BCI and Motion Capture Technologies for Rehabilitation based on Videogames

John E. Muñoz
Human Computer Interaction Group, Colombia
Maestría en Ingeniería Eléctrica
Universidad Tecnológica de Pereira
Pereira, Colombia
jemunozc@misena.edu.co

Ricardo Chavarriaga
Defitech Chair in Non-Invasive Brain Machine Interface
Center for Neuroprosthetics
EcolePolytechniqueFédérale de Lausanne
Lausanne, Switzerland
ricardo.chavarriaga@epfl.ch

Julian F. Villada
Human Computer Interaction Group, Colombia
Maestría en Instrumentación Física
Universidad Tecnológica de Pereira
Pereira, Colombia
jfvillada@utp.edu.co

David SebastianLopez
Human ComputerInteractionGroup, Colombia
Programa de Ingeniería en Sistemas
Universidad Tecnológica de Pereira
Pereira, Colombia
daselopez@gmail.com

***Abstract*— this paper presents a cost-effective rehabilitation system based on videogames and multimodal recordings of physiological signals. The system targets patients with sensory-motor impairments resulting from lesions of the central nervous system (e.g., due to stroke or traumatic injuries). It relies on a wireless low-cost hybrid interface combining a consumer-level electroencephalographic (EEG) device and the Kinect sensor to record the motion capture information. Thus providing quantitative physiological measures to support medical evaluations and improve the personalization of health service. Furthermore, through the design of specialized videogames for rehabilitation, this approach aim at increasing the patient's motivation, potentially improving the service quality and the recovery process. The system is currently being used in a rehabilitation center in Colombia by patients with upper limb paralysis and balance disorders after stroke or traumaticuries. Initial results show significant improvements in the mobility of affected joints, improved adherence to treatments by patients, and high acceptability by therapists and end-users.**

Keywords— Rehabilitation, Stroke, Brain Computer Interface, Kinect, Motion Capture, Videogames, Multimodal Interface.

I. INTRODUCTION

In Colombia, physical rehabilitation service is undervalued and its impact on a variety of individuals and disorders is minimized. This is due in large part to the lack of quality of service in many rehabilitation centers triggered by economic constraints, where in order to be profitable, these centers are forced to increase the offer rather than the quality of service [1], [2]. To tackle this problem, rehabilitation centers acquire equipment and implement complementary therapies in order to improve the service. However the cost of technological innovation is often high, which limits the use of complementary therapies and technology-based therapies to a few rehabilitation centers in the country. This is particularly the case in Colombia where a large number of people with disabilities depend on the social security system to have access to rehabilitation therapies. Unfortunately, this system does not prioritize the access to technology-based approaches, or research on this field[3].

In Colombia, the prevalence of diseases and injuries of Central Nervous System (CNS) leading to a sensory-motor impairment is as follows: of 300-560 cases per 100,000 inhabitants of Cerebro Vascular Accident (CVA or stroke) [4], of 2-5 cases per 100,000 inhabitants for Multiple Sclerosis [5], 1.4 to 2.7 per 1000 live births for cerebral palsy (CP) [6] and in the spinal cord injury is estimated to be 223-755 per million inhabitants [7]. Generally all these people require physical rehabilitation and / or neurorehabilitation sessions to improve certain aspects of their condition. Rehabilitation centers are hired by the health providers (Empresas Prestadoras de Salud, EPS) in order to provide, which is this service included in the POS (Plan Obligatorio de Salud).However due to the low cost of the service that is covered by the POS, these centers must address a large number of patients per hour, which greatly reduces the efficiency of the process. Furthermore, considering that normally no records of objective measures are performed to ensure the patient's progress in therapy. This lack of systematic and individualized information usually guarantees to corroborate the efficacy of therapies in order to quantify the evolution of the patient.

