Haptic Stimulation Glove for Fine Motor Rehabilitation in Virtual Reality Environments

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Abstract. This paper presents a fine motor rehabilitation system for upper limbs by using a virtual reality environment. For this purpose, a glove of stimulating bilateral haptic is built, which allows directly to determine the finger's position through flexibility sensors. Also stimulate the medium and ulnar nerves of hand's palm by using vibratory actuators in charge of feedback to contact with virtual surfaces. This system is based on bilateral communication between the virtual environment in the Unity 3D graphics engine and the haptic glove. It is responsible for analyzing the movements used by the patient and interact with the Oculus Rift and Leap Motion for an increased immersion of the patient in the virtual rehabilitation environment. In addition, it generates vibrating feedback submitted to contact with virtual objects. The connection and transmission of data is done through wireless technologies in charge of creating a reliable and real time communication. The patient performs exercises based on fine motor rehabilitation which they are feedback with haptic glove and validated by algorithms based on Euclidean distance. The experimental results show the correct operation of the glove and the virtual environments oriented to virtual rehabilitation systems.

Keywords: Rehabilitation System, Haptic Glove, Virtual Reality.

1 Introduction

New Technologies have been integrated into the development of innovative systems that include different types of user interaction and control prototypes [1]. Haptic technology is positioned among the most representative tools. In industry Field this technology has participated in the creation of management and control systems in prototypes of teleoperated mobile robots [2,3]. Currently the haptic devices have an important role in medicine. Especially in the implementation of rehabilitation systems where the tactile sensitivity and movement are of great importance [4,5].

Different studies have determined that the inclusion of haptic devices improve the interaction with the user. Providing stimulation to the sense of touch by using force feedback [6,7]. This kind of system have been used together with virtual interfaces of high immersion for limbs strengthening and recovery of fine motor skills [8]. In the systems of virtual reality to rehabilitation have been integrated infrared cameras or optical tracking sensor. Whose purpose is to provide support in the recovery processes [9,10]. These types of components are integrated into different systems for handling them, through the analysis of signals obtained from the movement of hands [11,12]. For the development of complete platforms dedicated to rehabilitation is incorporate to these technologies the use of virtual reality glasses. These devices increase the immersion of virtual rehabilitation system [13].

Virtual reality represents a great support in the treatment for patients with motor problems [14,15]. Virtual environments become an attractive alternative in fine motor rehabilitation therapies. As well as providing a motivational system for the patient to continue with the treatment [16]. Therefore, new studies have been revealed for the creation of treatments through the use of multisensory and high interaction virtual environments, these studies have been of great benefit in the work of rehabilitation specialists. The haptic elements, optical tracking and virtual reality glasses have been incorporated into virtual reality in the treatment of motor problems, as a result, virtual reality is an excellent option by its high innovation and good rehabilitation technique [17,18].

The implementation of Haptic gloves stands out for its comfort and ease of use; through the integration of different sensors, haptic gloves participate in the development of multiple applications dedicated to fine motor rehabilitation. The signals provided by this type of system allow to analyze problems of coordination, weakness and muscular rigidity [13-19]. This tool has been included in friendly and immersive virtual environments, where the patient interacts in real physical therapy routines with adequate and repetitive exercises, these routines offer an effective recovery of their motor skills [20]. The development of haptic gloves for virtual rehabilitation increase the user's domain on this type of interfaces and increase the realism during the interaction [21,22].

Methods based on Virtual Reality provide high-impact rehabilitation systems, under clinical experience is possible to demonstrate that strength test and its feedback of upper limb-isolated muscles can be useful in the evaluation and recovery of an injury. For rehabilitation have focused mainly on motor rehabilitation through movements and stimulates which improves the processes of care [23], among the principles of rehabilitation should be supported in promoting repetition, task-oriented training, adequate feedback and an intuitive and patient-friendly environment [24].

Innovative studies present the development of haptic gloves that use different methods to generate tactile stimuli in user hands. A method is the use of motorized mechanisms to give movement to the joints of the hands. In addition, another prototype that has participated in the rehabilitation of the Stroke uses a system of compressed air to generate the movement sensation in the fingers. [25-26].

This work presents a rehabilitation system for loss of sensitivity and fine motor, through the construction of a haptic glove and interaction into a virtual reality environment. The system integrates virtual activities, which promote a new type of cognitive rehabilitation. Thus leaving the traditional processes of therapy with movements of object manipulation making clamp, hand extension and joints flexion. The sensory and data acquisition system is formed by bending gauges distributed in the phalanges and metacarpals as well as the main points of movement of the hand. In addition, the glove has vibrating actuators placed on the middle and ulnar nerves of the palm of the hand. These actuators are responsible for providing a stimulating vibratory feedback to contact with surfaces and virtual objects. The virtual interface is developed in the Unity 3d graphic engine. This interface allows the interaction of the glove with the patient to generate exercises based on skills and surface contact. Finally, communication is done through wireless technologies to obtain a real-time and ergonomic data management system.

This paper details the following developmental stages: Section II describes the structure of the rehabilitation system, the composition of the haptic glove for vibratory stimulation. The development of the virtual rehabilitation environment, multilayer diagram of the virtual environment is detailed in section III; section IV contains the results obtained in this work through the rehabilitation system in the virtual environment. Finally, section V details the conclusions obtained during the development.

2 Structure of the System

The purpose of the proposed system is to improve the fine motor rehabilitation. As well as generate vibratory stimulation to each of the upper extremity's fine engine regions, depending on the patient's interaction with the surfaces in the virtual environment. The system consists of an architecture consisting of two modules that show in structural form each of the steps and methods used for the rehabilitation session. Fig. 1, highlights each of the essential parts of the interaction process between the *interface module* and the *patient module*.

