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Integration of emerging motion capture technologies and videogames for human upper-limb telerehabilitation: A systematic review

Mauro Callejas-Cuervo [a], Gloria M. Díaz [b] & Andrés Felipe Ruíz-Olaya [c]

[a] *Facultad de Ingeniería, Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia. mauro.callejas@uptc.edu.co*
[b] *Facultad de Ingeniería de Sistemas, Universidad Antonio Nariño, Bogotá, Colombia. gmdiazca@uan.edu.co*
[c] *Facultad de Ingeniería Electrónica y Biomédica, Universidad Antonio Nariño, Bogotá, Colombia. andresru@uan.edu.co*

Received: February 14th, 2014. Received in revised form: June 10th, 2014. Accepted: July 11th, 2014.

Abstract
Integrating emerging technologies has shown to have the potential to improve access to rehabilitation services and the adherence for physical therapy when they are applied into telemedicine environments. This systematic review aims to explore telerehabilitation systems that use motion capture and video games for upper-limb rehabilitation purposes. Motion capture was focused on the information fusion from inertial sensors and other technologies. The search was limited to 2010-2013, from which 667 papers were obtained; afterwards, duplicate papers were removed, thus, reducing the sample to 57 papers with full text availability. Finally, only 3 of them were selected by approaching the subject of this study. We conclude that the fusion information from inertial sensors and other motion capture technologies appears to be a new tendency in remote monitoring of motor rehabilitation process. However, the combination of them with active video games in physiotherapy programs is only an emerging research area with promising results.

Keywords: telerehabilitation or tele-rehabilitation, markerless motion capture, inertial sensors, active videogames, upper limbs, systematic review

Integración de tecnologías emergentes de captura de movimiento y videojuegos para la telerehabilitación de miembro superior: Una revisión sistemática

Resumen
La integración de nuevas tecnologías ha mostrado tener el potencial de mejorar el acceso a servicios de rehabilitación y la adherencia de los pacientes a la terapia física cuando éstas son usadas en servicios bajo la modalidad de telemedicina. Esta revisión sistemática busca explorar sistemas de telerehabilitación que usan nuevas tecnologías de captura de movimiento y video juegos para rehabilitación de miembro superior, haciendo énfasis en la captura de movimiento que fusiona información de sensores inerciales y otras tecnologías. La búsqueda fue realizada entre 2010 y 2013, encontrando 667 artículos; que se redujeron a 57 artículos con texto completo, luego de un proceso de remoción de artículos repetidos. Finalmente, solo tres de ellos fueron seleccionados por abordar el tema de este estudio. Esta revisión nos permite concluir que se presenta una tendencia en usar la fusión de información proveniente de sensores inerciales y otras tecnologías de captura de movimiento para monitorear procesos de rehabilitación motora. Sin embargo, la integración de estas tecnologías con video juegos activos en programas de fisioterapia es apenas un campo emergente de investigación con resultados prometedores.

Palabras clave: telerehabilitación o tele-rehabilitación, captura de movimiento sin marcadores, sensores inerciales, videojuegos activos, miembros superiores, revisión sistemática.

1. Introduction

Telemedicine can be defined as the provision of long distance medical services by using information and communications technologies [1]. Telemedicine includes medical consultations via telephone, monitoring, diagnosis, analysis and risk control, as well as remote execution of medical procedures. This allows the use of technological resources as a communication means to provide health services from specialized therapists to people living in distant zones and who lack medical assistance from those specialists [2,3]. Telerehabilitation is subsumed into this discipline. It offers long distance rehabilitation services by using technological tools [4]. Nowadays, telerehabilitation has become a research focus due to emerging technologies such as inertial sensors, mechanisms of optical motion capture with and without marker, robots, among others. These technologies allow achieving rehabilitation from the patient's location, and transmitting the results from there to the specialized medical center, saving time and money and increasing patient's comfort by reaching their recovery in their homes.

On the other hand, computer games have been recognized as a motivational tool in rehabilitation, which increase the patient interest in performing intensive training tasks that are considered repetitive and boring by them. They also distract the patient's attention, by which can be used to aid in the management of pain [5].

