Use of Gaming Sensors and Customised ExerGames for Parkinson's Disease Rehabilitation

A proposed Virtual Reality Framework

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Abstract— **The research in –progress presented in this paper proposes the use of a low-cost, customized and off-the-shelf motion capture system (employing commercial game controllers) with bespoke video games tailored to suit the requirements of Parkinson's Disease (PD) rehabilitation protocol. The proposed system is designed to capture various movements of the upper limbs, unilateral or bilateral, and the motion captured is represented one-to-one in the virtual world of the video game. Furthermore, the captured data is fed online to a Virtual Reality (VR) instructor platform to realize the potential of live biofeedback and game difficulty adjustment by the clinician. The pilot study design for evaluating the proposed platform is also presented.**

Keywords—Parkinson's, rehabilitation, physiotherapy, wiimote, exergames, serious games, virtual reality, customised, motion analysis, difficulty adjustment

I. Introduction

Parkinson's disease (PD) is a slowly progressing neurodegenerative brain disorder. PD is caused by the reduction of the neurons in the substantia nigra, the brain area responsible for the dopamine production. This fact itself provides enough evidence for the debilitating motor and non-motor symptoms of a Parkinson's patient.

It is estimated that 6.3 million people suffer from PD worldwide [1], with no discrimination to race or cultural background. According to statistics, PD patients in the USA numerate about 1 million [2] , in Europe there are over 1,2 million [3] and in the UK alone there are about 120,000 patients, according to HESonline [4] and Parkinson'sUK [5]. The age group mostly affected by PD is between 60-79 years [5], nevertheless there are cases of PD in the age range of 20-39; the "the young outset" of PD.

The motor deterioration symptoms are characterized by four cardinal features: Tremor, Muscular Rigidity, Bradykinesia or Hypokinesia and Postural Instability.

A. Motor Symptoms

The motor symptoms of PD are the following [6]:

- Tremor is the involuntary shaking/tremble of the various parts of a patient's body.
- Postural Instability is the tendency of the patient to fall caused by the impairment of the righting reflexes.
- Rigidity is the inflexibility or stiffness of the limbs or joints of the patient.
- Bradykinesia as a term is used often to describe the closely related symptoms of Akinesia and Hypokinesia. Bradykinesia is the decrease of speed of movement during task performance or the difficulty to initiate movement spontaneously.

B. Physical Rehabilitation

After the diagnosis of PD and the classification of the patient through the Unified Parkinson's Disease Rating Scale (UPDRS), exercised-based interventions are an essential part of the rehabilitation regime of the patient, especially the ones that are not to undergo a surgical procedure[7]. Numerous studies have proven the efficacy and motor function stabilization as well as the improvement of the quality of life of the PD patient, through rehabilitation interventions that include physical exercise as reviewed in [8]. Apart from the generic physical activity rehabilitation protocols, target-specific strategies have been developed and very widely prescribed with the Training BIG protocol being the one mostly applied [9]. Furthermore, special behavioural strategies have been developed to train patients to compensate motor functions. For example, visual and auditory cues have been used to overcome the symptoms of PD like freezing, postural impairments and gait [10].

The high numbers of PD patients as well as their age group suggest home-based rehabilitation as a fundamental solution towards the reduction of the therapy costs. Moreover, the use of VR interventions has been shown to have positive effects in comparison with physical reality; not only in PD but in other motor degenerating conditions as well [11]. Additionally, several studies have been conducted on the use of commercially available gaming consoles and the dopamine release effects related to playing them as the latter occurs with every kind of physical activity [12][13]. The problem here is that commercially available video games have to be customised in order to comply with the rehabilitation

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requirements presented above. Therefore, the home-based VR and customised video games solution for PD rehabilitation is enabled as a favourable strategic solution in the quiver of the clinicians when they come to prescribe rehabilitation instructions to PD patients.

