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A Comparison of Virtual Rehabilitation Techniques

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Abstract **-**Virtual rehabilitation (VR) has been proposed as an alternative to traditional rehabilitation due to its advantages of motivating the patient, providing targeted tasks and quantifying performance and progress. Furthermore, the increasing use of commercial gaming sensors in VR systems has made them both affordable and suitable for home use. In the past few years, there has been a flood of research and publications in this field mainly demonstrating the efficacy of VR in treating disabilities. The aim of this paper is to survey and compare the rapidly changing state of the art in neuromuscular VR systems from a technical design perspective. It is not a comprehensive review however it compares both the hardware used and the software design: rehabilitation tasks, pre-treatment quantitative assessment capability, self-adaptive capability, quantitative progress reports, and possibility for home use. The survey showed that most current systems use the Microsoft Kinect® sensor. It indicated that there is a vast number of rehabilitation games targeting a variety of physical disabilities. However, it also showed that there is still a need for more complete systems which minimize clinician input, reduce cost and can be used in the home setting.

Keywords**:** virtual reality; rehabilitation; games; Kinect; stroke; neuromuscular

1. Introduction

Rehabilitation is basically a process to restore a patient's physical, sensory, and mental capabilities that were lost due to age, illness, trauma, or disease (Web-1). Because rehabilitation is an effective form of treatment, there has been a global interest in the development and improvement of rehabilitation systems.

Virtual Rehabilitation (VR) is a field that has attracted significant interest in the past few years, with several dedicated conferences and numerous publications. In brief, it involves applying the tools of virtual reality and gaming for developing interactive physical rehabilitation software and hardware. With VR, patients are motivated to perform the tedious repetitive rehabilitation protocols, the exercises can be specifically designed and customized to target specific disabilities, quantitative outcomes can be computed and progress can be quantified and reported. Furthermore, with the current pervasive use, and consequent affordable cost, of gaming sensors, VR systems do not require the patient to wear any sensors and are now being designed for home use. This decreases the cost of rehabilitation and reduces the need for hospital visits.

The aim of this paper is to survey the current state of the art in neuromuscular VR systems from a technical design perspective, investigating and comparing their design features. To the authors' knowledge, there is no other similar technical comparison study. This survey identifies many possible features of a comprehensive VR system and can thus serve as a baseline for further development and improvement of these systems. The comparison only includes systems for neuromuscular rehabilitation both in the research phase as well as commercial systems. The paper also overviews traditional as well as gaming sensors used for data acquisition in rehabilitation.

2. Methodology

The survey data are collected from different sources and analysed to form a comparison of the technical features of available VR systems. The data are collected from conference proceedings, transactions, international journals, reviews (e.g. Cochrane review (Laver, et al. 2011), theses, books, websites and other publications and projects in VR.

Journal sources include the IEEE (Institute of Electrical and Electronic Engineers) electronic library, Google Scholar, and ACM (to August 2014). International conferences searched included ICVR (IEEE International Conference on Virtual Rehabilitation), ICDVRAT (Intl Conference on Disability, Virtual Reality & Associated Technologies), CIG (IEEE Conference on Computational Intelligence and Games), International Conference on Intelligent Networking and Collaborative Systems, and FITAT (The Fifth International Conference on Frontiers of Information Technology)**.** Several studies were found in journals such as: JNER (Journal of Neuroengineering and Rehabilitation), IJIET (International Journal of Information and Education Technology), JRRD (Journal of Rehabilitation Research & Development), and Games for Health Journal.

Data collected were concerned with hardware choices as well as software design. Software design not only includes the game or tasks required for rehabilitation, but also includes features of the package such as quantitative assessment of disability prior to the treatment, computing quantitative performance measures, tracking and storing patient progress reports and automatically adjusting the level of difficulty according to each patient’s ability.

3. Data Acquisition for Rehabilitation

Different methods have been used for data acquisition in rehabilitation therapy. The conventional methods include marker-based systems (Gabel, et al. 2012), force plates (Gabel, et al. 2012), wearable motion sensors (accelerometers and gyroscopes (Kavanagh and Menz 2008)), PIR (passive infrared) motion sensors (Kaye, et al. 2012) and markerless motion capture systems (Moeslund, Hilton and Kruger 2006). Although they each have advantages, they have some limitations regarding their use in VR. Some need a very large well-controlled environment like a laboratory and are not suitable for in-home monitoring, some have limited motion tracking, and markers and sensors need to be precisely placed on the body. Furthermore, most of them are very expensive.

