Technologies Solutions Schemes for Patients’ Rehabilitation

Methodologies, Models and Algorithms

Habib M. Fardoun¹; Abdulfattah S. Mashat²

¹Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia; ²University of Jeddah, Jeddah, Saudi Arabia

1. Introduction

Information and Communication Technology (ICT) continues being a popular tool, which empowers innovation, to improve physical rehabilitation process and motor control research [1]. Thus by obtaining better health and wellbeing through ICT, this helps making current research and innovation turn the future of health into the present [2].

What have the best brains in rehabilitation research come up with to use ICT in the training of individuals with severe functional impairments? Technologies are integral part of a rehabilitation programme for training, where doctors and physiotherapists use these resources as a useful addition to other treatment methods [3].

ICT is in continuous use to improve openings and, at the same time, to develop a number of possibilities to improve rehabilitation environments and health care solutions through the development of innovative frameworks that use ICT in the preparation and training of people with diverse sorts of disabilities, through the use of Virtual Reality (VR) as a necessary piece of a rehabilitation programme [4, 5].

Thus rehabilitation aims to improve the potential of people with disabilities to achieve their goals through the use of technology. New technologies applied to medicine are beginning to cover all fields. Some advantages are (1) Enhancing functional capacities by eliminating or minimizing functional limitations imposed by disability; (2) Leading to and/or expanding vocational rehabilitation, independent living rehabilitation, and employment opportunities by eliminating barriers; and (3) Conducting eligibility determinations and developing an Individual Plan for Employment.

The focus theme contains a set of research articles that focus on technologies and human factors related to the use of ICT for improving patient rehabilitation. It contains research papers in conjunction with case studies, perspectives on rehabilitation and rehabilitation in practice.

2. Selected Papers

Ten papers were selected, after a peer review process, as the best papers presented at the REHAB-Workshop [6] and were included in the focus theme “Technologies solutions schemes for Patients’ Rehabilitation: Methodologies, Models and Algorithms”.

2.1 Technology in Rehabilitation: Evaluating the Single Leg Squat Exercise with Wearable Inertial Measurement Units

The authors of the presented paper, Wheelan et al. [7], attempted to determine if inertial measurement units (IMUs) positioned on the lower back and left leg could distinguish between acceptable and aberrant single leg squat (SLS) technique. The SLS is a common rehabilitation and
strength and conditioning exercise. It is also used as a screening tool to assess for lower limb injury risk. Currently, objective quantification of SLS biomechanics has been determined using marker-based motion analysis systems, which are expensive and time consuming. Clinical assessment involves real-time visual evaluation, which is quick and inexpensive. However it is also subjective and can be unreliable. The authors proposed to use IMUs as they offer the potential for objective biomechanical evaluation quicker and more economically than previously possible. In order to determine the potential of an IMU system to assess SLS biomechanics, the authors recruited eighty-three healthy volunteers and asked them to complete 10 SLS repetitions with IMUs placed on the lower back, left thigh and left shank. These IMUs recorded tri-axial accelerometer, gyroscope and magnetometer data during all repetitions. The SLS repetitions were analysed by a Chartered Physiotherapist and errors were recorded using a previously validated evaluation framework. Features were extracted from the recorded sensor data and used to train and evaluate a variety of classifiers that assessed SLS technique.

The authors found that an IMU system was moderately successful in detecting aberrant SLS biomechanics. Furthermore, they were able to show that a single sensor system produced comparable classification scores relative to multi-sensor systems. Finally, the author’s hope these findings can aid in the creation of a wearable IMU system that can offer clinicians the potential to remotely track exercise compliance and technique while also assessing for increased musculoskeletal injury risk.

2.2 Combined Vision and Wearable Sensors-based System for Movement Analysis in Rehabilitation

Spasojevic et al. [8], propose a portable and affordable rehabilitation system, suitable for the home environment, which combines vision-based and wearable sensors. This research work presents a novel approach for examining and characterizing the rehabilitation movements, using quantitative descriptors. The authors propose new Movement Performance Indicators (MPIs) that are extracted directly from sensor data and quantify the movements of different body/hand parts and that can potentially be used by therapists for diagnosis and progress assessment.

The experimental group consists of thirty Parkinson’s disease patients and the control group of healthy subjects. Experimental exercises refer to full-body movements captured by the Kinect sensor and fine hand movements measured with the data glove. All subjects have been examined under the same conditions and instructed by a neurologist and therapists. Full-body movements are quantified with ten different MPIs that result from the combination of four measurement categories (speed, rigidity, the range of motion and symmetry). As for the hand movements, fifteen MPIs are designed with respect to: (1) range of motion of the characteristic hand and finger joints; (2) velocity values derived from the sensor angular data and (3) velocity and acceleration parameters between estimated thumb and index finger tips. MPIs are further tested for correlation with clinical scales and in the classification procedure across the groups of interest: controls and patients (support for diagnosis) and patients with different disease stage (support for monitoring).