II. Summary of Related Work

There is a wide range of studies available in the literature that takes into account the use of VR technologies as assessment or rehabilitation interventions. The capture of the motion is performed through the use of highly precise equipment, namely infrared cameras, or with gaming sensors like the Wiimote, Microsoft Kinect, Playstation Eye, joysticks or webcams. Amongst these studies, some of them utilise visual and auditory cues like [14], [15], [16] and [17] and a number of them employs Training BIG as the rehabilitation protocol ([15], [16] and [17]). Although the latter studies fulfil the favoured rehabilitation protocol and also utilise sensory cues, all of them are restricted to capturing movement on the frontal plane due to the restrictions of the motion sensors employed. This fact significantly constrains the range and number of targeted rehabilitation exercises. Furthermore, there is lack of biofeedback in terms of accurate quantitative analysis of motion that would be beneficial to the clinician; for example the range of rotation of a given limb in Euler angles.

Therefore, the literature review indicates that there is no prior study to the best of our knowledge that fulfils all of the following requirements which are proposed by our system:

- *Accuracy*: The motion capture system, utilised for the purposes of a study as this, should be very accurate as the biofeedback is to be analysed to evaluate the performance and progress of the patient.
- *Home-based solution:* The gaming sensors that are to be employed for the motion capture need to be commercially available and of low-cost.
- *Real-time biofeedback:* The rehabilitation platform should realise the potential of real-time biofeedback to the clinician.
- *Custom Games:* The designed games should enable visual and auditory cues, and adjustable level of difficulty that can monitored remotely by the clinician. The genre of these games is also referred to by the term “exergames” which is a portmanteau of exercise and game.
- *PD Rehabilitation Protocol:* The designed games should be a translation of Training BIG exercises into VR games. The proposed system must be very flexible so that the translation of any exercise into a mini-game to be very easy to accomplish.

The abovementioned requirements are met by the system proposed by this paper. Following is a presentation of the design of such a system.

III. Design of the Proposed Framework

The aforementioned problem presents potential application for home-based rehabilitation strategies that utilise commercially available gaming sensors like the Nintendo Wii and bespoke computer games. This paper proposes and presents a VR framework that consists of a motion capture device, namely the Nintendo Wiimote, a custom video game to correspond the rehabilitation requirements and a VR instructor platform to realize the potential of live biofeedback and difficulty adjustment to the clinician. Figure 1 illustrates the schematic diagram of the proposed system.