Given the advantages of these emerging technologies is obvious to assume that their integration could help improve the results of home rehabilitation processes. The current study was designed to explore the available evidence on the trending of developing telerehabilitation systems using emerging motion capture technologies and videogames by undertaking a systematic review of scientific papers published between January 2010 and June 2013, reporting progress in the use of the above-mentioned technologies, which assist upper limb rehabilitation services for people suffering different pathologies.

2. Method

The process of selection and analysis of the scientific literature aimed by this study is described below:

2.1. *Selection Criteria*

Firstly, papers reporting technology incorporation in the distance physical rehabilitation process (telerehabilitation or tele-rehabilitation) between 2010 and 2013 were selected. Then, publications reporting combination of sensors and other technologies such as videocameras, virtual reality helmets, infrared cameras, and other types of optical motion capture with or without indicators, were taken into account. Afterwards, papers reporting rehabilitation focused on upper limbs of the human body, with full text availability were selected. Finally, works reporting rehabilitation by using videogames were selected.

2.2. *Search Strategy*

A search of publications was conducted on PubMed (236 publications), Scopus (479), Embase (249), ScienceDirect (254), IEEE Xplore Digital Library (118), EBSCO- Medline (230), ISI Web of Knowledge (311). This search was related to the term "telerehabilitation or tele-rehabilitation". Then the search was limited to 2010-2013, and it was limited to the presence of the word in the title, abstract and keywords.

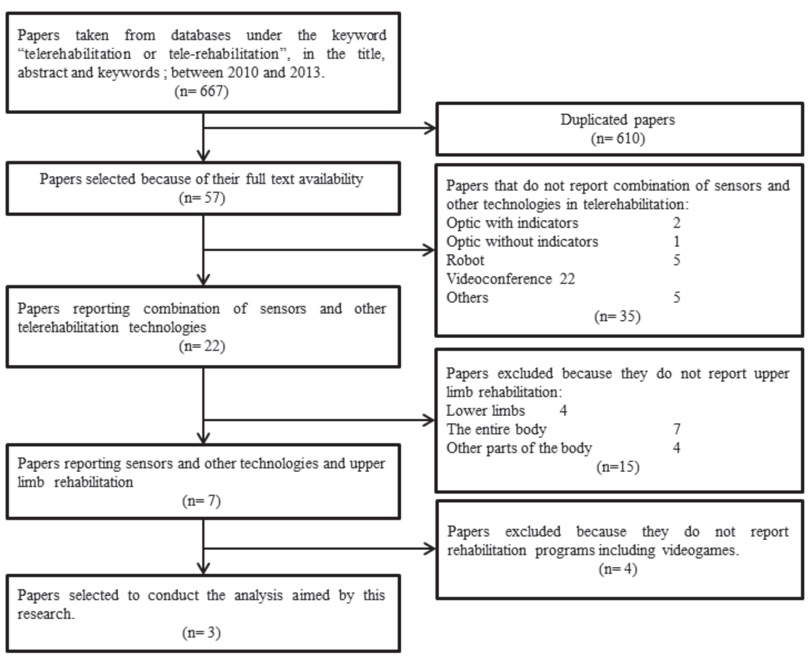

Figure 1. Study selection flow for the analysis aimed by this research.
Source: The authors.

2.3. *Study Selection*

1877 scientific papers published between 1998 and June 2013 were found, which contained the term: "*telerehabilitation* or *tele-rehabilitation*". Then the search was limited to 2010-2013, since it was in this period of time that the latest advances regarding the inclusion of motion capture technologies were reported. A search was conducted with the same term in the title, abstract and keywords; from this, 667 papers were obtained. Afterwards, duplicated papers were removed, reducing the sample to 57 papers with full text availability. Then, by using Mendeley reference manager tool, the papers were classified according with the technological tools used in the rehabilitation process, and a complete analysis of the literature was carried out, grouped by the technology type used. Finally, the sample was reduced to 3 publications dealing with the subject of this study. The procedure of literature inclusion and exclusion is shown in Fig. 1.

2.4. Data Analysis

The search of publications was conducted from the need of establishing a state of the art of the telerehabilitation process based on the combination of inertial sensors and optical motion capture, resulting from a Ph. D. thesis research.

