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A reliability assessment software using Kinect to complement the clinical evaluation of Parkinson's disease

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***Abstract*— Parkinson's disease is characterized by alterations in the gait pattern that may increase the risk of falls. Variations in the gait pattern cannot be objectively measured in clinical examination, so it is necessary to adapt devices to measure objectively, valid and replicable changes in gait patterns that are part of the evolution of the disease and / or pharmacotherapy. In an interdisciplinary effort, we developed the "e-Motion Capture System" software, which is able to calculate motor (cadence, stride and step length) and spatiotemporal (velocity and acceleration) parameters that affect quality of life in patients with Parkinson's disease. In this paper, we show results of the comparison between our e-Motion software and a benchmark reference, multiple-camera 3D motion capture system to track a gait pattern. This analysis was performed to compare the spatial locations of the ankles of a volunteer under indoor controlled conditions. Our results for the comparison between e-Motion and the 3D motion capture system show excellent agreement.**

I. Introduction

Aging and related diseases, including Parkinson's disease, have become a worldwide public health problem due to the increase of health care costs. In the elderly population, alterations in gait and posture may increase the risk of falls and lead to mobility disability which, in turn, impacts activities and independence in daily life [1, 2]. The gait pattern in patients with Parkinson's disease is characterized by reduced walking speed, increased stance phase, decreased stride length and decrease in the amplitude of the lower limbs [3].

Gait variations cannot be objectively measured during clinical examination to track the course of the disease and make decisions in an effective manner. Available methods consist of complex motion capture systems that have limitations for access and use in the clinical setting; therefore, it is necessary to adapt devices to objectively measure subtle changes in gait patterns. Interest in the use of Kinect™ as a motion capture sensor in different contexts such as videogames can be identified in publications since the sensor was released with the console. Some studies reporting applications have been published, like new methods for real-time body tracking [4] and ergonometric workplace measurements [5]. After adapting this kind of device for different applications, it is necessary to evaluate its performance with respect to a reference method and define whether the methods are interchangeable or complementary through formal validations.

Some studies have carried out comparative analysis between benchmark references and Kinect™. An assessment of static foot posture found that using the Kinect™ measurements was more reliable than the traditional visual assessment of the Foot Posture Index [6, 7]. In postural control assessment for reach and standing balance, Kinect™ was compared to the benchmark system and the results showed an excellent concurrent validity with a P-value >0.9 [8]. In a walking test on a treadmill, Kinect™ measurements were not reliable for clinical measurement analysis due to variability in the hips test, although for knee and stride they were better correlated with the benchmark and may be a clinically acceptable tool [9]. The results found in the last study may be due to the Kinect™ being located in lateral view (45 degrees) in contrast with other studies where Kinect™ was in frontal view (90 degrees). Finally, in a gait assessment for Parkinson's Disease (PD) performed with patient and controls measurement using Kinect™ to discriminate between non-PD and PD subjects, the results showed that variance of the center shoulder velocity represents the highest value to differentiate [10].

Motor parameters affect quality of life in patients with Parkinson´s disease. In an interdisciplinary work we developed the "e-Motion Capture System", a software able to calculate from the position of ankle, motor (cadence, stride and step length) and spatiotemporal (velocity and acceleration).

Our interest is to determine and compare the reliability of the e-Motion Capture System, incorporating Kinect™ as the main capture device, and a multiple-camera 3D motion capture system in the gait laboratory during a walking test.

The paper is organized as follows: In section II we describe the systems being compared and the method to obtain the joints data location. In section III the results from analysis are shown. In section IV there is discussion of the results. Finally, in section V, we present conclusions and future work.

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II. Description of the System

An interdisciplinary team, consisting of specialists in neurology, neuropsychology, epidemiology, and information and communications technology engineering, developed the project.