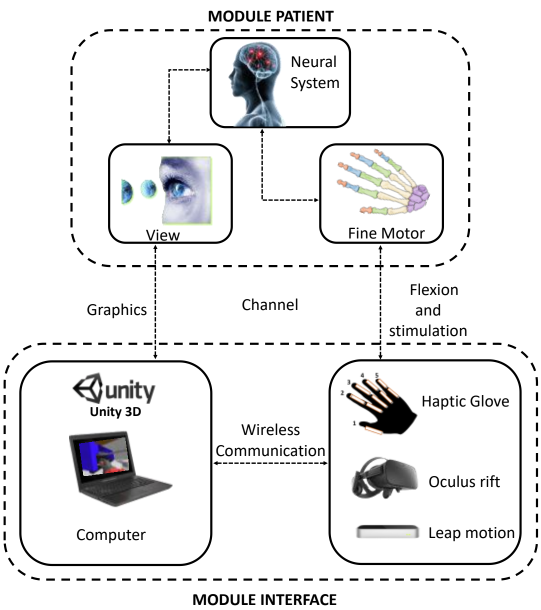


Fig. 1. System structure.

The communication process is developed in bidirectional form between two modules, the *interface module* and the *patient module*. These modules are constantly communicated to monitor the displacement and flexion of the phalanges, metacarpals of the hand. As well as generate feedback of haptic vibratory stimulation into the area of affection, generated by interacting with the virtual rehabilitation environment.

The *interface module* is comprised of two blocks: the computer is responsible for providing the rehabilitation virtual environment to the patient, simultaneously executing methods and algorithms of data processing to establish a relational logic between action and the reaction to each movement. The second element corresponding to the interface module is the haptic stimulation glove. This device is fundamental in the process due to it performs the sensing function of flexions of hand's fingers. In addition, it provides haptic vibratory feedback in specific points of glove surface that stimulate the middle and ulnar nerves of the hand; i.e. The glove is responsible for exercising haptic vibratory feedback and monitoring the flexions of fine motor within the system. Oculus Rift generates immersion into the virtual environment. On the other hand, Leap motion traces the hand's displacement that together with the flexion gauges placed into the glove. These gauges sense the fingers's flexion even when Leap motion presents singularity points, which it does not trace the hand, all together provides a greater immersion of the patient in virtual reality.

The *patient module* is formed by three blocks within the rehabilitation process. Vision is responsible for interpreting the virtual environment by recognizing the shapes, profiles and textures. Each one of the images perceived by the eyes are directly sent to the neural system which emits a logical meaning to the observed. As well as it establishes a motor action in the fine motor of the hand to manipulate and interact with the virtual environment. At the same time, this module has a vibratory stimulation feedback in the hand by using the glove. While the haptic glove has an ergonomic architecture between sensing and stimulation systems. It generates an easy-to-use system for patient.

The glove operation is comprised of three main stages, as shown in Fig. 2, each block interacts sequentially and in real time in order to sense the flexions and generate proportional vibrations to the stimulation.

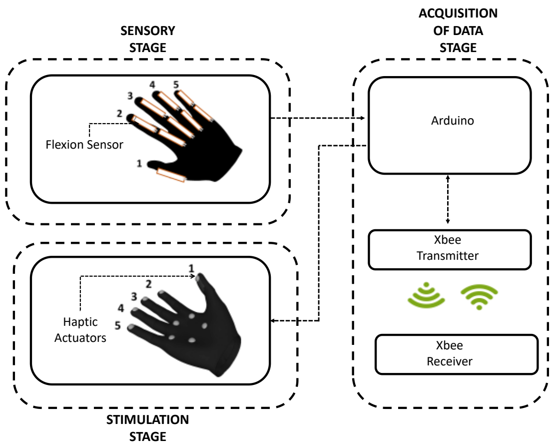


Fig. 2. Composition of the haptic glove.

Sensory Stage, the flexion sensing stage of the hand's phalanges and metacarpals is formed by nine flexion gauges located; Four flexion sensors between the medial and proximal phalanges in the fingers 2, 3, 4, 5 and five flexion sensors between the proximal and metacarpals phalanges in the fingers 1, 2, 3, 4, 5 of the hand, as shown in Fig. 3. Each one of the hand's fingers play an important role by its movement composition in each of the phalanges and metacarpals, flexion sensors are able to measure the level and flexion moment of the joints in each of the fingers.

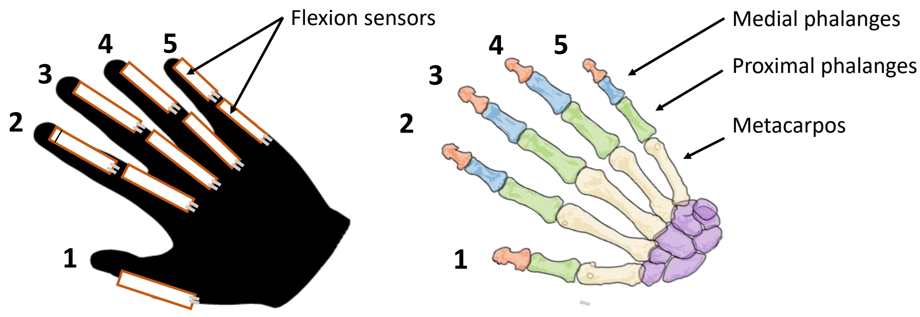


Fig. 3. Location of bending gauges in the glove.

Stimulation Stage, the stimulation stage is formed by ten vibratory actuators that generate haptic feedback by using vibratory stimuli proportional to the interaction of patient with the virtual rehabilitation environment. The vibratory actuators are distributed in the ten specific points of the glove that stimulate the median and ulnar nerves of the hand's palm. These nerves are attached to the brachial plexus which is a nerve network that is located at the base of the neck and connects the spinal cord with the peripheral nerves of the hand. This nerve transmits the information motor and sensory of the upper limb as shown in Fig. 4. Each one of the actuators is activated according to the exercise and/or interaction of the patient with the virtual environment receiving haptic vibration stimulation in these nerves. The vibratory actuators are important in the immersion in the virtual rehabilitation environment because their vibratory stimulus in each one of the zones produces concentric movements that give the sensation of touching objects in the virtual environment. Therefore, the glove generates immersion and interaction with the patient, its homogeneous structure and design transform it into an ergonomic system and comfort to use.