The results of Spasojevic et al., suggest significant differences between patients and controls, as well as disease stages for the proposed MPIs and the possibility of successfully classifying the two conditions. The data glove sensor has proven to be more informative than the Kinect for assessing the Parkinson’s disease main symptoms and the disease stages. The majority of the proposed MPIs are correlated with the official clinical tests and scales for Parkinson’s disease, which is particularly important for the possible inclusion of the proposed MPIs into rehabilitation protocols.

2.3 Eye Movement Analysis and Cognitive Assessment: The Use of Comparative Visual Search Tasks in a Non-immersive VR Application

Rosa et al. [9] proposed Non-immersive Virtual Reality Applications (VRAs) could be used to assess cognitive functions. Though promising, VRAs-based assessment usually uses indirect behavioural measures to measure attentional and mnestic functions (e.g. number of errors, task completion time) [10, 11]. This research work explores whether eye tracking can provide more accurate and direct indicators of cognitive processing during comparative visual search tasks (CVSTs) in non-immersive VRAs. To test this methodology, 50 healthy participants performed two randomized CVSTs in the Systematic Lisbon Battery (VR system that has been used to assess attention and memory) [12, 13] while their eye movements were continuously recorded. Three ocular parameters, the total fixation duration and the number of visits in the areas of interest and in the interstimulus space were combined with a motor index (total execution time) to assess attentional and mnestic processes. The research work results revealed that ocular and motor pattern behaviours in the CVST depend on general cognitive functioning as measured with the Mini Mental State Examination. These results highlight the possibility of combining both non-immersive VRAs and eye tracking, adding an unobtrusive and reliable solution for cognitive assessment in non-clinical samples. Moreover, since this combined approach was sensitive to subtle changes in cognitive function in healthy individuals, this method might prove to be useful also for screening individuals in early stages of neurodegenerative disorders such as Alzheimer’s disease.

2.4 An Immersive Virtual Reality Platform to Enhance Walking Ability of Children with Acquired Brain Injuries

Biffi et al. [14] developed and tested a rehabilitative protocol for an immersive virtual reality platform (GRAIL- Gait Real-time Analysis Interactive Lab by Motekforce-Link) for the recovery of walking abilities in children affected by acquired brain injury (ABI). In this research work, authors’ analysed functional scales and gait data, acquired both overground and on GRAIL, before and after the treatment in order to evaluate the efficacy of this protocol. With this aim, 12 children with ABI were re-
REHAB
cruited from the in-patient setting of the Acquired Brain Injury Unit, Scientific Institute E. Medea, Bosiso Parini, Italy and were asked to perform a 10-session treatment in virtual reality (VR).

The VR platform used is the GRAIL, a dedicated solution for gait analysis and training in engaging environments. It is an integrated platform made up of an instrumented dual-belt treadmill, two degrees of freedom motion frame and embedded force plates. The combination with synchronized VR environments, which are projected on a 180° cylindrical projection screen, allows the subject to walk and move in natural and attractive settings. Authors evidenced significant improvements in gross motor abilities, especially in standing and walking, increased endurance and enhanced autonomy in daily life activities, flanked by gait pattern improvements in spatiotemporal parameters and joints range of motion.

The results of Biffi et al. suggest that even a short training on GRAIL platform may produce improvements in walking abilities and pattern of children with ABI, thus supporting further testing of longer rehabilitative protocols.

2.5 MaLT – Combined Motor and Language Therapy Tool for Brain Injury Patients Using Kinect

Wairagkar et al. [15, 16] developed MaLT – a combined motor and language therapy tool for brain injury patients using Kinect motion sensor technology. The functional connectivity and structural proximity of elements of the language and motor systems result in frequent co-morbidity post brain injury. Motor and language impairments have long-term implications for individuals' functional independence, social contact, self-esteem and mental health. Language treatments improve when combined with higher physical activity. Although rehabilitation services are becoming increasingly multidisciplinary and integrated, treatment for language and motor functions often occurs in isolation. Hence, authors collaboratively developed MaLT, which is a high dosage rehabilitation therapy tool targeting language and motor therapy simultaneously for the use in home environments for prolonged periods of time. MaLT comprises a suite of different levels of language therapy games for word comprehension, initial phoneme identification, rhyming words detection and speech practice. The games are played interactively using Kinect sensor by performing upper-limb movements to select correct answers which provides motor therapy. A database of over 750 objects was used to programatically generate questions for unique game play every time. In order to track patients’ engagement and rehabilitation progress, the game records patient performance data for the therapist to interrogate. MaLT is easy to use, playable, engaging, flexible, low cost tool for home environment that provides feedback to the patients and monitors their performance.