A. E-Motion Capture System

The e-Motion Capture System is a software system based on Kinect™ that is able to calculate motor (cadence, stride length, and length step) and spatiotemporal (velocity and acceleration) variables. This system is part of the System for Neurological Diseases (SND) platform. SND stores all the information of the system and is responsible for the integrity and availability of data; additionally, it provides a summarized report about detailed records on the onset and ending of symptoms and their temporal relation to treatment.

The e-Motion system consists of four elements:

- A motion sensing device: Kinect™
- A computer with e-Motion.
- A capture area free of interference.
- A person to handle the system (physician or related).

The Kinect™ is a motion sensing input device developed by Microsoft for the Xbox 360® video game console and Windows OS. Based around an infrared camera, Kinect™ enables users to control and interact with the PC without the need to touch a controller [11]. This device was validated for the assessment of postural control against a benchmark reference [8].

B. Benchmark gait laboratory

The benchmark multiple-camera 3D motion capture system specialized in gait analysis consists of five elements:

- A set of optoelectronic infrared cameras (18 cameras).
- Passive reflective markers for each point of interest to analyze (at least 30 to 40 markers to represent all anthropometric joints for gait tracking).
- Computers and specialized software for processing all data frames (a network 1Gbps LAN, at least one server to process all 3D images, and Visual3D®).
- Capture area free of interference.
- At least two qualified staff to handle the entire system [12].

C. Capture area free of interference

The benchmark and e-Motion need a capture area free of interference. The area's dimensions are at least 4x4 meters for the benchmark and 4x1.5 meters for e-Motion, without objects, and with indoor conditions (lights and wind controlled).

III. Test Procedure

A. Capture area settings

Every test consists of one volunteer who walks down a corridor of about 4 meters length by 1.5 meters wide. Each volunteer is located at the far point, just in front of the Kinect™ (called point B), and walks directly to the Kinect™ (called point A, 5 meters away). At the end of the corridor, he turns on his own axis and returns to point B. A route has two paths: the first path is BA, towards the Kinect™. The second path is AB, towards the starting point. Three route-tests were conducted for a total of 18 paths, and the corresponding simultaneous captures with e-Motion and the benchmark system. The AB paths were discarded because the performance [13] of the Kinect™ is better when people walk towards it, leaving nine valid BA paths as shown in Fig. 2.

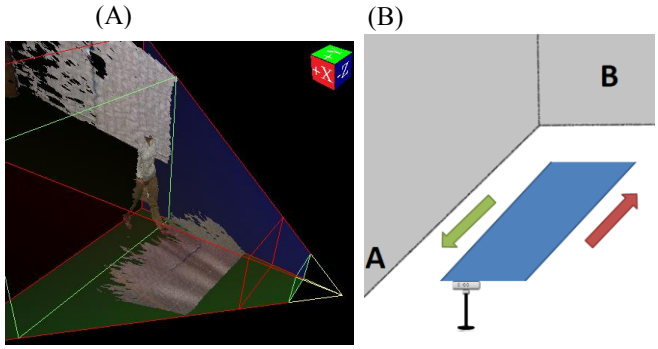

Fig. 1 (A). Point of view of Kinect™ generated by Microsoft® Kinect Studio Software. (B). Corridor schema. The valid BA path was selected for analysis.

B. Reflective markers settings

The markers for the benchmark capture system were configured anatomically corresponding to the body model used by Kinect™ as shown in Fig. 2. These markers will be represented in the analysis model as the joints of the human body. The interest points selected for our comparison were the ankles because the marker position does not differ between the anthropometric standard model used in the benchmark capture system and e-Motion.

C. Volunteers

A team member volunteered. She is a 34 year old woman, with a body mass of 60 kilograms, height 1.70 meters, and practices regular physical activity, and has no symptoms or neurological disease that might affect the voluntary control of her movements. Because the main objective of this work is to compare the Kinect based system with the benchmark capture system, a healthy subject is sufficient for the test.