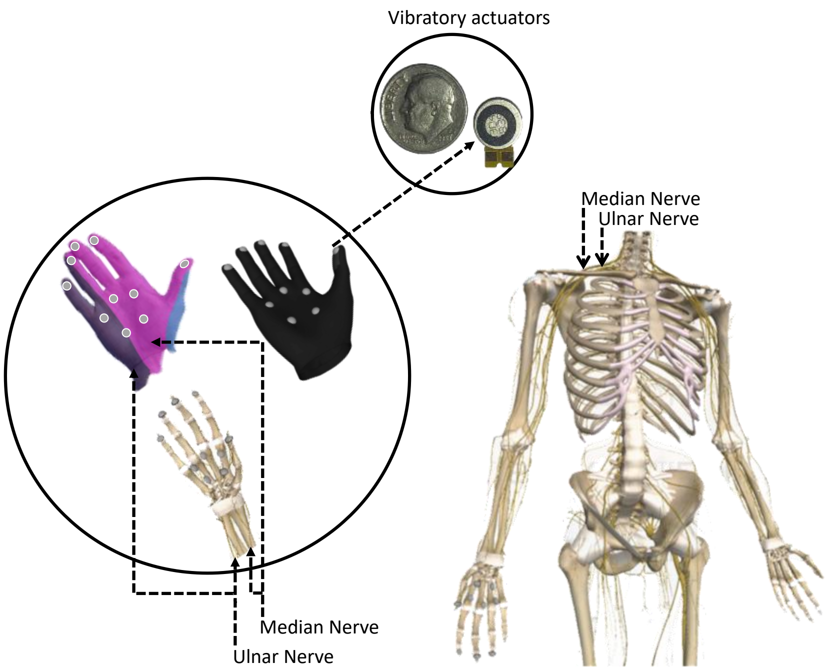


Fig. 4. Location of vibrating actuators and sensory stimulation in the nerves.

Data acquisition stage, finally, the communication between the virtual environment and the haptic glove is developed with the implementation of Xbee wireless technology which provides real-time data. As well as eliminates cabling and promotes an ergonomic and immersive system for the patient. This allows a better validation of behavior based on data processing protocols.

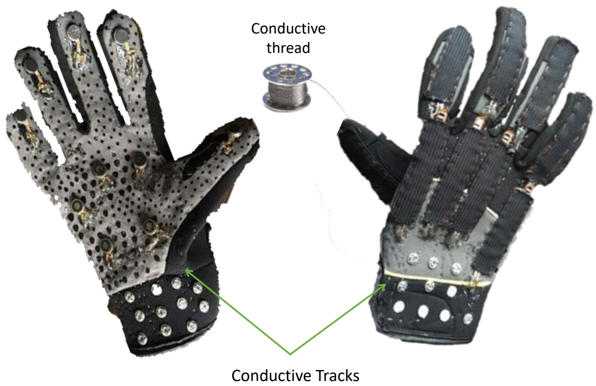


Fig. 5. Conductive tracks of the glove.

On the other hand, the glove presents conductive tracks to acquire the information of the gauges flexion and carry the electric impulses towards the vibratory actuators, by using conductive wire as shown in Fig. 5. The conductive thread facilitates the movement of the hand inside the glove and generates an ergonomic texture in the use of the glove on the part of the patient in the rehabilitation.

3 Virtual Environment with Stimuli Rehabilitation

The operative scheme of fine motor rehabilitation is developed as a 3D virtual reality application that consists of three stages: input and output; virtual environment and scripts, as shown in Fig. 6.

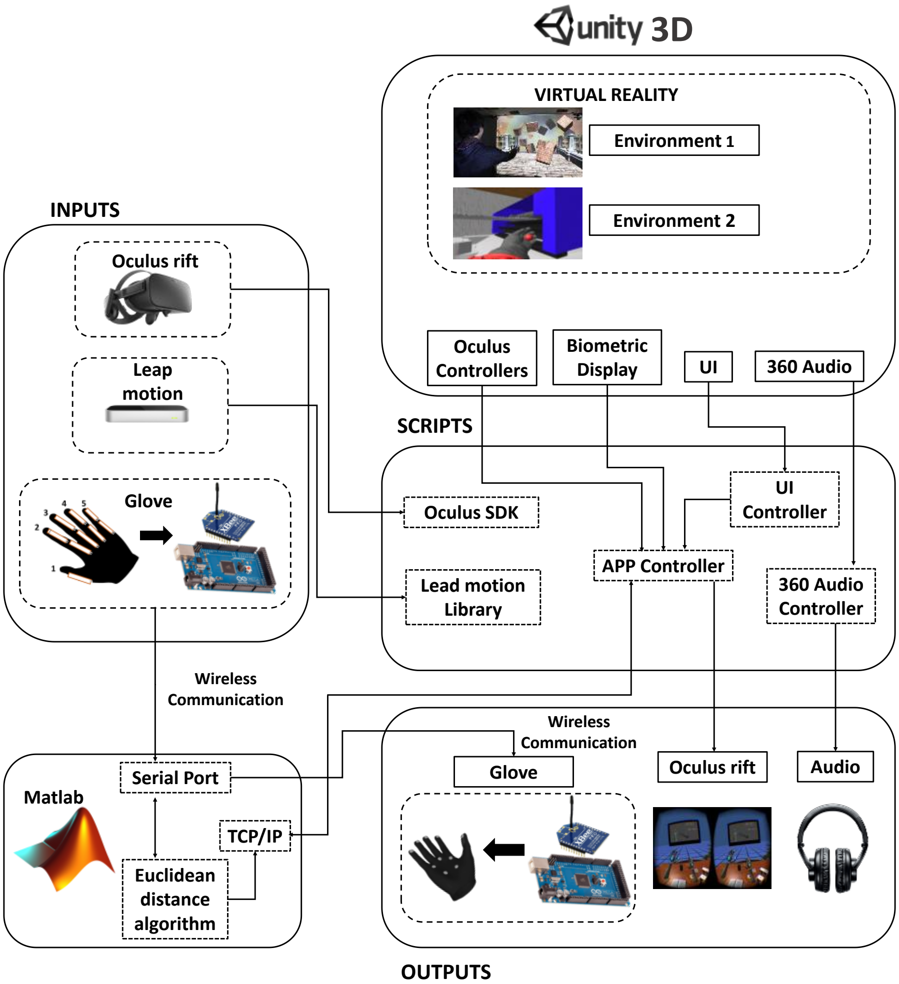


Fig. 6. Operative Scheme.