The first search was made without restriction using the term telerehabilitation or tele-rehabilitation, obtaining the results recorded in the previous section of this paper. Afterwards, an analysis was done on the technologies used, classified as follows: 5.26% was optic capture with or without indicators; 38.60%, videoconferences; 8.77%, robots, and 8.77%, other type of technology. On the other hand, 29.82% uses technology to rehabilitate upper limbs, and 70.18% use it to rehabilitate other body areas. Finally, it was found that 5.26% of the recorded works in the mentioned databases approach upper limb rehabilitation development by combining the use of inertial sensors and other technologies (videocameras, virtual reality helmets, infrared cameras and other types of capture with or without indicators) and apply videogames in their rehabilitation programs.

3. Results

From a total of 57 publications referenced in this paper, 2 report using optical motion capture with indicators [6,7]; 1 uses optical capture without indicators[8]; 5 report using other technologies (internet, telephone, platforms' proposals[9-13]) in the process; 5 use robots[14-18]; 22 report remote assistance to the rehabilitation process by combining sensors and other technologies[19-40]; and finally, 22 use videoconference assistance[41-62]. These technologies have been used for rehabilitation of different parts of the human body, as it is shown in Table 1.

Table 1.
Publications reporting the use of technology in the rehabilitation of different parts of the body.

Technology type	Number of publications between 2010 and 2013	Upper limb	Lower limb	Other parts of the body
Optic with indicators	2	0	1	1
Optic without indicators	1	1	0	0
Others	5	1	0	4
Robot	5	4	0	1
Sensors and other technologies	22	7	4	11
Video-conference	22	4	8	10
TOTAL	57	17	13	27

Source: The authors.

On the other hand, this analysis includes three studies combining sensors and other technologies in the distance rehabilitation process of the upper limbs of the human body, using videogames in the rehabilitation program development [34,35,38].

3.1. Studies Description

Golomb's study[34] introduces the development of a videogame platform designed with virtual reality, which enables the rehabilitation of teenagers affected by cerebral palsy. It searches to improve hand motion function and the consistency of forearm's bones. This platform is composed by three subsystems: the first one manages the videogame, the second one captures the patient's movement, and the third one visualizes the virtual environment of the game. Three teenager patients suffering from spastic hemiplegia (a 13 year-old boy, a 15 year-old boy and a 15 year-old girl) took part in this research's proof of concept. The initial test was conducted one week before starting the videogames exercises; then, videogames were set up in the patients' homes in order to develop rehabilitation activities, which lasted between 84 and 90 days and, finally, the follow-up evaluations were conducted. Observations made during this experiment identified some technical difficulties such as: TV sets' dysfunctional operation, defective internet connections and software failures, which were later all corrected. On average, patients interacted with videogames between 20 and 22 minutes per day during 60 days for the 13 year-old boy, 67 days for the 15 year-old boy, and 36 days for the girl. The patient who practiced 36 days abandoned the telerehabilitation process due to the many technical problems experienced.

Among the main results reported in this study, it was found that all of the three participants showed an improvement in the adhesion rehabilitation test and the Jebsen's test [63], including a higher ability for object lifting. The occupational therapists reported that participants 1 and 2 – who were constantly practicing with the videogames- showed more important progress in their hand rehabilitation than participant 3.

Technology used in the rehabilitation plan consisted in a videogame system that includes a *5DT Data Glove 5 Ultra* and a *PlayStation 3* game console, which was installed at the participants' places of residence; then, every system was networked with the Riley Hospital and the Tele-rehabilitation Institute of the University of Rutgers, through a DSL (Digital Subscriber Line). PlayStation 3 game console works under Linux operating system and was used because the videogames were programmed in open code (Java 3D). The videogames included in this study were customized by the University of Rutgers; *sliders* -one of the games- was used for the patients to make movements of hand opening and closing; the second game - *chasing a butterfly*- was applied to produce higher velocity in the hand movement.

It can be concluded from this study that telerehabilitation based on videogames and virtual reality can improve the hand function and the health of the forearm bones in teenagers suffering from hemiplegic cerebral palsy.

The study also considers the need of generating more studies that focus on creating new forms of distance rehabilitation therapy.

In the study reported in [35], a system of serious games based on mixed reality for motion rehabilitation of upper limb after a brain damage is shown. This system helps to understand the potential and advantages of virtual reality from the therapist's point of view and is expected to increase the patient's motivation, making the user interface highly intuitive. Besides, the system allows the therapist to monitor patients and makes possible to work with the telerehabilitation method, thus reducing its implementation costs.