Pilot study was conducted with three stroke survivors for 6 to 8 weeks. Patients' performance was monitored through MaLT's reporting facility. The patients exhibited good level of engagement in the therapy. The results presented the statistics of the patients' performance; time spent playing each game, number of trials completed, and accuracy in the response and whether they used the affected hand to play the games. Pilot study patients as well as the Patient Public Involvement group indicated satisfaction with this multimodal approach to rehabilitation techniques and enhanced usability for individuals with acquired brain injury. The initial studies on stroke survivors have demonstrated that the combined therapy approach is viable and that the stroke survivors with chronic language impairments can use the software independently. Wairagkar et al. demonstrated that motion sensor technology can be employed successfully to target multiple cognitive functions simultaneously. This approach has the capacity to provide high dosage therapy in the home environment to a significant number of individuals living with the long-term consequences of acquired brain injury. The success of initial trials on stroke survivors has led to collaboration with a company with the intention of commercializing the MaLT combined therapy approach.

2.6 The Effect of Balance Training on Postural Control in Patients with Parkinson’s Disease Using a Virtual Rehabilitation System

Albiol-Pérez et al. [17, 18] tested and verified improvements related on spatial postural control in patients with Parkinson’s disease (PD). This experiment analyses the attitudes and the behavior of patients with PD in relation to the spatial postural control and shows if the use of a Virtual Motor Rehabilitation technological system produces improvements of this. During the experiment, the authors tested the hypothesis in the intervention period, following the ethical standards of Declaration of Helsinki, in 15 therapeutic sessions. In this period of time, the system stored the different types of pressure carried out by the participants in each session by using the Active Balance Rehabilitation (ABAR) system. ABAR system stored pressures on the left, on the right, and in the center in sitting position using a low-cost device, the Nintendo® Wii Balance Board. For this purpose, 10 patients with PD were recruited (4 males and 6 females) with a mean and a standard deviation baseline outcomes in cognitive, functional and emotional test of: MEC-Lobo 28.20(4.55); the Barthel index 76.29(17.87); Lawton's Philadelphia Geriatric Center Morale Scale 08.86(3.72); and the Charlson comorbidity index 4.30(1.42).

The inclusion criteria of this experiment were: signed written informed consent; with an age ranged from 18 years-old and 92 years-old; with gait instability; with mild-moderate cognitive impairment (MEC-Lobo) > 23; with comprehension of the instructions provided by the ABAR system; and with moderate visual/auditory injuries. On the other hand, the exclusion criteria were: participants with severe visual/auditory injuries; with traumatological injury that had not been solved before; and with PD that refused to participate in the experiment.

The results of Albiol-Pérez et al., suggest that the use of VMR systems in the rehabilitation process in patients with PD demonstrate that they maintain or improve their postural control on the left, on the right, and in the center position. It is due mainly because ABAR system requires a
high attention of the participants in the therapeutic sessions, stimulating cognitive processing.

2.7 Evaluation Results of an Ontology-based Design Model of Virtual Environments for Upper Limb Motor Rehabilitation of Stroke Patients

This research study presented by Ramírez-Fernández et al. [19, 20], echance the content of an ontology to design virtual environments (VEs) for upper limb motor rehabilitation of stroke patients according to the suggestions and comments of rehabilitation specialists and software developers, and to characterize the perceived importance level of the ontology, determine the perceived usefulness of the ontology, and finally, to identify the safety characteristics of the ontology for VEs design according to the rehabilitation specialists. For that, the authors’ conducted two semi-structured WEB questionnaires. As results of such study, significant differences in the importance level were obtained for the Stroke Disability, VE Configuration, Outcome Measures, and Safety Calibration classes, which were perceived as highly important by rehabilitation specialists. While regarding usability, the ontology was perceived by both groups with high recommendations.

As a conclusion the authors shows the importance of the contained information in the ontology regarding motor rehabilitation of the upper limb.

2.8 Cognitive Training through mHealth for Individuals with Substance Use Disorder

Gamito et al. [21], reports a study that test the efficacy of an alternative mHealth approach using tables and serious games to simulate cognitive functions in recovering addicts. For that a small-scale cognitive training program that use serious games was implemented and executed with a sample of mal participants, with heroin addicts, and who are undergoing a rehabilitation program.

As a result of such study, the authors found consistent improvements in cognitive functioning between baseline and follow-up assessments for frontal lobe functions, verbal memory and sustained attention as in cognitive flexibility, decision-making and in depression levels. The shown results in the study, show a promising data, but it still require randomized control trails to determine the efficiency of this approach as an alternative to cognitive rehabilitation programs in heroin addicts.