The *inputs* stage consists in bending the hand's fingers, the signals of the flexion gauges generate data see Fig. 7, that are acquired and processed in Matlab. Later transferred to Unity 3D through TCP/IP communication, the data of resistance variation are converted to digital through an ADC are interpreted as flexion angles of the fingers in the virtual environment to evaluate the movements of each one of the fingers. In addition to generate feedback and validate the exercise of rehabilitation by using the Euclidean distance algorithm.

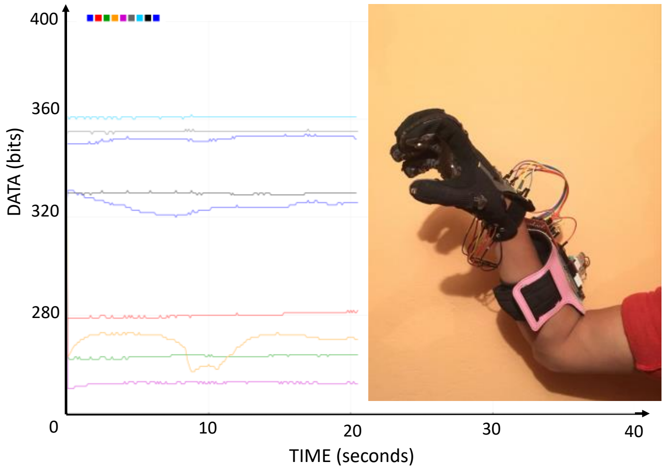


Fig. 7. Signs of flex gauges.

Each rehabilitation movement generates digital values of each bending gauge and is stored in a database, through Matlab evaluates the value of data stored in the database and compares it with the value of each finger flexion data in real time using the following equation:

$$D(F_a, F_r) = \sqrt{\sum_{i=1}^{9} (F_{ai} - F_{ri})^2} \quad (1)$$

where F_{ai} is the flexion of each one of the nine gauges stored in the database of each rehabilitation exercise and F_{ri} is the flexion of each gauge in real time. To finally interpret the Euclidean distance and evaluate it with what type of rehabilitation exercise the patient performed and save it in a *.txt* file to be sent to Unity as a response to the type of exercise and to perform the interaction with the patient.

At the stage of the *outputs* through the interaction of the hand with the virtual environment generates a haptic feedback to the glove. That generates vibrational stimulation in the hand's palm when interacting with the virtual environment in conjunction with Oculus Rift and 360 Audio Surround where the patient experiences greater immersion in the virtual environment.

In the *scripts* stage, communication with the input and output devices is implemented, so that the virtual environment performs the required functionality; The APP controller manages the hand movement and interaction with haptic feedback generating vibratory stimuli.

Finally, the *virtual environment* stage presents 3D environments, which are based on generating an immersion in the patient an immersion where the brain does not distinguish between the real and the virtual to perform the rehabilitation exercise. The haptic glove allows the interaction optimally with the virtual environment getting a greater immersion of the user. The functionality of the virtual rehabilitation environment is described through the multilayer scheme, see Fig. 8. This scheme describes the interaction between virtual environments, script and hardware; all the components that form this system are linking in an orderly manner. Its contents are presented as follows:

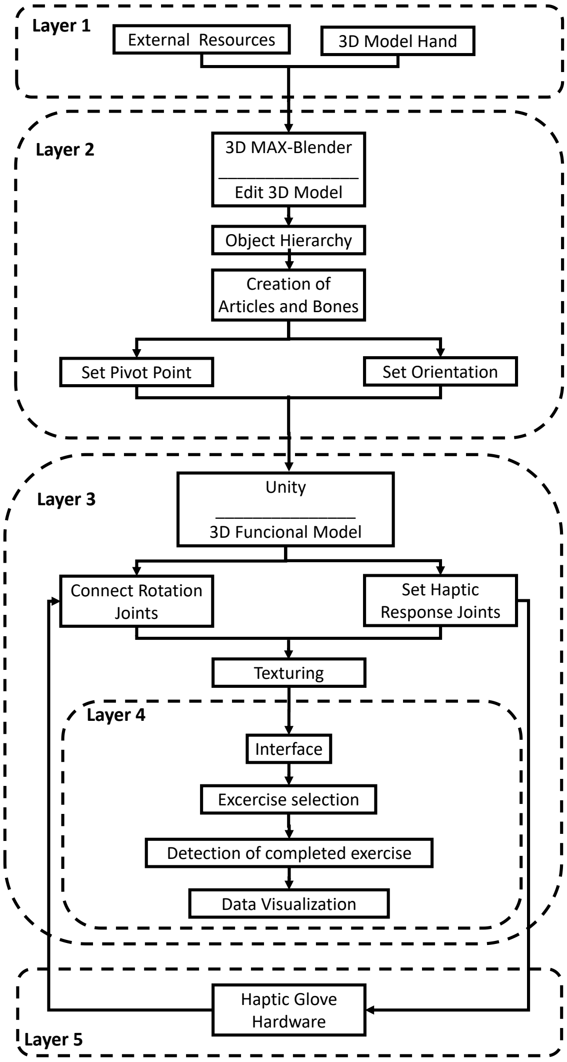


Fig. 8. Multi-layer diagram.

Layer 1. This layer defines the materials and resources needed to be used in the design process. For the resources selection was necessary criteria of design and planning for the elaboration of an effective recreational and multisensory system for fine motor rehabilitation. Among these materials you have: images, colors, audio, textures and basic figures, in addition, molds and hand templates were chosen with striking and real features, which will contribute to the creation of high quality virtual models.
Layer 2. This layer describes the process of 3d objects creation through specialized design software for modeling such as: 3Dmax and Blender among others. Virtual objects are built using selected resources from the previous layer, which are given shape and realism through mesh and texturing implementation. When the 3d hand model is implemented, it is necessary to create a set of bones and joints, with the motive of giving an adequate movement that overlap to the movement of a real hand. These elements will be strategically ordered with hierarchies and inheritances. Which allow much more realistic movements, finally the design is completed by placing all the bones and articulations created within the virtual hand model see Fig. 9.