This paper proposes the use of low cost technologies (such as the Kinect sensor) which allows reducing the wide gap that separate the scientific development in universities with the punctual problems that are presenting on health sector. The implementation of methodologies for computer assisted rehabilitation seeks to carry out a remarkable improvement of the service, transforming it into on more personalized and efficient for the community. Particularly, the use of interactive technologies and the development of biosignal processing systems provide a holistic approach between patients and health care providers in order to humanize this relationship. Introduce the technologic development in the everydayness of people should be a predictor of progress and the improvement of the quality of life of the inhabitants of a country. Also, this work explores the use of neural engineering systems and theirthree principal approaches used for rehabilitation of impaired motor functions: restoration, replacement and neuromodulation [8]. Particularly, the neuromodulation is the process of inhibition, stimulation, modification, regulation or therapeutic alteration of activity, electrically or chemically, in the central, peripheral or autonomic nervous systems in order to induce plasticity through artificial stimulation of afferent pathways and/or by artificial enhancement of efferent neural and muscular signals provided as feedback [9]. Then, this work shows a novel multimodal interface called BKI (Brain Kinect Interface) which propose the hybridization between brain computer interface (BCI) videogames and Exergames or exertion videogames to improve the rehabilitation processes in Colombia. Particularly, a rehabilitation center called ―Clinica de Dolor del Eje Cafetero" in the city of Pereira has been chosen as research center for developing studies with patients using the BKI system.

II. Related Works

Neurorehabilitation is entering an exciting new era. A wide range of new technologies are constantly being developed, based on real problems in clinical practice and increasing the potential for therapists and clinicians to rehabilitate, diagnose and generate knowledge. Portable and wearable robots, virtual reality, brain computer interfaces, game development for therapeutic purposes and neural prostheses are playing a convergent role in this innovation process [10]. Considering some of these parameters, one review of the companies, developments and outstanding scientific projects in the area of physical rehabilitation and neurorehabilitation that are part of the background of products using interactive technologies, virtual reality and neurophysiologic data capture between others was carried out:

- MindMaze (Swiss Company): this start-up perform a combination between immersion technologies using virtual reality and training through videogames, brain imaging and motion capture (MoCap) technology to build platforms for neurorehabilitation. The MoCap sensors provide positions and orientations to allow movement registration using avatars, virtual reality technologies offer stimulation environments that can be adjusted to any patient and finally, non-invasive EEG signals are recorded to investigate the underlying multisensory and motor processes in motor restoration.
  Webpage (www. mindmaze.ch)
- RehabNet (Portuguese Consortium): is a highly interdisciplinary project that addresses several research areas including: a) clinical research, b) robotics, c) human computer interaction, d) neurofeedback and neuroscience. RehabNet proposes to develop a novel rehabilitation paradigm, based on low cost technology that can deliver motor rehabilitation for several groups of patients, anywhere they are. This technological advances have a strong potential towards novel and low cost treatments, health promotion, disease monitoring and promotion [11]. Webpage (http://neurorehabilitation.m-iti.org/rehabnet/).
- Poizner Lab (American Researchers): this group is focused in study both normal human performance and its breakdown following dysfunction of specific brain systems. They develop and use contemporary technologies for 3D motion analysis, robotics and immersive virtual reality in conjunction with noninvasive brain imaging (EEG, fMRI) in order to simultaneously record movements of the limbs, body, head and eyes and EG while subjects act in large-scale, immersive virtual environments. One of the domains of the studies in this group involves analysis of the breakdown in motor control in patients with Parkinson's disease [12]. Webpage (http://inc.ucsd.edu/~poizner/).

This type of multimodal developments created for the study of interactions and motor/neurological behaviors mediated with virtual reality immersive systems and specialized videogames, constitute a powerful tool for the understanding of brain behavior relationships in the high-dimensional world, and for use it in assessment and treatment of several neurological diseases.