The research reports a pilot study conducted in agreement with a hospital, which involved three therapists who served as patients (due to the experience they showed in the treatment conventionally used in rehabilitation of upper limbs). That study suggested the development of three therapy sessions: one with conventional rehabilitation, another applying a customized game developed for personal computers, and the other one with a mixed-reality version of the same game.

The technology used in that pilot study includes mainly three subsystems: (1) the game subsystem, in charge of managing the game application; (2) the motion capture subsystem, in charge of the patient's biomechanical monitoring; and (3) the visualization subsystem, responsible for showing the virtual environment of the game in a real environment. The first subsystem defines a client-server application, which allows to set up the game's difficulty levels; it receives captured signals and visualizes the videogame virtual environments. The second one uses an infrared transmitter attached to the patient's hand with a Velcro belt, and an infrared camera that captures the monitoring of the infrared transmitter to generate an image of the patient in the virtual environment based on the received images. This camera is a Nintendo Wiimote. The third subsystem is a processing software that translates the Wiimote events into mouse events for both the infrared transmitter and the infrared camera to be considered as a signaling device of the virtual environment.

The virtual setting used is based on a character that surfs to catch fish in a fish tank, were the player's aim is to touch any fish; every time the player touches a fish, he moves forward a progress bar and he wins the game when that progress bar is completely filled up.

The experiment includes three 15-minute sessions: classic therapy session, computer game session and mixed reality game session, carried out by the three participants (therapists playing the role of patients).

That study ends by claiming that the effort made by the patients to do the exercises was almost the same for all the systems (the classic one, the PC game and the Mixed Reality Game), but mixed reality can be a way for the patients to forget about their effort and increase the number of exercises they could do. Nevertheless, because of the features of the mixed reality and PC games, patients prefer these two systems, with a higher preference for the mixed one. Finally, it is stated that one of the problems in most of the PC rehabilitation games was the use of the mouse as a pointer device, since precision when selecting certain objects from the screen is low if there are motor disabilities; but these problems become advantages in the mixed reality.

The study proposed by Burdea[38] presents a rehabilitation plan based on the videogames executed in a PlayStation 3 game console and using 5Dt sensing gloves focused on upper limb rehabilitation, specifically the hand. This experiment was applied in two pediatric patients suffering from hemiplegia. In the system proposed here, while the participants practice the rehabilitation games, the data on obtained scores, the amount of time used to finish each test, and the session date and time, are recorded inside the PlayStation console. This information allows to record the progress during the entire rehabilitation program. Videogames have a special feature: they can be set up according to each patient's needs.

About the technology used in this experiment, three important aspects are taken into account when hand rehabilitation is performed: the gloves to be used, the games and the video game console, and the Internet connection. Motion detection gloves used in this study were adapted to be smaller, and they use just one optical fiber sensor per finger; thus global flexion can be measured only on the hand gauge. It is also mentioned that the motion gloves used have a restriction in their design since it is difficult to wear them on the spastic hand and the optic sensors tend to come off when the glove is taken off.

Sliders was the game with the highest number of participations. In it a graphic representation of the hand on the computer screen (avatar) "cleans" the screen to show a pleasant image. A screen section is assigned to each finger, so that all the fingers can be used in the "cleaning" process. The score of the game is determined by the extension or flexion percentage, i.e., if all of the four fingers are completely spread or bent, the result is 4*100= 400. Thus, if the four fingers reach 90% of their base line rank, the score is 4*90= 360. It is also mentioned that the participant had initial threshold values of 45% in extension and 70% in flexion. After two months of training (and more than 1200 practice minutes) the values changed to 70% and 90% respectively.

The study mentions that the participants practiced another game called UFO. This game requires the participants to repulse a UFO or spacecraft by spreading or blending the fingers during a period of time. The participants' time of reaction is given according to the UFO's speed. Points are taken away if the finger's movement has not ended when the spacecraft is close to the hand avatar.

Finally, the study reports that the obtained results are promising regarding the possibility of applying the rehabilitation method in upper limbs (hand) of the human body and that improvements can be obtained in the long term in hand's force and function.

4. Discussion

The analysis specifies that telerehabilitation allows patients from different zones located far away from important rehabilitation centers to have a chance to fully accomplish their rehabilitation programs proposed by the specialists. It is important to take into account that one of the main causes of permanent disabilities in patients is failure to complete such programs.