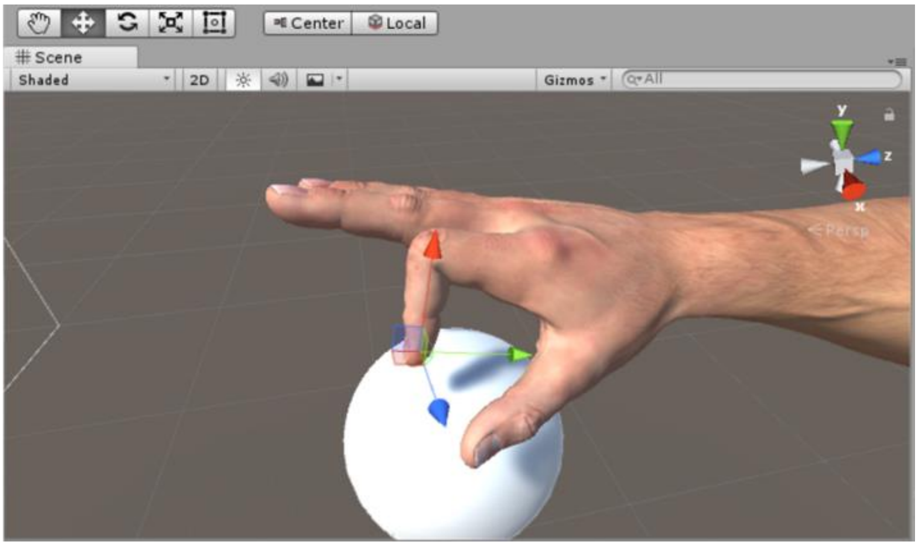


Fig. 9. Virtual Hand.

Layer 3. In this layer all virtual objects are imported into the Unity 3d graphic engine. This tool integrates all the elements created previously with the development and implementation of virtual environments. The graphical engine creates a new texture of virtual objects, which together with their movement show interactive scenarios, with high immersion and real-time functionality. In addition, in this process the virtual objects are linked with script components to give the operation mechanics and allow the interaction with the tasks presented during the rehabilitation sessions see Fig. 10. The main virtual element that participates in the execution of the tasks is the 3D hand model, which allows to interact with the proposed objectives and to carry out routines of rehabilitation exercises within a high immersion system.

Fig. 10. Game of Rehabilitation.

Layer 4. The layer indicates the relationship between script and interaction within the virtual environments by means of the interface, giving the functionality to the rehabilitation system. They run a script that allows the selection of routine of rehabilitation exercises. As well as manage the actions and information in real time within the application execution. In the development of the proposed tasks through scripts generates relevant information for therapies such as: number of successes and failures, the time to finish each task, and characteristic signals of the movements used in fine motor. All data generated in this process will be analyzed and evaluated by a specialist.

Layer 5. This layer links the main hardware component, the haptic glove, which performs a digital signals exchange, sending the hand real movements towards the virtual environment and receiving interaction in the form of haptic stimulation when activating the colliders while manipulating virtual objects. Through this interaction the system obtains a multisensory characteristic, this hardware component creates a feedback loop between the virtual environment and the sense of touch at levels of vibratory haptic stimulation, allowing the user to interact and feel real-time events occurring during the use of the rehabilitation system see Fig. 11.

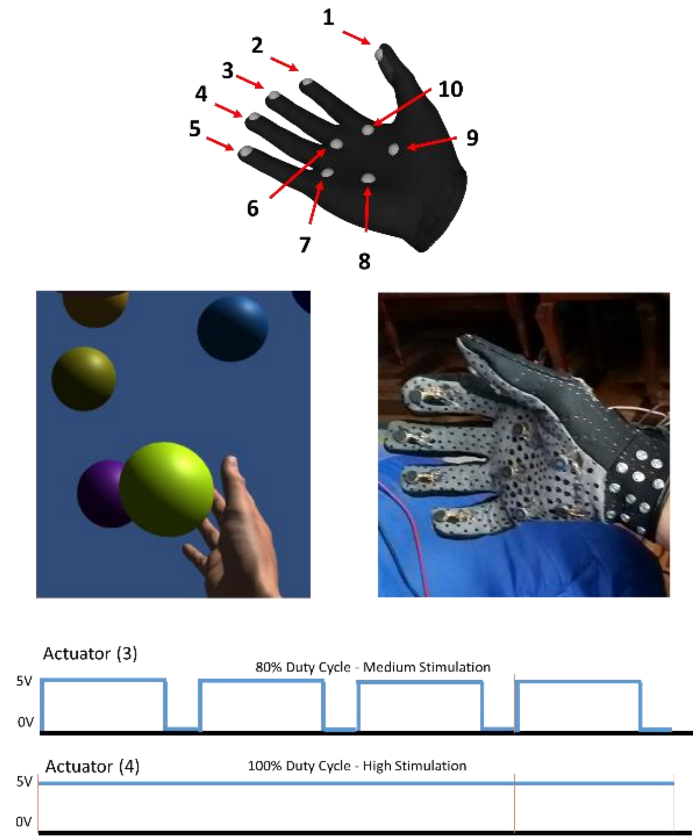


Fig. 11. Levels of vibratory stimulation, where the vibratory actuators 3 and 4 intervene when interacting with the virtual object.

4 Experimental Results

One of the relevant factors is that the patient, having tactile sensations of what he touches in the virtual rehabilitation environment, his tactile haptic feedback causes the nerves of the hand to begin to generate stimuli to the brain that helps in the rehabilitation since the problems of fine motor skills are caused by difficulties in coordination. Therefore, this section presents some of the results obtained from the virtual application developed, aimed at patient rehabilitation in order to exercise fine motor skills, sensitivity and coordination of movements according to the type of game selected. In Fig. 12, it shows the immersion of the patient in the virtual environment, to perform fine motor rehabilitation therapy. The applications performed stimulate the patient in a visual, tactile and auditory way allowing the interaction with the environment to be as real as possible, that is, the patient is immersed in animations, sounds and vibratory stimuli depending on the selected environment for which Oculus Rift, hearing aids and haptic glove are used.

Fig. 12. Virtual reality patient immersion.

As described in Fig. 13, shows the developed application consisting of a virtual menu with two games for the patient to select the environment according to the type of rehabilitation that he wishes to perform. It should be noted that in each of the virtual environments the control algorithm used (Euclidean distance) is considered, which allows a real-time response to the type of exercise performed by the patient based on the data processed from the gauges and treated in Matlab.