III. BKI: Brain Kinect Interface

Our work, the BKI approach is a multimodal interface that aims to consolidate a neural engineering real-time processing system based on EEG and Kinematic signals [13]. In general terms, the diseases and injuries of the central nervous system (CNS) leading to sensory-motor impairment are the problem to solve. This diseases and injuries can roughly group sensory-motor deficits: a) stroke, which causes impairments due to changes in blood supply to the brain; b) spinal cord injuries (SCIs), which result in total or partial obstruction of flow of both sensory and motor information between the peripheral and central nervous system; c) non-traumatic disorders of the CNS (amyotrophic lateral sclerosis and multiple sclerosis); and d) cerebral palsy [8]. The neuroscience provide a better understanding of the brain mechanisms for recovery and research on the human computer interaction explores the way to optimize the interaction naturalness in the set of tasks surrounding rehabilitation therapies.

The BKI system uses specialized virtual reality videogames: Exergames (exercise videogames) and BCI videogames through motion capture and brain computer interface technologies respectively, in order to provide new methodologies for rehabilitation. The system has three layers: first guarantee interactivity in the therapies through videogames, the second layer allow capturing and processing the kinematic and neurophysiologic biosignals using low-cost sensors and finally the system has an interface to monitoring the therapies and validate the results.

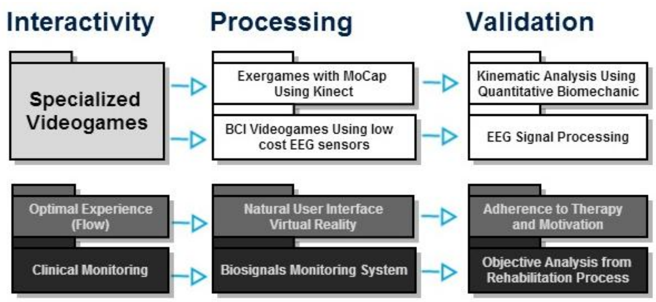

Fig. 1.Brain Kinect Interface Layers.

The main function of the first layer (Interactivity) is establish a new methodology of therapy based on videogames to provide motivation and entertainment to the patients in where they can reach the flow state: a mental state of operation that produce an optimal experience in which the patient performing specific tasks feeling an energized focus, full involvement and enjoyment of this activity [14]. The second layer (Processing) uses hardware and software elements to carry out the processing of the biosignals to improve the user experience within the videogame and collect physiological information of the patient while is playing the rehabilitation Exergame. The last layer (Validation) monitors the evolution of the patients and save a logbook of the whole rehabilitation process taking in account elements such as patient‘s moods, opinions and qualitative analysis of caregivers and therapists, biomechanical analysis of the movements in particular joints using angular transforms [15] and analysis of neurophysiologic data recording from low-cost EEG-BCI systems [16].

A. Hardware

Given the existence of novel low-cost portable sensors such as commercial BCI systems and inexpensive RGB-D cameras (e.g. Kinect, Asus Xtion Pro), the BKI aims to establish a very simple, comfortable and portable platform for rehabilitation. Even, the system can be proposed for rehabilitation at-home tasks. The system has two medullar interactive technologies:

Gesture Interaction: this technology allow digitalize the movement to the users on a computer and interpret actions within a virtual environment; these actions range from moving the mouse cursor to interpret the movements of a virtual representation of the user (Avatar) [17]. The movements of the hands or the body are sensed by means depth cameras (RGB-D) [18], making them a real platform for natural interaction, so that the experience is more dynamic for the user who does not need perform any physical contact with a surface and that gestures can be interpreted in the air. The cost of the RGBD cameras is approximately $ 350, which is a comfortable price to start investigations in motion capture technologies for developing countries.

Brain Computer Interface: a BCI directly measures brain activity associated with the user‘s intent and translates the recorded brain activity into corresponding control signals for final applications. This translation involves signal processing and pattern recognition, which is typically done by a computer [19]. A BCI must have four components. It must record activity directly from the brain (invasively or non-invasively). It must provide feedback to the user, and must do so in real time. Finally, the system must rely on intentional control. That is, the user must chose to perform a mental task whenever s/he wants to accomplish a goal with the BCI. Some commercial sensors such as the Emotiv EPOC neuroheadset, provide a comfortable connection without losing reliability in the EEG signals.

