between game score, and effort expressed by intensive muscle activity the scores for each game session was stored and later analyzed. The evolution of the temperature on the hand skin level, before and after two minutes training based on serious game for virtual reality scenario, is presented in Fig. 8.

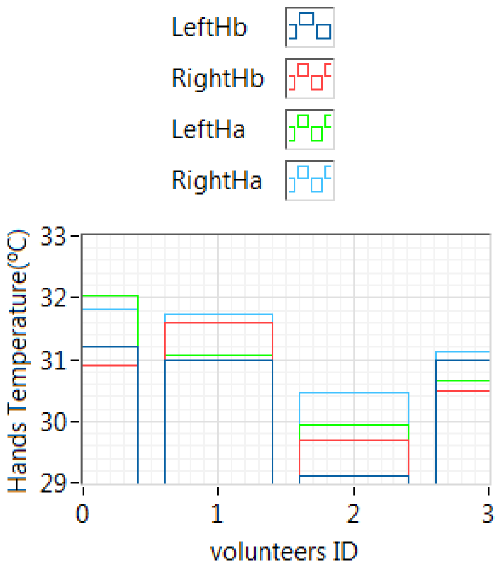

Fig. 8. Average temperature evolution of hand skin temperature before and after 2 min training

In Fig. 8 it can be observed that in some of the cases that the game practicing originates temperature variations on the level of hands' skin. However the number of tests and the fact that part of the user are using only one of their hand to catch red or green cubes and put in collecting box requires new additional tests that are running now with an extended number of participants. The relation between learning and game scores are represented in Fig. 9. It can be observed that some particular low performance was occurred for 1min training, while for 1.5min and 2min the players increase their performances according with their knowledge about this new game.

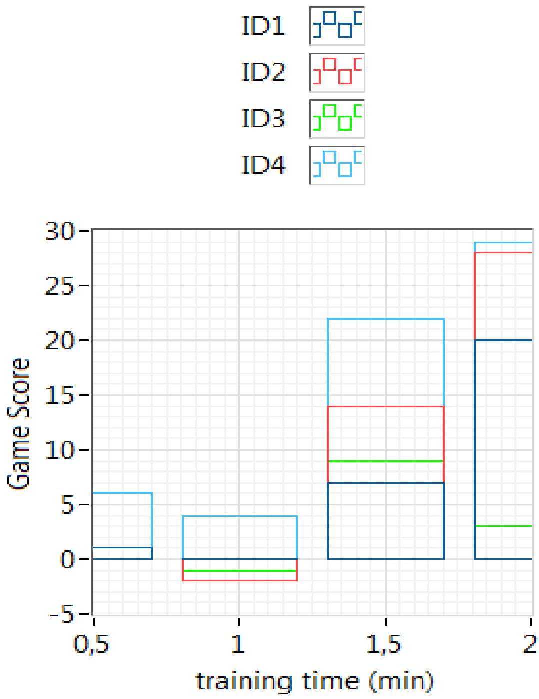

Fig. 9. Score Evolution for different training durations (IDi volunteer ID)

The comparison between the obtained scores by the participants when they are playing in virtual reality scenario or real scenario was carried out. The volunteers obtained better scores at the beginning on serious game in real scenario while latter the obtained scores are near each other (ID3 volunteer: 5 for 1min serious game for VR scenario, 3 for 1 min serious game for real scenario).

An important part of the serious game effectiveness evaluation was based on the comparison of the temperature variation on the hands' skin when the user performs the serious game for real and for virtual scenario. The tests represent an ongoing work involving an extended number of volunteers. The results obtained in one of the cased is presented in Fig. 10, where it can be observed that for real scenario the values of average temperature after 1 min playing time is in general higher than obtained for VR scenario. The reduced number of tests does not permit to decide about the type of serious game that is more appropriate for rehabilitation regarding the intensity of muscle activity.

VI. Conclusions

A serious game "Collect Color Cube" was designed and implemented for virtual reality scenario including virtual object and user hand avatar and for real scenario where the user interact directly with real objects. Important work was done regarding the serious game interaction based on Leap Motion considering the game personalization according to the patient needs.

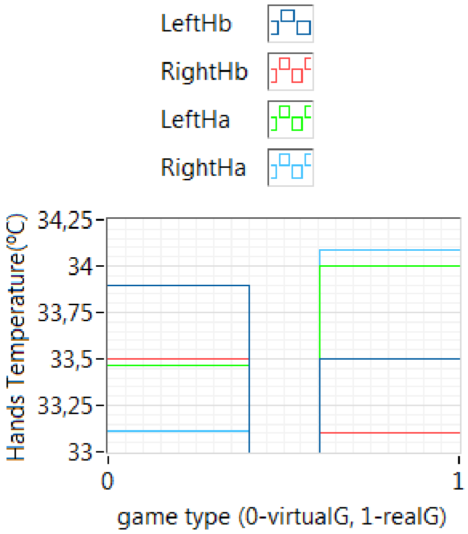

Fig. 10. Hand' Average temperature evolution for virtual training game and real training game (LeftHb, LeftHa- temperatures of left hand before and after training, RightHb, RightHa – temperatures of right hand after) for one volunteer

The serious game for real scenario was materialized using an innovative solution that permit the object identification and automatic recording of the number of cubes captured and collected on the boxes. Based on RFID technology and appropriate software, the same functionalities as for VR game were implemented. Thermography usage for unobtrusive evaluation of the muscle activity during serious game session proves to be one of the promissory solution taking into account that no contact with the user body is required. However, additional thermographic camera calibration concerns must be addressed taking into account the importance of temperature measurement accuracy before and after the game sessions. Future work involves additional tests with an extended number of users that are under rehabilitation processes. An extended approach concerning the sources of uncertainty that affect the system accuracy will be considered for the future developments..