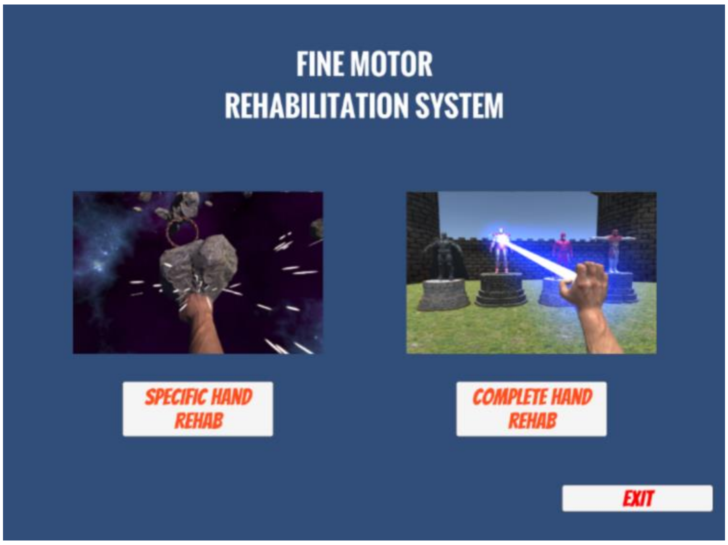
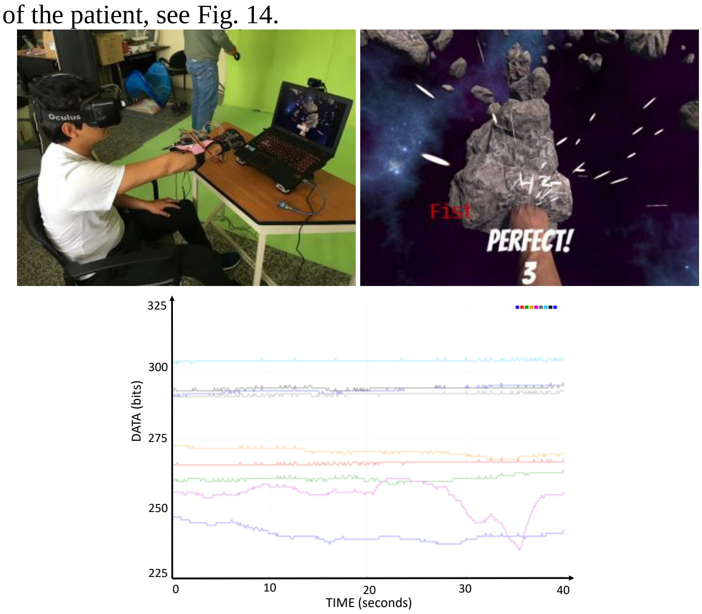
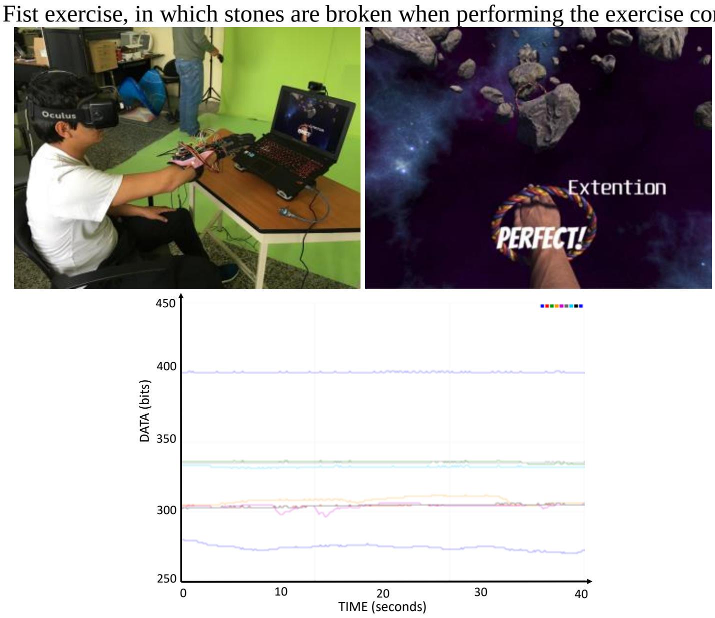


Fig. 13. Menú of virtual rehab.

The first game considers a virtual environment with the purpose of destroying stones and passing rings, the same ones that reach the patient in a direct and friendly way by means of which using the specific exercises fist and extension will validate the affection and ability of the patient, see Fig. 14.



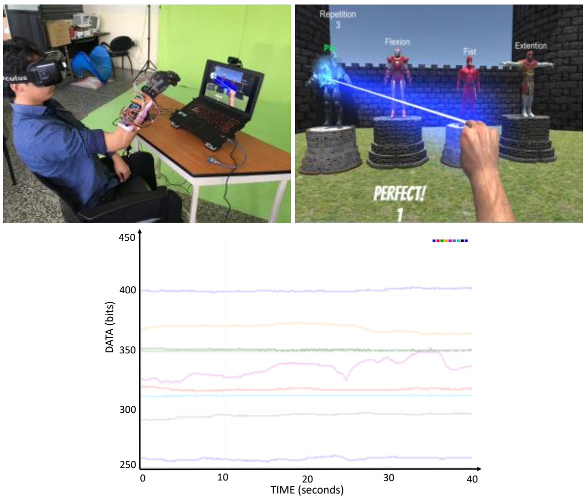
(a) Fist exercise, in which stones are broken when performing the exercise correctly.



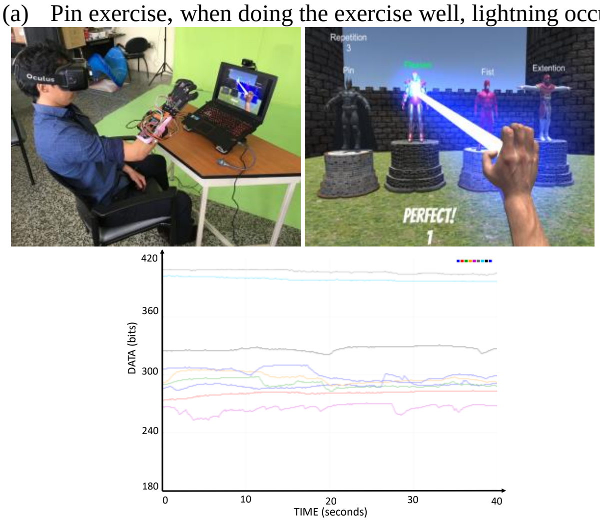
(b) Extension exercise, in which vibratory haptic vibration is received when passing the ring and doing the exercise correctly.