With the spread and decreasing cost of new gaming technologies, different game controllers and sensors which detect and track the patients’ movements have been used for VR systems. These are described below:

a) **Wii Balance Board:** composed of four pressure sensors. Information is transmitted wirelessly to the computer. User can perform balance exercises while standing, sitting, or kneeling (Kozyavkin, et al. 2012).
b) **Wii Remote:** composed of two accelerometers that transmit information about the position of the body part they attached to (Kozyavkin, et al. 2012).
c) **Wii MotionPlus:** measurs angular rate around three axes (Geurts, et al. 2011).
d) **EyeToy Camera:** supports computer vision and gesture recognition. Players interact with the game using motion, color detection and sound (Rehabilitation of stroke patients using virtual reality games 2010). Sony PlayStation3 Eye Camera (Graaf 2010), is a successor of the EyeToy.
e) **P5 Glove:** used to detect finger motion and the position and orientation of the hand (Arunkumar, et al. 2013).
f) **Kinect:** is a single, low cost, vision-based sensor device that allows for a 3D representation of the environment. It is composed of: RGB camera, IR emitter and IR depth sensor, multi-array michrophones, and 3-axis accelerometer for the following purposes: capturing a color image, forming a depth image, capturing sound, and determining the kinect orientation respictevely (Rego, Moreira and Reis 2014).

The Kinect sensor provides skeletal tracking and can retrieve twenty joints coordinates of the tracked user. Kinect is wireless and markerless thus offering total freedom in movement. The precision in the computation of joint angles using the Kinect was shown to be sufficient for most clinical rehabilitation treatments compared to a professional optical motion capture system (Baena, Sus´ın and Lligadas 2012).

Fig. 1 shows different game controllers and sensors used for virtual rehabilitation. Fig. 2 shows the Kinect sensor and its components.

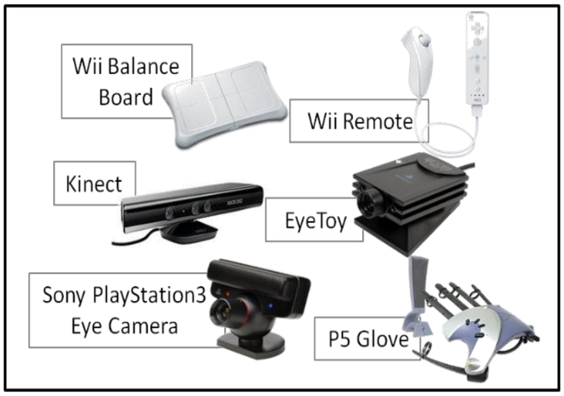

Fig. 1. Game Controllers.

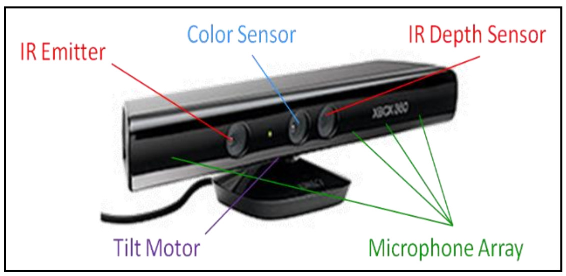

Fig. 2. Kinect Sensor.

4. Virtual Rehabilitation Systems

Table I. shows a comparison between VR systems surveyed in this work. For each system, the table includes the following information: the name of the system or game, the type of sensor used to track patient motion, and the targeted rehabilitation objectives. It also includes information about whether the system includes quantitative pre-rehabilitation assessment, whether it is self-adaptive meaning it automatically changes the level of difficulty according to patient performance. This feature reduces patient boredom if the task is too easy and patient frustration if the task is too difficult. Finally, the table includes whether the system provides a reporting capability to store patient records and progress and whether the system can be used in the home setting.

5. Conclusion

A survey of the literature and a comparison of the technical design aspects of VR systems were carried out. The comparison included both the hardware used as well as the software design. It was found that most current VR systems use commercial gaming sensors which are easily available and low cost. Regarding the software, there is a huge variety of games targeting most neuromuscular disabilities. Most systems were designed for training only and a few were designed for assessment only. Three systems included both assessment and training. Only three systems were self-adaptive. The limitation of this work is that it is not a comprehensive review of the literature. However, the authors have found no other similar technical comparison between the technical features of existing VR systems. This study can thus serve as a baseline for further development and improved design of VR systems.