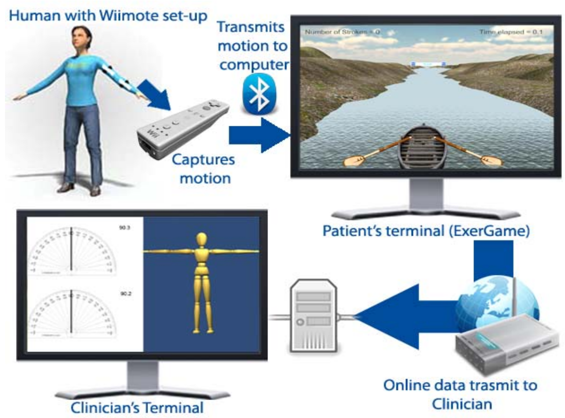

Fig. 1. Schematic Diagram of the Proposed Framework

A. Motion Capture System

The motion capture system employed for the purpose of this research comprises of an off-the-shelf gaming sensor, i.e. the Ninteno Wiimote, and a bespoke communication interface between the Wiimotes (up to two) and local or computers via Bluetooth and Internet. The motion data received by the terminals undergo a process of smoothing and multiplexing using a data fusion algorithm in order to achieve higher accuracy and precision. The end results are mapped into quaternion forms that translate the orientation of a constructed 3D body model and also are free from gimbal-lock. The angular rate measurements captured by the gyroscope sensor can be used to distinguish true linear motion from the accelerometer readings. The gyroscope is not free from noise, but since the measured rotation is less sensitive to linear mechanical movements and without amplifying hand jitter, both of which accelerometers suffers from, it allows capturing more complex orientation with a relatively better estimate than we would obtain by using accelerometers alone. A sensible approach for maximising efficiency is to average or concatenate the data that comes from the accelerometer and gyroscope by using a data fusion algorithm and simultaneously, we have been able to employ a smoothing algorithm to remove any excessive noise from the signals while still retaining the useful information. Filtering out and removing as much random noise as possible from the sensors’ output raw information whilst retaining quality data is of fundamental importance [18][19]. The Wiimote sensors are very responsive, but they cannot respond to the linear movement accelerometers specialise in. Yet, as described in the above section, when a gyroscope and an accelerometer are combined, the pairing of sensors facilitates a highly accurate one-to-one representation of the control device in 3D space. The quaternion data is forwarded locally or online and thusly can manipulate a virtual 3D object on the local computer (exergame) or provide the biofeedback to the clinician's party (remote terminal).

B. Pilot Games

As stated in the previous section, the orientation data captured with the aid of the Wiimotes is sent online to the connected terminals. The data represents the movement of the selected limbs of the patient in 3D space. This movement has to be mapped to a virtual object within the game and according to the game mechanics to provide feedback to the patient playing it. The challenge of designing such a game is to match the targets of each exercise in a manner that will represent an engaging activity. We have designed two pilot games as case studies that represent two unique exercises with different rehabilitation targets. The exercises were referred in [20] and customised accordingly to match computer gameplay.

Fig. 2. "Arm Reaching" Exercise [20]

The Rowing game: The player will control a two-paddled row boat (bilateral movement) and the challenge will be to reach a specific point at a given time. The targeted exercise is shown in Figure 2.

- Target: Speed, rigidity, range of movement, bilateral movement
- Biofeedback (to be measured in the game and displayed in the Clinician Platform): Range of movement of upper limbs in Euler degrees, speed in m/s^2, spontaneity of movement etc.

Arm (both arms simultaneously) reaching exercise from a seated position. Visual cues will appear on the screen to direct player's movement. Audio will be used to set the rowing tempo.

The Water Valve Mini golf game: The player has to rotate the valve in several repetitions in order to release steam to push the ball into the hole within a given time. The targeted exercise is shown in Figure 5.

Fig. 3. The Rowing Game Screenshot

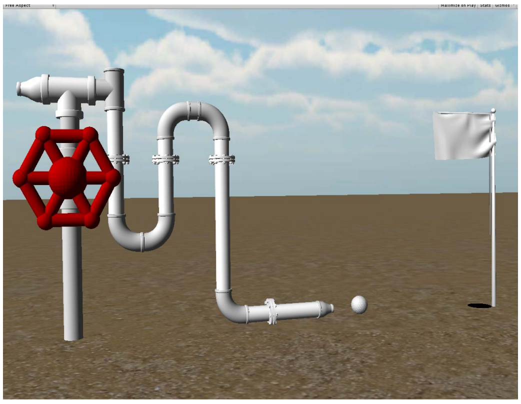

Fig. 4. The Mini-Golf Game Screenshot

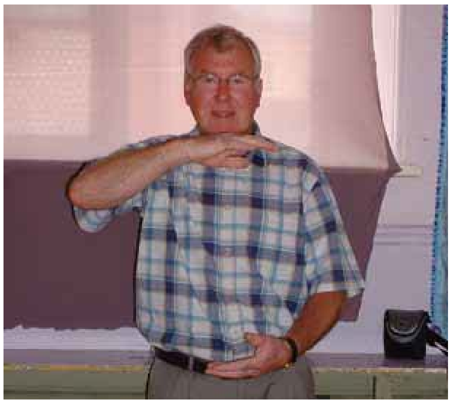

Fig. 5. "Rolling a ball" exercise [20]

Visual cues will appear on the screen to direct player's movement. Audio will be used to set the rotation tempo.

