Proposal of a Kinect^{TM}-based system for gait assessment and rehabilitation in Parkinson's disease

Jorge Cancela, Maria T. Arredondo and Olivia Hurtado

***Abstract*—It has been proved that audio and visual cueing can improve the motor performance of Parkinson's disease patients. Specially, gait can benefit from repetitive sessions of exercises using cues. Nevertheless, these effects are not permanent and fade away with time, in that sense, home game systems can be an excellent platform for patients to perform daily exercises, as well as to coach and guide them in a smarter way. Within this work a method to track the walking movement is proposed based on the signals coming from the Kinect sensor of Microsoft. At the same time, different setups have been tested in order to study the feasibility of using this sensor to build a game platform for gait rehabilitation for Parkinson's disease patients.**

I. Introduction

Chronic diseases are prolonged conditions that normally do not improve with time and are rarely cured completely. Most of these diseases are closely bound with age. Longer life expectancy is directly related with the increasing numbers of people living with chronic conditions, not only one but in most cases two or three chronic conditions at the same time. In almost every country, the proportion of people aged over 60 years is growing faster than any other age group, as a result of both longer life expectancy and declining fertility rates. According to the World Health Organization forecast between 2000 and 2050, the proportion of the world's population over 60 years will double from about 11% to 22%. The absolute number of people aged 60 years and over is expected to increase from 605 million to 2 billion over the same period [1]. The prevalence of Parkinson's disease (PD) in industrialized countries is generally estimated at 0.3% of the entire population and about 1% in people over 60 years of age. Reported standardized incidence rates of PD are 8 – 18 per 100000 person-years. Onset of PD is rarely before age 50 years and a sharp increase of the incidence is seen after age 60 years [2]. About 20% of people over the age of 80 have Parkinsonism associated gait disturbances. The major motor disturbances in PD are bradykinesia (i.e. slowed movement), hypokinesia (small amplitude movements), resting tremor, rigidity, and postural instability [3]. These major motor features of PD are associated with, and are largely a result of, the loss of dopaminergic innervation of the basal ganglia.

Research supported by CEI Moncloa and European Commission through the 7th Framework Programme project PERFORM (Grant Agreement 215952).

J. Cancela is with the CEI Campus Moncloa, UCM-UPM and with the Life Supporting Technologies, Technical University of Madrid (UPM), Madrid, Spain (e-mail: jcancela@lst.tfo.upm.es).

M.T. Arredondo is with Life Supporting Technologies, Technical University of Madrid (UPM), Madrid 28040 Spain (e-mail: mta@lst.tfo.upm.es).

O. Hurtado is with the Departamento de Farmacología, Facultad de Medicina, Universidad Complutense de Madrid, Madrid, Spain (e-mail: olhurtad@med.ucm.es).

Several studies pointed out that repeated gait exercises lead to significant results in gait rehabilitation [4], [5]. Furthermore, several works have being using external cueing techniques as recurrent tool used in order to help the patient to improve their gait parameters [6]–[9]. There are two main types of cueing used: audio cueing and visual cueing. All the experiments show that gait of PD patients can be improved by a long and repeated treatment made of exercises. The tools used to coordinate the patient are the ones which can provide a certain rhythm. Cueing appears like a good solution in Parkinson's disease gait rehabilitation, because it provides a good rhythm regulator that can adapt to the patient preferences for a cheap cost. At the same time, it has been showed that games contribute to increase motivation in rehabilitation sessions, which is the major problem in therapy sessions, caused by the repetitive nature of exercises [10]. With respect to long-term motivation, apart from methods and concepts for personalization and adaptation, multiplayer games can provide additional stimulation compared to single player games [11]. In a previous work we elaborated a review of games for health focus on Parkinson's disease [12]. Most of the games focus on the repetition of movements following visual and audio cueing. Combining auditory and visual cues with games seems to be a promising research field for the PD rehabilitation. Keeping the patients motivation and engage them in the daily practice has special relevance in PD rehabilitation since the effects of gait improvement are not permanent and fade away with time. For this reason, it could be interesting to move the rehabilitation process to the patients' homes, given them more flexibility to exercise in a daily basis in their own homes using already existing game platforms as distribution channel.