Table. 1. Comparison of Systems for Virtual Rehabilitation

Author, Year, Reference	*System Name*	*Game Controller*	*Function*	*Features*			
				Self-adaptive	*Reporting capability*	*Assessment /Training*	*Home use*
(Davaasambuu, et al. 2012)	ExtremeTuxRacer	Kinect	Movements (walking, sitting, standing, jumping, & swinging the hands)	No	No	training	Yes
(Arunkumar, et al. 2013)	3D virtual kitchen rehabilitation game	Kinect P5 Glove (finger motion detection)	- mass flexion/extension of the digits - forearm pronation/supination - elbow extension - shoulder abduction	No	No	training	Yes
(Kozyavkin, et al. 2012)	Doggie, Turbo Racing,….	Wii balance board Kinect a joystick	Balance function	No	Yes	training	Yes
(Calin, et al. 2011)	MIRA (BeatBalls, Puzzle, Butterfly…)	Kinect	- extension& flexion of shoulder and elbow - rotation of the shoulder - dexterity and reflexes of the hand - detailed finger motion	No	Yes	training	Yes
(Dukes, et al. 2013)	Duck shoot	Kinect	Upper limb rehabilitation	No	No	training	No
(Geurts, et al. 2011)	Catching Dishes	Webcam	Stretching and bending of the arms	Yes	No	training	Yes
	Collecting Eggs	Wii remote MotionPlus	Maintaining balance standing on one leg				
	Preparing Recipes	Wii remote	Controlled head movements				
	Flying Dragons	Balance board	Transfer of weight and balancing when seated				
(Tsoupikova, et al. 2013)	Tea Party (from the classic story of Alice in Wonderland)	Pneumatic glove (finger) Magnetic trackers (head and hand)	Hand Rehabilitation Reach-to-grasp movements; - grab and objects, - use individual fingers for finger painting, - rotate the arm	No	No	training	No
(Turolla, et al. 2013)	2 Scenarios of reaching movement	3D motion-tracking system	Upper limb motor function	No	No	training	No
(Su 2013)	KHRD	Kinect	Shoulder rehabilitation	No	Yes	training	Yes
(Freitas, et al. 2012)	Dolphin Adventure, RealRehabilitation	Kinect	Upper limb rehabilitation	No	Yes	training	Yes
(Shin, Ryu and Jang 2014)	RehabMaster: Underwater fire game	OpenNI-compliant depth sensor	Forearm movement and eye-hand coordination	No	No	training	Yes
	Goalkeeper game		Upper extremity, endurance, and ROM				
	Bug hunter game						
	Rollercoaster game		Upper extremity and trunk movements				
(Huber, Leeser and Sternad 2013)		Kinect	Diagnose impairment in patient functional ability	No	Yes	both	Yes
(Norouzi-Gheidari, et al. 2013)	Jintronix rehabilitation game-based system	Kinect	Upper limb rehabilitation	No	Yes	training	Yes
(Pirovano, et al. 2012)	Fruit Catcher 2 Scenarios (Weight Shifting & Stepping)	Wii Balance Board Kinect	Balancing ability Movement	Yes	Yes	training	Yes
(Stone and Skubic 2013)		Kinect	Gait analysis (Walking Speed, Stride Time, stride lenght)	No	Yes	assessment	Yes
(Skelton 2011)		Kinect	Arm joint angles for the motor arm exercises	No	Yes	assessment	Yes

Error! Reference source not found.		Kinect	full body gait analysis measure arm kinematics and stride information	No	Yes	assessment	Yes
(KitsunezakiKi, et al. n.d.)		Kinect	walking time measurement joint angle ranges measurement	No	Yes	assessment	No
(Lewis and Skelton n.d.)		Kinect	motor leg and motor arm	No	Yes	assessment	Yes
(Web-2)	OmniVR™	Advanced 3D camera	Walking, balance, gait, upper extremity, seated exercises	No	Yes	both	Yes
(Cameirao, et al. 2010, 2011)	Rehabilitation Gaming system (RGS), Spheroids	Camera Glove Virtual arms	Upper limb rehabilitation	Yes	Yes	both	Yes

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