Fig. 14. Expecific hand rehab.

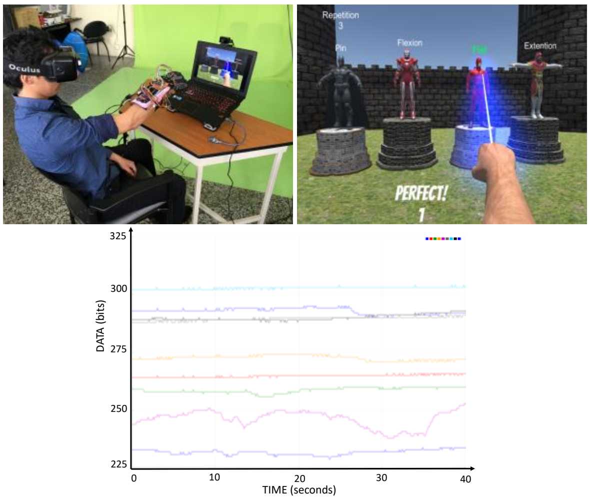
When the patient correctly performs the *fist exercise* see Fig. 14 (a), the stone explodes and all the actuators vibrate, so that the haptic glove stimulates the patient's hand, activating all the actuators according to the intensity of the impact (fist-stone); On the other hand, the hand *extension exercise*, see Fig. 14 (b), when performed correctly when the hand passes through the ring, the actuators of the haptic glove are activated sequentially with the hand passing through the ring.
In the second game it is oriented to the complete rehabilitation therapy, by means of repetition of the exercises of *grip*, *flexion*, *fist* and *extension*, when performing each of the exercises correctly, activate the laser that collides with the specific avatar with each exercise, activating the actuators of the haptic glove, to finally visualize in an indicator that the exercise of the therapy was performed correctly see Fig. 15.



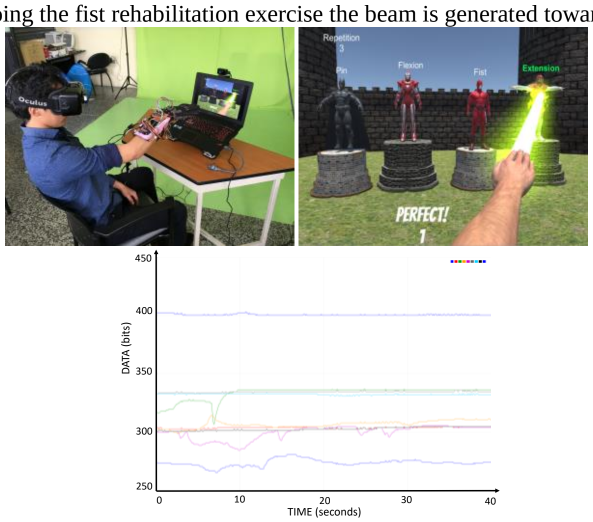
(a) Pin exercise, when doing the exercise well, lightning occurs.



(b) Flexion exercise, exercise is performed correctly and lightning is generated.



(c) When doing the fist rehabilitation exercise the beam is generated towards the avatar.



(d) Extension exercise, by doing it correctly the lightning occurs.

Fig. 15. Complete hand rehab.

The result of system usability is presented. Eight children between 10 and 23 years old completed the SEQ survey. The outcomes (56 ± 0.42) in Table I are according to [27]. If SEQ result is within a range of 40-65, the application is considered for rehabilitation. This result indicates that the virtual system has acceptance to be used in rehabilitation.

Table 1. SEQ Mean and Standard Deviation

Questions	Results (N=8)	
	Means	SD
Q1. How much did you enjoy your experience with the system?	4,63	0,48
Q2. How much did you sense to be in the environment of the system?	4,75	0,43
Q3. How successful were you in the system?	4,5	0,71
Q4. To what extent were you able to control the system?	3.5	0,71
Q5. How real is the virtual environment of the system?	3,88	0,78
Q6. Is the information provided by the system clear?	4,38	0,69
Q7. Did you feel discomfort during your experience with the system?	4,5	0,71
Q8. Did you experience dizziness or nausea during your practice with the system?	4,63	0,69
Q9. Did you experience eye discomfort during your practice with the system?	4,88	0,33
Q10. Did you feel confused or disoriented during your experience with the system?	4	0,71
Q11. Do you think that this system will be helpful for your rehabilitation?	4,13	0,59
Q12. Did you find the task difficult?	4,63	0,48
Q13. Did you find the devices of the system difficult to use?	3,63	0,69
GLOBAL SCORE(Total)	56	0,42

5 Conclusions

The results in the system of fine motor rehabilitation for extremities through virtual reality environments is an acceptable method for rehabilitation according to the SEQ survey with results (56 ± 0.42), the rehabilitation system shows good experience when interacting in virtual reality environments, which allow patients to overcome problems in the affected areas. The haptic stimulation provided by the vibratory actuators towards the hand generates a tactile response when we manipulate a virtual object, with the aim of creating an attraction and realism for the patient using intuitive graphic environments that allow the development of their sensitivity while the patient recovers from your condition.