B. Software

There are two types of software which can be identified according the layers of the BKI system: software for patient interaction and specialized software for signal analysis:

Videogames for health using virtual reality: as a previsualization and sensorial stimulation technology, the system developed uses the virtual reality (VR)[20]. The recent advances in technology of videogames development and the availability of low cost tracking devices have widely increase the capacities of the interfaces, software and hardware for VR, it allow a significant integration of this digital tool in several health-care areas. The VR offers certain advantages in the neurorehabilitation and physical rehabilitation processes compared with the real-world conventional practice [10]: i) individualization and specific tasks training: the VR can provide the means to safely expose to the patient with emulation of functional and realistic environments that can be tailored to each patient‘s abilities and can be implemented in rehabilitation therapies at home, ii) motivation: the VR offer a realistic conditions, safe and motivational in which the patients can practice complex activities; evidence suggests that when an user focuses on the videogame rather than their disability or their pain, exercise becomes more enjoyable, motivating and it is very likely that these aspects are maintained during several therapy sessions, necessary to induce changes in the plasticity in the nervous system, iii) feedback: the user always need to know how and when a task was completed successfully (or not) in order to promote (or correct) the learning process and avoid the frustration. Now, to achieve better adherence to treatment and improve the motivation of patients with the interventions, it has created a basic set of videogames, which have been specially designed for specific rehabilitation processes.

Each videogame have a previous investigation about requirements and specifications that are performed by health

care professionals, engineers and designers. The majority of these videogames are Exergames, which allow complement the traditional physiotherapy process, adding game dynamics to any routine. Also, the research group have designed videogames based on specific mental strategies such as motor imagery and hybrid videogames using gestural and mental interaction.
Below are listed the videogames developed and its state:

- Karate Rehab: Exergame designed for the rehabilitation of shoulder flexo-extension movement in monoparetic patients result of a Pyramidal Syndrome. (State: Validated).

- Cognitive Balance: the first hybrid videogame between an Exergame and BCI Game. The videogame was designed to perform rehabilitation therapies in hemiparetic stroke patients that have standing balance problems. The patient uses body movements and their mental intentions as a control input of the interactive system. (State: ongoing study)

- BCI Duck Hunt: is a BCI videogame based on the Motor Imagery mental strategy. The user needs to imagine the movement of his/her hands in order to produce neural patterns called Event Related to Desynchronizations (ERDs) and provide the output signals. The videogame is based on the classic of Nintendo ―Duck Hunt” and was created to establish training sessions in patients with spatial neglect, Parkinson or monoparetic stroke patients. (State: recruiting patients).

- Kicker Rehab: Exergame designed for the rehabilitation of knee flexo-extension movement in patients with knee injuries, monoparesis or gait problems. The videogame allows to the patients to hit a virtual soccer ball in order to shoot down as many possible bricks of a wall that is right in front. (State: recruiting patients).

The designed videogames were based on operant conditioning theories applied to videogames [21].The videogame was implemented in the Unity3D engine, which provides some tools and libraries to generate the multimodal interaction between the motion capture data and the BCI system data. Some videos about the implementation of these videogames in Colombia can be seen inyoutube: https://www.youtube.com/channel/UCni4RDLTpalF98cUx9eowdw.

Finally, there are two software tools used to perform the monitoring and evaluation process of the biosignals collected during the videogame sessions:

Software for the analysis of biomechanical signals: this software allows a data analysis from motion capture files registered during the videogames intervention with the Kinect sensor[22]. The data are processed and delivered in lineal graphs that show positions and angles of the interaction points (joints) captured with the sensor and its time evolution. The software was called Bio-Cirac(see fig. 2) and allow upload the MoCap file using a Graphical User Interface (GUI); after that the user choose the file to analyze, the software show a 3D model that represent the user and the movements registered (skeleton). The second graph shows the joint‗s positions in three axis (XYZ), where zero point (0,0,0) is located on the initial position of the user.