- Target: Speed, rigidity, range of movement, bilateral movement
- Biofeedback (to be measured in the game and displayed in the Clinician Platform): Range of movement of upper limbs in Euler degrees, speed in m/s^2, spontaneity of movement etc.

The two cases presented above are two physiotherapy exercises, prescribed by the Parkinson's Disease Society, translated into mini-games that will engage the patient enabling the home-base rehabilitation to become more motivating and immersive. On top of that, the clinician will be provided with real-time biofeedback realising the potential to regulate the level of difficulty of the performed action as well as to record the data for future reference and further analysis through the proposed Clinician Platform.

C. Clinician Platform

The Clinician Platform is the tool of the health professional to monitor in real-time the performance of the patient that can be in a remote location. The platform we design is an easy-to-use tool that very simply realises the opportunity to the clinician to manipulate the prescribed exergame and provides with the biofeedback of the targeted parameter. For example in the first exergame, the biofeedback which as stated is the speed and range of movement (in degrees) will appear on the screen of the clinician live while the patient performs the repetitions required to accomplish the given task.

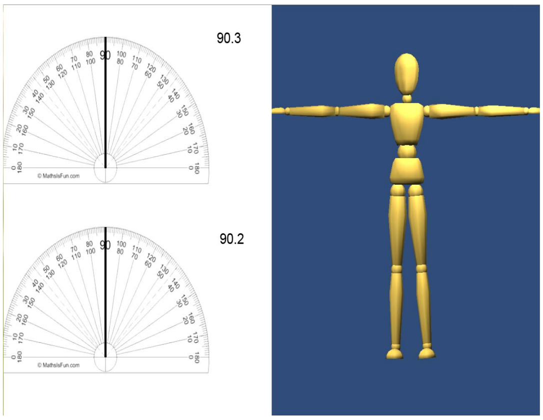

Fig. 6. Screenshot from the Clinician Platform

IV. PILOT STUDY DESIGN

The aim of the pilot study is twofold. Firstly to investigate the acceptability, user experience and appropriateness of he designed games; and secondly to evaluate the Clinician Platform on the accuracy and usefulness of its feedback.

Three to five participants will be recruited for the pilot. These will be PD patients in the early/mid stages of PD who are currently on medication. The pilot will take place in a research lab and each session will last an hour. Participant information will be collected prior to the study. Participants will be shown and given the opportunity to familiarise with the two games and then be asked to engage with these. Each session will be recorded using video cameras. Also the biofeedback (including Wiimote motion capture) of each game session will be recorded by the system for later analysis. A questionnaire will be distributed after each session and a focus group will also take place with all study participants.

After the completion of the pilot all data will be analysed and user feedback will be employed to modify the games and Clinician Platform accordingly in order to repeat the pilot in a few weeks.

V. CONCLUSION

The proposed VR rehabilitation framework for PD consists of a customised motion capture system utilising a commercially available and low-cost sensor, a customised exergame and a biofeedback platform. It has the ability to send biofeedback data in real-time to remote locations. Furthermore, the game mechanics follow therapy-relevant physical rehabilitation protocols, including sensory cues such as visual and auditory feedback to the patient. A pilot study has been also designed in order to measure the platform and the designed games' usability, user experience (patient and clinician) and accuracy of motion data results.

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REFERENCES

[1] "About Parkinson's Disease." [Online]. Available: http://www.medtronic.com/patients/parkinsons-disease/index.htm.

[2] "Statistic's on Parkinson's." [Online]. Available: http://pdf.org/en/parkinson_statistics.

[3] P. Andlin-Sobocki, B. Jönsson, H.-U. Wittchen, and J. Olesen, "Costs of disorders of the brain in Europe.," *European journal of neurology□: the official journal of the European Federation of Neurological Societies*, vol. 14, no. 2, p. e9, Feb. 2007.