D. Data filtering process

Kinect data was collected through e-Motion system and export in C3D format which is supported by benchmark gait laboratory. Preliminary analysis we used XYZ axes for the corresponding 3D space. For the analysis, the Z axis was selected because it represents the depth (distance from a point captured to the origin coordinate system) and also because the values of this axis enable the variables of interest that e-Motion calculates to be constructed.

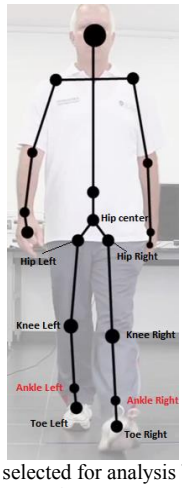

Fig. 2. Both ankles were selected for analysis because in the benchmark system they were the same anatomical point.

Storing criteria for data by e-Motion:

- The data on the depth axis must be between 1.5 meters and 3.5 meters. This corresponds to the technical specifications of the manufacturer of Kinect™ and corresponds to the optimal viewing range of the device [11].
- A sample was taken every 0.0167 seconds. This corresponds to 60 Hz and 30 FPS.
- E-Motion is able to recognize if a particular joint can be captured or not. For this analysis it was determined that the capture state of the body should be TRUE, i.e. that all joints have been captured and are stored in the system.

For the benchmark capture system, the storing criteria consist of checking if the reflective markers are in vision range or not. The sample frequency was 120 Hz.

E. Design of the study for measure of reliability

The unit of analysis corresponds to the location of the spatial points which belong to each joint location analyzed. This analysis aims to obtain the variation between the two measurement systems. The locations in the space of each of the joints of interest obtained from each system were exported to a database which was analyzed using the statistical software Stata12®. Since movement is a continuous variable, the intra-class correlation coefficients for the entire path and for each of the stages of walking (balancing and support) were estimated. Of the three types of analysis-of-variance models considered for the reliability study, we chose the two-way mixed-effects model, where each target (location in space) is rated by the same set of k independent raters (e-Motion and benchmark system).

IV. Results

We collected a huge amount of data (approximately 42,000 individual records); however, we created a filter to get finally 1200. Filtering of the data consisted of two processes. First, an adjustment was made for the number of volunteers, number of systems, number of tests performed, number of valid paths for the test performed, number of axes to be analyzed, number of joints to capture: both ankles, and the average number of lines of samples. That is, with each system three tests were performed, and for each test the three valid paths were taken. For each record line a data of Z was selected for each joint: left and right ankle. Table 1 shows the amount of data after each filtering process.

Second, due to both systems having different sampling frequencies and coordinate systems, it was necessary to synchronize their scales for time and depth. For synchronization in time, we selected 60 Hz, making a decimation process in the benchmark system.

	All data	First filter process	Second filter process
Volunteer	1	1	1
Systems	2	2	2
Test	3	3	3
Valid paths per test	18	1	1
Axes	3	1	1
Body joints	20	2	2
Samples lines average	194	194	100
Total of data	1,257,120	2,328	1,200

Table 1 Overall data in each step of filtering process

This synchronization means that for every t there is a triplet $\langle X, Y, Z\rangle$; then

$$\begin{gathered} if\ t = t_{eMotion} = t_{benchmark} \\ \therefore \langle X_{i_{eMotion}}, Y_{i_{eMotion}}, Z_{i_{eMotion}}, \rangle \\ \cong \langle X_{i_{benchmark}}, Y_{i_{benchmark}}, Z_{i_{benchmark}} \rangle \\ \Longrightarrow \langle t, Z_{i_{eMotion}}, Z_{i_{benchmark}} \rangle \end{gathered} \quad (1)$$

For synchronization in depth axes, the following steps were applied:

1. An adjustment of data from the benchmark capture system:

$$Z'_{i_{benchmark}} = Z_{i_{benchmark}} \times -1 \quad (2)$$

2. The optimal vision range of Kinect™ is between 1.5 meters and 3.5 meters in the depth axis. Therefore, the zero point was fixed:
   a. Consequently, the zero point was fixed as:

$$\begin{gathered} P_{Zero} = Z_{i_{benchmark}} - Z_{i_{eMotion}} \\ where \\ 1.49 \leq Z_{i_{eMotion}} \leq 1.50\ meters \end{gathered} \quad (3)$$

   b. Then

$$Z'_{i_{eMotion}} = Z_{i_{eMotion}} + P_{Zero} \quad (4)$$

   c. Finally, a new triplet was built:

$$\langle t, Z'_{i_{eMotion}}, Z'_{i_{benchmark}} \rangle \quad (5)$$

Fig. 3 shows the same data, after the synchronization process described above.

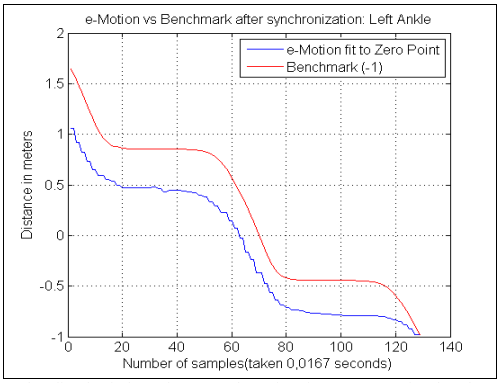

Fig. 3. The final triplet after synchronization process in the depth axis $\langle t, Z^i_{eMotion}, Z^i_{benchmark} \rangle$

In the timeline, the systems were set at 60 Hz. From the benchmark gait laboratory, we obtained data corresponding to 60 Hz, i.e. every 0.0167 seconds. Because each system locates the origin of the coordinates in a different way, a coordinate translation was necessary to make them comparable and synchronize them spatially. For the purposes of this analysis, we selected data for: one of the three paths included in the test, one of the three axes of analysis (z) and two joints of interest (ankles). In the selected path, the general agreement between the two methods, as well as the agreement between the methods for the left ankle and right ankle was explored.

The index for the reliability and the laterality (N=599) of both systems were averaged together 0.96 (IC95% 0.94–0.97). For the left ankle (N=103), the index was 0.96 (IC95% 0.88–0.98), and for the right ankle (N=112), the index was 0.97 (IC95% 0.85–0.99). According to guidelines for the evaluation of intra-class correlation coefficients, the inter-rater agreement between e-Motion and the benchmark system is excellent [14]

V. Discussion

This analysis was performed to compare the spatial locations of the ankles from a volunteer under indoor controlled conditions. The importance of comparing each spatial location lies in the fact that calculating spatial-temporal variables requires each location point to be known, on an interval time. Each point from e-Motion was compared against an equivalent point obtained with a multiple-camera 3D motion capture system benchmark gait laboratory, whose characteristics are based on international standards. With this spatial analysis, e-Motion is able to estimate variables of interest to quantify the gait analysis in a reliable manner. The information about the evaluation between e-Motion and benchmark gait laboratories provides useful evidence on the actual impact of rapidly evolving m-Health opportunities on health care.

VI. Conclusion and Future Work

These results contribute and provide useful information to improve the use of Kinect and processing methods for monitoring patients with Parkinson´s disease in clinical context.

The e-Motion system is a profitable option to complement the clinical assessment of patients with Parkinson's disease in the clinical and research context. Its potential in the analysis of gait is recognized as a powerful tool for decision-making during the follow-up and assessment in these patients[15].

The e-Motion Capture System could develop and quantify measurements of motor and spatial-temporal variables that are sensitive to change in the timeline of the disease. This innovative system would fit into the conditions in place in neurology clinics in low and middle income countries, since the Kinect™ sensor, compared to the benchmark gait analysis, has advantages such as low cost, portability, no need to use a landmark for capture and less complex settings.

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