Software for the analysis of the neurophysiologic signals: for EEG signal analysis captured from the BCI system during the videogame intervention, the open-source software ―OpenViBe” is used, it is a powerful tool created for experiments based on the use of brain computer interfaces. The five main reasons why the OpenViBe was choosen are: 1) is an open-source platform, 2) the connectivity with the Emotiv EPOC neuroheadset, 3) availability of several tools for each of the stages of BCI application, 4) the software‘s design is made for non-programmer users, which allows the development time of neuroscientist experiment decrease and that errors can be detected and corrected more easily and 5) the inclusion of functional boxes for communication with external devices and applications. The use of the EPOC system has enabled rapid prototyping dynamic with a relative low investment; the trend of development of systems that are becoming increasingly portable, practical and economic can trigger a growing interest in research in the computational neurosciences in developing countries such as Colombia.

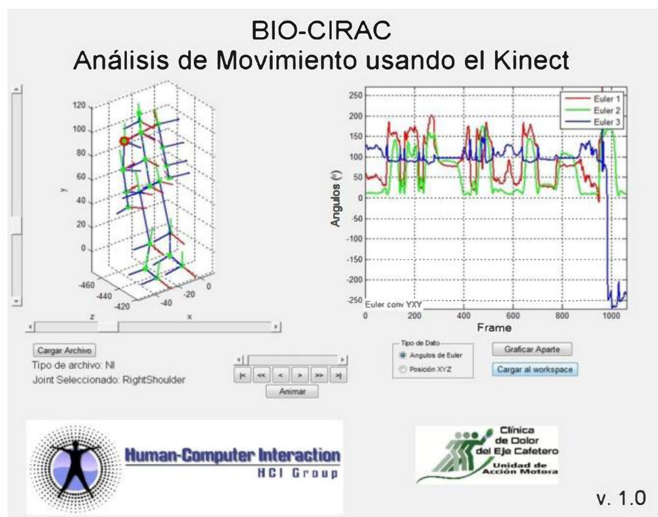

Fig. 2. Bio-Cirac GUI: specialized software designed to analyze the MoCap data.

IV. RESULTS

Through the development of the BKI multimodal system, some assemblies (see figure 3) have been performed in rehabilitation centers in the country in order to assess usability and acceptability aspects for the system. Particularly, a rehabilitation center in the city of Pereira has been chosen as research center for developing studies with patients, the assessment of developed videogames and the optimization of the interfaces used through the rehabilitation assisted by computer. In this place has been used Exergames in more than

700 patients with motor impairments ranging from knee injuries and trauma to patients with stroke and cerebral palsy. The test of these prototypes applied to physical rehabilitation or neurorehabilitation have shown to be a promising approach to improve the quality of research in these fields. This is particularly relevant in countries like Colombia, where despite having a lot of people in disability conditions and elderly people (in comparison with countries like Ecuador, México and Paraguay) [23]there are few developments in areas such as biomedical engineering or bioengineering [24], that are fundamentals for the convergence between technology and health.

Among the studiers carried out is “Shoulder Flexion Rehabilitation in Patients with Monoparesis Using an Exergame”, which has included patients with pyramidal syndrome, a set of neurological disorders that affects the motoneurons in a selective way. The MoCap data was analyzed reporting improvements in range of motion up 18 % in range motion after 4 months of intervention with a specialized Exergame (Karate Rehab).