[4] "Hospital Episode Statistics on Parkinson's HESonline NHS." [Online]. Available: http://www.hesonline.nhs.uk/Ease/servlet/ContentServer?siteID=1937&categoryID=868.

[5] "Parkinson ' s prevalence in the United Kingdom," 2009. [Online]. Available: http://www.parkinsons.org.uk/pdf/ParkinsonsprevalenceUK.pdf.

[6] J. Jankovic, "Parkinson's disease: clinical features and diagnosis.," *Journal of neurology, neurosurgery, and psychiatry*, vol. 79, no. 4, pp. 368–76, Apr. 2008.

[7] A. Moroz, S. R. Edgley, H. L. Lew, J. Chae, L. a Lombard, C. C. Reddy, and K. M. Robinson, "Rehabilitation interventions in Parkinson disease.," *PM & R□: the journal of injury, function, and rehabilitation*, vol. 1, no. 3 Suppl, pp. S42–8; quiz S49–50, Mar. 2009.

[8] H. Gage and L. Storey, "Rehabilitation for Parkinson's disease: a systematic review of available evidence," *Clinical Rehabilitation*, vol. 18, no. 5, pp. 463–482, Aug. 2004.

[9] B. G. Farley and G. F. Koshland, "Training BIG to move faster: the application of the speed-amplitude relation as a rehabilitation strategy for people with Parkinson's disease.," *Experimental brain research. Experimentelle Hirnforschung. Expérimentation cérébrale*, vol. 167, no. 3, pp. 462–7, Dec. 2005.

[10] B. G. Farley, C. M. Fox, L. O. Ramig, and D. H. Mcfarland, "Intensive Amplitude-specific Therapeutic Approaches for Parkinson ' s Disease," vol. 24, no. 2, pp. 99–114, 2008.

[11] M. F. Levin, O. Snir, D. G. Liebermann, H. Weingarden, and P. L. Weiss, "Virtual Reality Versus Conventional Treatment of Reaching Ability in Chronic Stroke: Clinical Feasibility Study," *Neurology and Therapy*, vol. 1, no. 1, p. 3, Aug. 2012.

[12] A. Sugumaran and A. Prakash, "Wii can rehabilitate□?," no. April, pp. 228–229, 2011.

[13] N. Ben Herz, “The Nintendo Wii© and PD,” *parkinson.org*, pp. 7–8, 2008.
[14] D. Lilla, M. Herrlich, R. Malaka, and D. Krannich, “The Influence of Music on Player Performance in Exergames for Parkinson ’ s Patients,” pp. 433–436, 2012.
[15] W. Yu and T. Ingalls, “An Interactive Multimedia System for Parkinson s Patient Rehabilitation.”
[16] C. H. Vuong, T. Ingalls, and J. J. Abbas, “Transforming clinical rehabilitation into interactive multimedia,” *Proceedings of the 19th ACM international conference on Multimedia - MM ’11*, p. 937, 2011.
[17] O. Assad, R. Hermann, D. Lilla, B. Mellies, R. Meyer, L. Shevach, S. Siegel, M. Springer, S. Tiemkeo, J. Voges, J. Wieferich, M. Herrlich, M. Krause, and R. Malaka, “Motion-Based Games for Parkinson ’ s Disease Patients,” pp. 47–58, 2011.
[18] E. Tsekleves, D. Skordoulis, I. Paraskevopoulos, C. Kilbride, and A. Warland, “Wii Your Health: A Low-Cost Wireless System for Home Rehabilitation after Stroke using Wii Remotes with its Expansions and Blender,” in *Proceedings of The …*, 2011.
[19] E. Tsekleves, D. Skordoulis, I. Paraskevopoulos, C. Kilbride, and A. Warland, “Personalised stroke rehabilitation intervention using open source 3D software and the Wii Remote Plus,” 2012, pp. 10–12.
[20] R. Webber and B. Ramaswamy, “Keeping Moving - Exercise and Parkinson’s.”