This work is the first step to build a game platform for PD gait rehabilitation. It is aimed to explore the feasibility of using the Kinect sensor as input method to build a platform able to study the walking movement with enough accuracy. In this initial phase only healthy subjects were considered in order to validate the feasibility of using the Kinect sensor to track and study the walking movement before involving real PD patients. To achieve such goal a Finite-State Machine (FSM) is proposed to model the walking movement according to a well-known human walking model. Furthermore, this work explores different configurations of the Kinect sensor in order to determine the best setups to maximize the accuracy in the walking identification. In the next section, the experimental scenario is described providing information about the software that has been developed as well as the users and the description of the experiments that have been carried out. Then, the methodology section describes the algorithms that have been implemented to model the walking movement, the result section analyses the outcomes of the experiment and finally the last section introduces some conclusions and future work.

II. Experimental Setup

The chosen sensor was the Microsoft® Kinect™ because of its capabilities and contained price. Therefore, as it was previously mentioned, the aim of this work is to explore the Kinect sensor as an input system for the gait assessment in order to build a platform for gait rehabilitation through gaming. Within this work the phase of the project is described, during this initial phase different setups were carried out to evaluate the feasibility of the Kinect to assess the gait and walking movements.

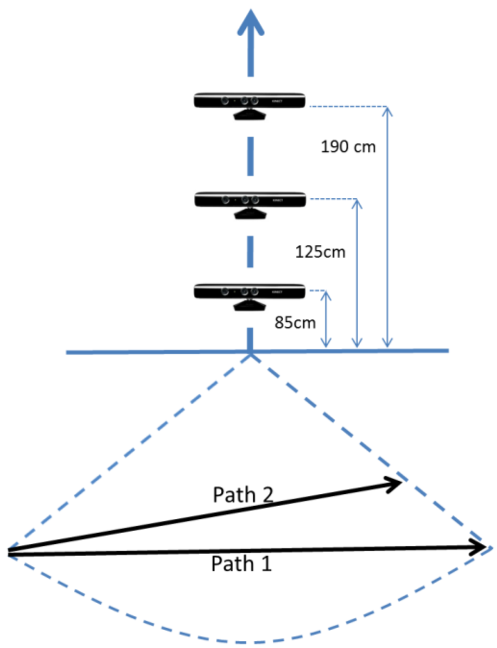

Figure 1. Experimental setup configuration

The Kinect is a motion sensing input device which was launched in November 2010. The Kinect sensor features a RGB camera, a depth sensor and a multi-array microphone which provides full-body 3D motion capture, facial and voice recognition capabilities. It is also able to automatically process a joints' tracking (such as head, right/left foot …). To handle the interactions between the application and the patient, this application uses the Kinect SDK v1.7.0 which was available since March 18th, 2013.

With this preliminary experiment with healthy subjects we tested the ability to identify and track the walking movements of each subject, when they follow different paths in in front of the Kinect sensor. This last point is extremely important since the accuracy of the measurements differs from one to another. 17 healthy subjects have been involved in this experiment with an average age of 28.52±4.69 years old. Figure 2 shows one of the subjects performing a gait test. The Kinect was placed on three different heights (85cm, 125cm, and 190cm). For each height all the users were asked to walk along two different paths, one parallel to the Kinect sensor and the second one approximately 20º closer to the sensor. Figure 1 shows a scheme with the different the setups and paths. Each path was drawn with landmarks on the floor with 60cm between each mark. While he was walking, the subject had to follow three different rhythms (40bpm, 80bpm, 120bpm). Each subject had to perform 18 tests per session (3 height x 2 paths x 3 rhythms).

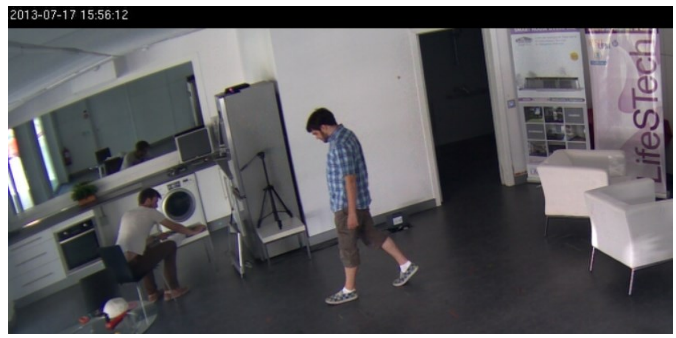

Figure 2. User performing a test session

The software developed for this initial prototype was:

- The Graphical User Interface (GUI). It is the part of the application that allows the interaction between the user and the software. In this version of the application the GUI shows the users already registered in the database. It also allows the user to start the next test and finally it shows information about the progress of the test (error, feedback information, status, etc…). It also provides instructions about how to proceed in each phase of the test.
- Database and database module. A MySQL database was set up to store users' data as well as the results of the performed tests. The database module is a software piece that works as interface between the application and the MySQL database.
- Kinect Module. It reads the Kinect sensors and analyzes the raw data in order to, firstly detect the walking movement and secondly segment these moments and extract parameters related with the subject gait such as step length, stride length and speed. This is the module where all the calculations and signal processing is performed and it is addressed in detail in the next section.

III. Methodology

As it was abovementioned we explore different setups of the Kinect sensor to assess the gait performance of different subjects walking through two different paths. The Kinect sensor provides a Skeleton Frame through its SDK which is refreshed 30 times per second. It provides information about 20 joints represented with 3 coordinates (x, y, z) which gives the spatial position of the joint. There are three different tracking nodes provided by the Microsoft Kinect: 1)

Tracked, The joint is in the Kinect field and its coordinates are correctly determined; 2) inferred. The joint is not in the Kinect field but its coordinates are calculated using the well tracked joints; and 3) not tracked: The joints coordinates can't be determined. In default range mode, Kinect can see people standing between 0.8 meters and 4.0 meters away; users will have to be able to use their arms at that distance, suggesting a practical range of 1.2 to 3.5 meters [13].

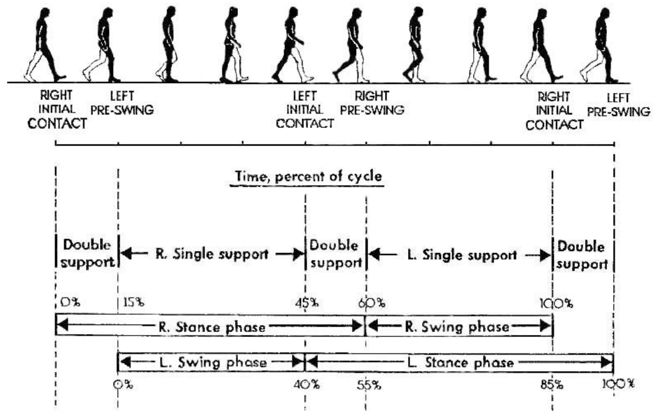

Figure 3. Human walking model [14]

The Figure 3 shows a diagram to study the gait cycle introduced by Inman et al. in 1981 [14] and widely used to study and model the human walking. According to it a subject performs a walking movement alternating from a Double Support (DS) phase to a Single Support (SS) phase, defined as follows:

- DS: period during which both feet are in contact with the floor. Both the beginning and the end of the stance phase are considered to be double-support period.
- SS: period starts when the opposite foot is lifted for the swing phase

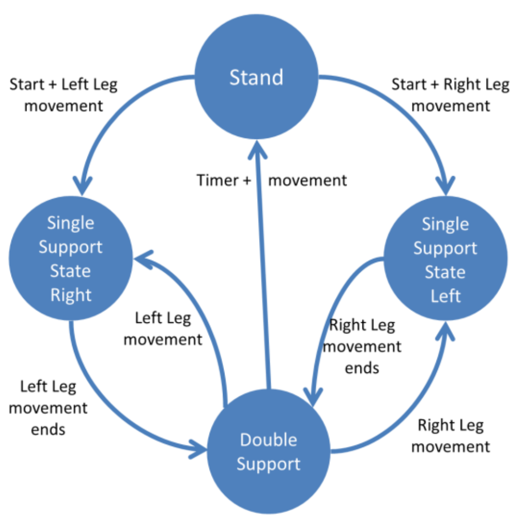

Figure 4. Implemented Finite-State Machine

As reference, in healthy subjects a DS usually comprises 20% of the normal gait cycle versus 80% of SS. The amount of time spent during double-limb support decreases as the speed of walking increases. Walking is differentiated from running, because in the latter there is no double-support period [15]. Based on this model a Finite-State Machine has been implemented within the Kinect module. The Figure 4 shows the scheme of the developed FSM. In this FSM the DS and SS (with the left and right leg) together with the stand position are the states of the FSM and the detection of leg movements are the events to trigger the change from one state to another. Using the FSM to analyze the signal coming from the Kinect sensor, Figure 5, it is possible to model the walking movement studying the transitions between the DS and SS states. And, consequently, it is possible to obtain several gait parameters [16]:

- Step length: One step is the action performed from one Single Support State to another Single Support State. For each step we calculate the time length, the distance moved by the subject and the arm swing range (the arm swing is an interesting parameter to be studied in the gait assessment [17]).
- Stride length: One stride is the action performed from one Double Support State to another Double Support State. For each step we calculate the time length, the distance moved by the subject.
- Velocity: with the information of the timestamp and the distance it is possible to know the velocity of each step and stride.
- Cadence or walking rate: is calculated in steps per minute.

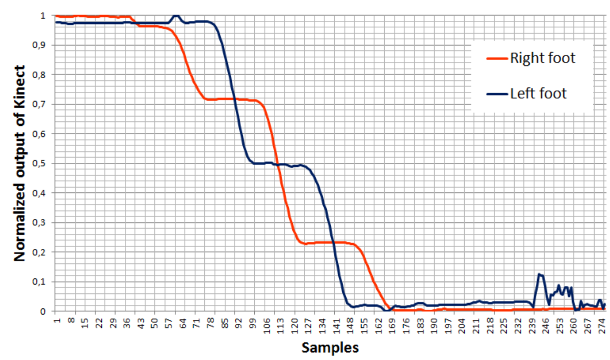

Figure 5. Normalized output signal (by subtracting the minimun and dividing by the range).

Even if the joint is well tracked, there is always an error margin between the joint's real position and the position given by the Kinect. For example, a joint which is not moving will not have constant for each of its coordinates. This problem leads to a possible loss of precision of the system.

IV. Results

The results obtained in this experiment have been summarized in TABLE I. It shows the detection error, i.e. the number of steps missed and the step length measure error, i.e. the error in the characterization of the step length (by comparing the output of our algorithm with the landmark references). These results are detailed by each path, height and rhythm that the subject should try to follow.

TABLE I. RESULTS TABLE

Path	Height (cm)	BPM	Results	
			Detection error (%)	***Step length measure error (%)***
1	85	40	20.51	8.17±3.36
		80	32.35	7.79±4.61
		120	23.52	8.91±4.26
	125	40	50.02	5.78±3.46
		80	32.55	6.97±3.42
		120	39.70	19.85±6.46
	190	40	22.05	4.16±7.75
		80	27.45	7.47±5.04
		120	21.56	6.92±6.74
2	85	40	11.76	5.08±5.25
		80	5.88	6.81±5.04
		120	33.33	8.41±4.02
	125	40	64.70	8.16±6.01
		80	56.86	5.14±9.23
		120	35.29	9.40±6.74
	190	40	70.58	6.99±4.78
		80	34.21	7.69±7.11
		120	74.50	11.62±13.34

We can observe that the step length measure error is quite homogeneous within all the configurations and the error rate is under acceptable thresholds in most of the cases. Nevertheless, the rate of step detection ranges in a wider way. The best results were obtained placing the Kinect sensor at 85 cm from the ground. Also, there is no apparent influence of the rhythm in these results. About the paths, Path 1 shows best results, especially in the detection phase.

V. CONCLUSION

Within this work we have shown the feasibility of the proposed FSM for gait modelling using a Kinect sensor from Microsoft. The Natural User Interface of Kinect allows the development of friendly games based in an intuitive human-computer interaction. Nevertheless, the continuous tracking of the walking movement can be sometimes being interrupted or misunderstood (e.g. confusion of left and right leg in the Kinect sensor); these issues can lead to mistakes in the interpretation of the raw data in the FSM and a degradation of the detection error. To guarantee a robust gait modelling the FSM should be improved to deal with these errors.

ACKNOWLEDGMENT

Research by Jorge Cancela has been partly supported by a PICATA predoctoral fellowship of the Moncloa Campus of International Excellence (UCM-UPM). This work was partially funded by the European Commission under the 7th Framework Programme projects PERFORM, CogWatch and HeartCycle (Grant Agreements 215952, 288912 and 216695).