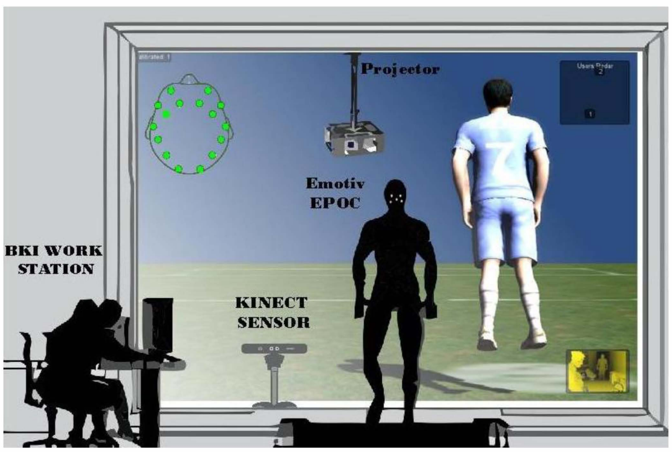

Fig. 3.Brain Kinect Interface elements.

Another study reveals the potential use of Exergaming as a postural balance valuation tools in both healthy subjects and patients with balance problems. This study allows assessing the balance time of each foot in 20 healthy people, using as biomechanical predictors, kinematic signals from the Kinect sensor acquired during the interaction with the videogame; the results showed an average increase in balance time of 15 % in comparison with another studies. Finally, studies with hemiparetic stroke patients (with problems of standing balance), multiple sclerosis and unilateral spatial neglect are ongoing. These studies areestablishing a solid scientific basis of the efficacy of technologies such as motion capture systems and brain computer interfaces in rehabilitation and neurorehabilitation processes assisted by computer in emerging countries such as Colombia. The development of engineering solutions for the study of neuroscience and the incorporation of these systems into clinical settings, constitute a valuable opportunity to generate added value to systems developed in the country, highlighting the validation in local patients and the development of solutions of real issues in the sector. Another qualitative results show significant improvements in adherence to treatments by patients and high acceptability by therapists and end-users.

The feedback from patients and therapists taken through open questions after each session was the development team has included negative aspects of virtual reality therapy using Exergames as:

- Difficulty to function correctly in video games (Exergame level of complexity).
- Difficulties with the initial calibration of the Avatar (initial pose recognition).
- Need to include landscape aspects in the modeling environment, in order to induce states of visual relaxation in the patient.

Some of the studies within the clinic involving the use of BCI systems. There have detected some problems that may be key to the development of the experiment, such as:

- Difficulties with neuroheadset initial connection to the user.
- Discomfort manifested after the first 40 minutes of use.
- Low level of awareness of enforcement.
- Lack of rich graphics in videogames that are used.

These recollected experiences in the rehabilitation center, allow individuals to establish a framework of possible sources of the problems that may arise in the course of investigations, in terms of interfaces, interaction and user experience.

V. CONCLUSIONS

The BKI system explores the development of a novel multimodal rehabilitation system based on videogames that sets the use of low cost emerging interactive technologies in order to broadly improve into two fundamental aspects of the rehabilitation sector: the effectiveness and personalized service physical rehabilitation and neurorehabilitation, and objective monitoring of the results achieved by patients throughout their therapies. These technological advances have a strong potential towards novel and low cost solutions for healthcare, the disease monitoring and the processes of social inclusion through the use of technologies. The benefits to use videogames in rehabilitation processes can be summarized in improving motivation and adherence to therapy by patients, the opportunity to dynamically monitor physiological variables of patients while they are playing and the possibility of providing a realistic vehicle that can complement clinical practice, optimizing the patient-physician relationship.

Currently, some researches of the Human Computer Interaction Group (spin-off) are developing a portable work station that allows the proliferation of these types of technologies and methodologies for rehabilitation in developing countries like Colombia and Panamá; this requires work on i) standardization of multimodal system so it can be easily used by clinical staff and ii) the systematic evaluation of videogames developed in groups of controlled patients in order to establish a solid scientific basis of treatment efficacy through videogames and iii) seek vehicles from private or public funding for prototype development.

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