From the systematic review, we can to conclude that there are few works that include rehabilitation technologies allowing people to feel they are in a pleasant environment to fulfill their recovery and, the most important thing, which use low-cost technologies that enable them to be installed in homes and/or easy-to-reach places. In this study only three works reported the integration of low-cost inertial sensors and computer videogames in telerehabilitation systems.

In Golomb's [34] work, a great progress in incorporating videogames in the telerehabilitation process is shown, even though the technologies used are a little expensive and not very easy to transport. Also, it is important to mention that information from therapies made by a patient must be recorded on the electronic medical record system in order to have the process timely and reliably assessed.

Also, in the study conducted by Ines[34], there is not any evidence of the way progress in therapies is quantified since the system does not have a process measurement section, and does not allow to demonstrate the effectiveness of practices carried out by patients. Another aspect that must be mentioned about this work is the high cost of its implementation since a Wiimote system and an infrared transmitter are not affordable to a low-income person. One of the disadvantages noticed when analyzing Ines' paper is that the tests were not conducted directly on patients but on the therapists, who performed the tests and exercises. Even though therapists had the professional experience in dealing with many different problems, this could show biased concepts in the experiment's results. Another aspect found was that no particular illness was identified; therefore a specific therapy program was not reported.

Finally, in Burdea's [38] work, a difficulty in technology inclusion is evidenced, since adapting gloves for spastic hands is complicated and expensive. This adds to the cost of the *PlayStation* game console and makes installing these devices at the patient's home complicated and unreliable.

4.1. Study Limitations

It is important to mention that a great deal of the literature reported in the bibliographic databases does not clearly identify the keywords or the indexation terms and, consequently, the search protocol and the subsequent meta-analysis do not reach all of the works reporting innovative and important developments in the studied field.

5. Conclusions

Telerehabilitation is a health service provision method that can be used in people suffering from different pathologies as the ones recorded on the analyzed papers. Nevertheless, a high cost of technology inclusion in physical rehabilitation processes is evidenced, as well as the high cost of its adaptation and equipment installation at the patient's home or at places distant from important rehabilitation centers.

On the other hand, it was noticed that few works report the combination of motion capture sensors and other technologies in the upper limb rehabilitation process using videogames in physiotherapy programs; that is why our interest to increase work in this area is highlighted.

Finally, a contribution to the progress of this discipline would be oriented towards the implementation of a motion capture and biomechanical analysis platform, based on inertial sensors and optical motion capture devices without indicators. This platform should also include a therapy program based on reliable active low-cost videogames, easy to install at the patient's home or at the place the therapy is conducted.

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M. Callejas-Cuervo, received the Bs. in System Engineering in 1997 and actually courses your PhD in Applied Science, both from the Antonio Nariño University, Colombia, also, is PhD student in Energy and Process Control in Oviedo University and received the degree the MSc. in Computer Science from Institute Technology of Monterrey, Mexico. He is a full professor of the Faculty of Engineering at the Pedagogical and Technological University of Colombia, member of the Software Research Group. His research interests include inertial sensor projects in telerehabilitation and development of video games actives, also the software engineering and business intelligence.

G.M. Díaz, received the Bs. in System Engineering in 2000 and PhD in Engineering in 2010, both from the Universidad Nacional de Colombia, Colombia. From 2000 to 2010, she was joined to the Telemedicine Center of the Universidad Nacional de Colombia as development engineer and

researcher. Currently, she is a full professor of the Faculty of System and Computation Engineering at the Antonio Nariño University, Colombia, and she's member of the Bioengineering Research Group. Her research interest include: medical informatics, telemedicine systems, medical image analysis and pattern recognition techniques applied to medical applications.

A.F. Ruiz-Olaya, received the Bs. in Electronic Engineering from University of Valle, Colombia and his PhD. from Carlos III University of Madrid, Spain. He is a full professor of the Faculty of Electronics and Biomedical Engineering at the Antonio Nariño University, Colombia, where he joined the Bioengineering Research Group. His research interests include rehabilitation robotics, multimodal human-robot interaction, bio-inspired control architectures and modelling of human motor control. Currently, he is working on several projects oriented to the development of neurorehabilitation systems to attend motor disabled people. Prof. Ruiz-Olaya is a member of IEEE. He has been author and co-author of multiple papers and has performed as reviewer of several international journals and conferences of relevance.