2.9 Can 3D Gamified Simulations Be Valid Vocational Training Tools for Persons with Intellectual Disability? An Experiment Based on a Real-life Situation

The hypothesis of this work, presented by von Barnekow et al. [22], is that gamified simulations and serious games can be an effective way of providing this personalized training. Persons with intellectual disability need personalized vocational training to get use to work procedures, be aware of safety protocols and be prepared to handle different situations in the workplace. A 3D interactive virtual environment was designed reproducing as accurately as possible a real work place, specifically a hostel. Different learning objectives were proposed to train persons in cleaning activities. A set of tasks addressing these learning objectives was designed taking into account special accessibility needs to facilitate interaction and understanding of the expected goals throughout the game. A pilot experiment was conducted on students of a specialized school. The results of the virtual training showed that students got a good understanding of the environment and the tasks and had a clear positive progression through time. In order to measure the transfer value of the game, two groups of students, one having trained and the other no, were confronted to the real workplace and asked to perform physically two of the virtual tasks. The results show that, in general, students with training managed better the situation. On the basis of this pilot study, we conclude that 3D gamified simulations can be efficient tools for vocation training of persons with intellectual disabilities and can contribute to their social inclusion through work.

2.10 Using Actigraphy and mHealth Systems for an Objective Analysis of Sleep Quality on Systemic Lupus Erythematos Patients

Balderas-Díaz et al. [23] present an analysis through complementary data provided by actigraphy and a mobile systems of how bedtime environment during sleep can influence diagnosis and treatment of Systemic Lupus Erythematous (SLE) patients intended to improve their quality of life. For that, a novel method was applied on the basis of the traditional method for collection data about sleep hygiene in SLE patients in combination with easy-use, non-intrusive ICT mobile systems. 9 women with SLE composed the sample, finally demographic and clinical variables between SLE patients and healthy control were compared with Fisher exact statistic and Mann-Whitney U test. As a result of such study, the SLE group showed worse sleep quality, and more pain intensity, fatigue and depression than healthy controls. While, there were no significant differences between SLE women and healthy controls in sleep parameters measured by actigraphy. Finally, the authors results underline the need to complement the subjective evaluation of the sleep with objective measures as actigraphy, in addition to, the employment of a new mHealth system that completes the standard evaluation by actigraphy with the measure of context variables provides new information of great clinical usefulness to effect a more complete evaluation of the patient and fit the treatment to the person.

3. Conclusions

The improvement and resulting setting up of PCs for the patients’ restoration procedure is of consistent intrigue and development. It has as of now been shown that utilizing ICT includes a more prominent feeling of strengthening and a change in the personal satisfaction of handicapped patients, permitting the improvement of new strategies to assess behavioural and utilitarian shortfalls all the more viably. Ten research works, were presented and discussed in the current focus theme, that...
presented various solutions for the use of ICT for the patients’ rehabilitation process, showing how the use of ICT has resolved or improved their daily life.

Whelan et al. [7] investigated if the inertial measurement units (IMUs) could distinguish between acceptable and aberrant single leg squat (SLS) technique. Alternatively, the paper of Spasojevic et al. [8] proposes a portable and affordable rehabilitation system, suitable for the home environment. Rosa et al. [9] proposed Non-immersive Virtual Reality Applications (VRAs) could be used to assess cognitive functions. Biffi et al. [14] developed and tested a rehabilitative protocol for an immersive virtual reality platform (GRAIL-Gait Real-time Analysis Interactive Lab by MotekforceLink) for the recovery of walking abilities in children affected by acquired brain injury (ABI). Subsequently, Wairagkar et al. [15] developed MalIT – a combined motor and language therapy tool for brain injury patients using Kinect motion sensor technology. Later, Albiol-Pérez et al. [17] tested and verified improvements related on spatial postural control in patients with Parkinson’s disease (PD). The research study presented by Ramírez-Fernández et al. [19], enhance the content of ontology to design virtual environments (VEs) for upper limb motor rehabilitation of stroke patients. While Gamito et al. [21], reports a study that test the efficacy of an alternative mHealth approach using tables and serious games to simulate cognitive functions in recovering addicts. Later the hypothesis presented by von Barnekow et al. [22], is that gamified simulations and serious games can be an effective way of providing this personalized training. Finally, the last paper by Balderas-Díaz et al. [23] present an analysis through complementary data provided by actigraphy and a mobile systems of how bedroom environmental during sleep can influence diagnosis and treatment of Systemic Lupus Erythematosus (SLE) patients intended to improve their quality of life.

These studies prove the effectiveness of employing ICT in the patients’ rehabilitation processes and it is important to chart the field and to open the dialogue between the different professionals working within it (e.g., researchers, clinicians and engineers).

Acknowledgment
We want to thank the editors of Methods of Information in Medicine for supporting us by publishing this focus theme.

References