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References

1. C. Ramírez-Fernández, A. L. Morán and E. García-Canseco: Haptic feedback in motor hand virtual therapy increases precision and generates less mental workload, In: 2015 9th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth), Istanbul, pp. 280-286 (2015).
2. J. H. Low et al.: Hybrid Tele-Manipulation System Using a Sensorized 3-D-Printed Soft Robotic Gripper and a Soft Fabric-Based Haptic Glove, in IEEE Robotics and Automation Letters, vol. 2, no. 2, pp. 880-887, (2017)
3. J. Li, M. Tavakoli and Q. Huang: Absolute Stability of Multi-DOF Multilateral Haptic Systems, in IEEE Transactions on Control Systems Technology, vol. 22, no. 6, pp. 2319-2328, (2014).
4. S. F. Atashzar, M. Shahbazi, O. Samotus, M. Tavakoli, M. S. Jog and R. V. Patel: Characterization of Upper-Limb Pathological Tremors: Application to Design of an Augmented Haptic Rehabilitation System, in IEEE Journal of Selected Topics in Signal Processing, vol. 10, no. 5, pp. 888-903, (2016).
5. T. T. Jiang, Z. Q. Qian, Y. Lin, Z. M. Bi, Y. F. Liu and W. J. Zhang: Analysis of virtual environment haptic robotic systems for a rehabilitation of post-stroke patients, in IEEE International Conference on Industrial Technology (ICIT), pp. 738-742.(2017)
6. F. Sanfilippo y K. Y. Pettersen: A sensor fusion wearable health-monitoring system with haptic feedback, In IEEE International Conference on Innovations in Information Technology (IIT), pp. 262-266, (2015).
7. M. A. Otaduy, A. Okamura y S. Subramanian: Haptic Technologies for Direct Touch ACM SIGGRAPH Courses, (2016).
8. M. Molinari, A. Esquenazi, A. A. Anastasi, R. K. Nielsen, O. Stoller, A. D'Andrea y M. B. Calatayud.: Rehabilitation Technologies Application in Stroke and Traumatic Brain Injury Patients, In Emerging Therapies in Neurorehabilitation II, pp. 29-64, (2015).
9. M. Iosa, G. Morone, A. Fusco, M. Castagnoli, F. R. Fusco, L. Pratesi y S. Paolucci: Leap motion controlled videogame-based therapy for rehabilitation of elderly patients with subacute stroke: a feasibility pilot study, In Topics in Stroke Rehabilitation, pp. 306-316, (2015).
10. M. Khademi, H. M. Hondori, A. McKenzie, L. Dodakian, C. V. Lopes y S. Cramer: Freehand interaction with leap motion controller for stroke rehabilitation. In CHI '14 Extended Abstracts on Human Factors in Computing Systems, pp. 1663-1668 , (2014).
11. V. Lahanas, C. Loukas, K. Georgiou, H. Lababidi y D. Al-Jaroudi.: Virtual reality-based assessment of basic laparoscopic skills using the Leap Motion controller, In Surgical Endoscopy, pp. 5012-5023, (2017).
12. N. Rodriguez,: Teaching Virtual Reality with Affordable Technologies, In HCI 2016: Human-Computer Interaction. Theory, Design, Development and Practice , pp. 89-97, (2016).
13. Mateo A. Parreño, Carmen J. Celi, Washington X. Quevedo, David Rivas, Víctor H. Andaluz.: Teaching-Learning of Basic Language of Signs through Didactic Games, In Proceedings of the 2017 9th International Conference on Education Technology and Computers, pp. 46-51, (2017).
14. D. E. Castillejos, J. Noguez, L. Neri, A. Magana y B. Benes,: A Review of Simulators with Haptic Devices for Medical Training, Journal of Medical Systems, (2016).

15. V. H. Andaluz, P. J. Salazar, M. Escudero, C. Bustamante, M. Silva, W. Quevedo, J. Sánchez, E. Espinosa y D. Rivas,: Virtual Reality Integration with Force Feedback in Upper Limb Rehabilitation, In International Symposium on Visual Computing, pp. 259-268, (2016).
16. C. Hatzfeld y T. A. Kern,: Motivation and Application of Haptic Systems, In Engineering Haptic Devices, pp. 3-28, (2014).
17. T. Garner,: Applications of Virtual Reality, In Echoes of Other Worlds: Sound In Virtual Reality, pp. 299-361, (2018).
18. B. Bonnechère,: Serious Games in Physical Rehabilitation: From Theory to Practice, Brussels: Springer, (2017).
19. M. Hoda, B. Hafidh and A. El Saddik,: Haptic glove for finger rehabilitation, In 2015 IEEE International Conference on Multimedia & Expo Workshops (ICMEW), Turin, (2015).
20. L. Connelly, Y. Jia, M. L. Toro, M. E. Stoykov, R. V. Kenyon and D. G. Kamper,: A Pneumatic Glove and Immersive Virtual Reality Environment for Hand Rehabilitative Training After Stroke, In IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 18, no. 5, pp. 551-559, (2010).
21. Z. MA and P. Ben-Tzvi,: RML Glove—An Exoskeleton Glove Mechanism With Haptics Feedback, In IEEE/ASME Transactions on Mechatronics, vol. 20, no. 2, pp. 641-652, (2015).
22. Andaluz V.H. et al.,: Training of Tannery Processes Throuhgh Virtual Reality, In: De Paolis L., Bourdot P., Mongelli A. (eds) Augmented Reality, Virtual, Virtual Reality, and Computer Graphics. AVR 2017. Lecture Notes I n Computer Scinece, vol 10324. Springer, (2017).
23. A. L. Fira, Mónica S. C., T. Paulino and S. B. i Badia,: The benefits of emotional stimuli in a virtual reality cognitive and motor rehabilitation task: Assessing the impact of positive, negative and neutral stimuli with stroke patients, In 2015 International Conference on Virtual Rehabilitation (ICVR), pp. 65-71. (2015).
24. L. E. Sucar, F. Orihuela-Espina, R. L. Velázquez, D. J. Reinkensmeyer, R. Leder, J. Hernández-Franco,: Gesture Therapy: Una Plataforma de Rehabilitación Motora de Base de Realidad Virtual, In IEEE Transactions on Neural Systems and Rehabilitation Engineering, vol. 22, no. 3, pp. 634-643. (2014).
25. P. Polygerinos, L. Stacey,W. Zheng, L.F. Nicolini,: Towards a Soft Pneumatic Glove for Hand Rehabilitation, In IEEE Intelligent Robots and Systems, pp. 1512-1517. (2013).
26. F. Yili, Z. Qinchao,Z. Fuhai, G Zengkang,: Design and Development of a Hand Rehabilitation Robot for Patient-cooperative Therapy Following Stroke, In IEEE International Conference on Mechatronics and Automation, pp. 112-117. (2011).
27. J. A. Gil-Gómez, H. Gil-Gómez, J. A. Lozano-Quilis, P. Manzano-Hernández, S. Albiol-Pérez and C. Aula-Valero, "SEQ: Suitability Evaluation Questionnaire for Virtual Rehabilitation systems. Application in a Virtual Rehabilitation system for Balance Rehabilitation," 2013 7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops, Venice, pp. 335-338. (2013).