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References

[1] Rego, P., Moreira, P.M., Reis, L.P., "Serious games for rehabilitation: A survey and a classification towards a taxonomy," Proc. 5th Iberian Conference on Information Systems and Technologies (CISTI), IEEE Press, New York, 1-6, 2010.
[2] Watters, C., Oore, S., Shepherd, M., Abouzied, A., Cox, A., Kellar, M., Kharrazi, H., Liu. F., Otley, A.," Extending the Use of Games in Health Care", Proc. of HICSS, 2006.
[3] Sinclair, J., Hingston, P., & Masek, M., "Considerations for the design of exergames," Proc. of the 5th international conference on Computer graphics and interactive techniques in Australia and Southeast Asia, 2007.
[4] Chang, C.-Y., Lange, B., Zhang, M., Koenig, S., Requejo, P., Somboon, N., Sawchuk, AA, Rizzo, AA, "Towards pervasive physical rehabilitation using Microsoft Kinect, Pervasive Computing Technologies for Healthcare (PervasiveHealth)," 2012 6th International Conference on, 21-24 May, 159-162, 2012.
[5] Madeira, R.N., Costa, L., Postolache, O., "PhysioMate - Pervasive physical rehabilitation based on NUI and gamification," Proc. 2014 International Conference and Exposition on Electrical and Power Engineering (EPE), 16-18 Oct., 612-616, 2014.
[6] Mapari Rajesh B, Kharat G., "Real time human pose recognition using leap motion sensor," IEEE International Conference on Research in Computational Intelligence and Communication Networks (ICRCICN), 2015.
[7] Clark, R.A., Pua, Y.-H., Bryant, A.L. and Hunt, M.A., "Validity of the Microsoft Kinect for providing lateral trunk lean feedback during gait retraining," Gait Posture, 38, 4, 1064–1066, 2013.
[8] Chang, Y.J., Chen, S.-F., Huang, J.-D., "A Kinect-based system for physical rehabilitation: A pilot study for young adults with motor disabilities," Research in Developmental Disabilities, 32 (6), 2566–2570, 2011.
[9] Postolache O., Girão P.M., Dias Pereira J. M., Postolache G., "Postural Balance Analysis using Force Platform for K-Theragame users," IEEE International Symp. on Medical Measurements and Applications - MeMeA, Benevento, Italy, Vol. 1, pp. 1 - 6, May, 2016.
[10] O. Postolache, "Physical Rehabilitation Assessment based on Smart Training Equipment and Mobile APPs," IEEE EMBS Romanian Chapter E-Health and Bioengineering Conference EHB, Iasi, Romania, Vol. 1, pp. 1 - 6, November, 2015.
[11] O. Postolache, F.C. Cary, N.D Duarte, P.M. Girão, "Physiotherapy Assessment based on Kinect and Mobile APPs," International Conf. on Information, Intelligence Systems and Applications - IISA, Corfu, Greece, Vol. 1, pp. 1 - 6, July, 2015.
[12] Colgan A, "How Does the Leap Motion Controller Work?" on-line at: http://blog.leapmotion.com/hardware-to-software-how-does-the-leap-motion-controller-work/, 2014.
[13] Leap Motion Developer, "Orion beta", on line at: https://developer.leapmotion.com/orion, 2016.
[14] Rocha R., Luís Paulo Reis, Paula Alexandra Rego, "Serious games for cognitive rehabilitation: Forms of interaction and social dimension," 10th Iberian Conference on Information Systems and Technologies (CISTI), 2015.
[15] B.B. Lahiri, S. Bagavathiappan, T. Jayakumar, John Philip, "Medical applications of infrared thermography: A review," Infrared Physics & Technology, Volume 55, Issue 4, July 2012, pp. 221–235.
[16] C. Hildebrandt, C. Raschner, K. Ammer, "An Overview of Recent Application of Medical Infrared Thermography in Sports Medicine in Austria," Sensors (Basel). Vol. 10, issue. 5, pp. 4700–4715, 2010.
[17] Flir, Flir Tools/ Tools+ User manual", https://www.ivytools.com/v/flir-manuals/software/flir-tools-manual.pdf, 2016.
[18] Flir, "Infrared Camera Accuracy and Uncertainty in Plain Language", on-line at: http://www.flir.com/science/blog/details/?ID=74935, 2017.