REFERENCES

[1] WHO, “Ageing and Life Course,” 2013. [Online]. Available: http://www.who.int/ageing/about/facts/en/index.html. [Accessed: 29-Jul-2013].

[2] L. M. L. de Lau and M. M. B. Breteler, “Epidemiology of Parkinson’s disease.,” Lancet Neurol., vol. 5, no. 6, pp. 525–35, Jun. 2006.

[3] C. Tugwell, Parkinson’s Disease in Focus. Pharmaceutical Press, 2008, p. 237.

[4] T. Herman, N. Giladi, L. Gruendlinger, and J. M. Hausdorff, “Six weeks of intensive treadmill training improves gait and quality of life in patients with Parkinson’s disease: a pilot study.,” Arch. Phys. Med. Rehabil., vol. 88, no. 9, pp. 1154–8, Sep. 2007.

[5] O. Bello, J. a Sanchez, V. Lopez-Alonso, G. Márquez, L. Morenilla, X. Castro, M. Giraldez, D. Santos-García, and M. Fernandez-Del-Olmo, “The effects of treadmill or overground walking training program on gait in Parkinson’s disease.,” Gait Posture, Feb. 2013.

[6] M. F. Del Olmo and J. Cudeiro, “Temporal variability of gait in Parkinson disease: effects of a rehabilitation programme based on rhythmic sound cues.,” Park. Relat. Disord., vol. 11, no. 1, pp. 25–33, Jan. 2005.

[7] a Nieuwboer, G. Kwakkel, L. Rochester, D. Jones, E. van Wegen, a M. Willems, F. Chavret, V. Hetherington, K. Baker, and I. Lim, “Cueing training in the home improves gait-related mobility in Parkinson’s disease: the RESCUE trial.,” J. Neurol. Neurosurg. Psychiatry, vol. 78, no. 2, pp. 134–40, Feb. 2007.

[8] M. Suteerawattananon, G. S. Morris, B. R. Etnyre, J. Jankovic, and E. J. Protas, “Effects of visual and auditory cues on gait in individuals with Parkinson’s disease,” J. Neurol. Sci., vol. 219, no. 1, pp. 63–69, 2004.

[9] L. Rochester, K. Baker, V. Hetherington, D. Jones, A.-M. Willems, G. Kwakkel, E. Van Wegen, I. Lim, and A. Nieuwboer, “Evidence for motor learning in Parkinson’s disease: acquisition, automaticity and retention of cued gait performance after training with external rhythmical cues,” Brain Res., vol. 1319, pp. 103–111, 2010.

[10] P. Rego, P. M. Moreira, and L. P. Reis, “Serious Games for Rehabilitation A Survey and a Classification Towards a Taxonomy,” Heal. San Fr., pp. 1–6, 2002.

[11] S. Göbel, S. Hardy, V. Wendel, F. Mehm, and R. Steinmetz, “Serious Games for Health – Personalized Exergames,” Film, vol. 498, no. October, pp. 1663–1666, 2010.

[12] J. Cancela, M. Pastorino, M. T. Arredondo, and C. Vera-Muñoz, “State of the Art on Games for Health Focus on Parkinson’s Disease Rehabilitation,” in The International Conference on Health Informatics, Springer International Publishing, 2014, pp. 13–16.

[13] Microsoft, “Kinect for Windows SDK.” [Online]. Available: http://msdn.microsoft.com/en-us/library/hh855347.aspx. [Accessed: 09-Jan-2014].

[14] V. T. Inman, H. J. Ralston, and F. Todd, Human walking. Williams & Wilkins, 1981.

[15] S. Cuccurullo, H. Uustal, and E. Baerga, “Gait analysis,” 2004.

[16] J. Cancela, M. Pastorino, M. T. Arredondo, K. S. Nikita, F. Villagra, and M. a Pastor, “Feasibility study of a wearable system based on a wireless body area network for gait assessment in Parkinson’s disease patients.,” Sensors (Basel)., vol. 14, no. 3, pp. 4618–33, 2014.

[17] J. Cancela, M. Pastorino, M. T. Arredondo, M. Pansera, L. Pastor-Sanz, F. Villagra, M. A. Pastor, and A. P. Gonzalez, Gait assessment in Parkinson’s disease patients through a network of wearable accelerometers in unsupervised environments. IEEE, 2011, pp. 2233–2236.