Evaluation of physical-motor status of people with reduced mobility using motion capture with Microsoft Kinect

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***Abstract*—We present a system for capturing and processing the motor state of patients with reduced mobility aimed to provide clinical feedback for the conduction of a quantitative and objective evaluation of patients. We evaluated our system with patients of a physiotherapeutic clinic. They performed a set of exercises and the system provided tools to measure position, angle and velocity between different points of the body detected with the Microsoft Kinect. We tested the coherence between the Kinect-based assessment and standardized clinical assessment. Results show that our system allows obtaining more precise data from patients with balance impairments, thus, it might be used to carry out an analysis of their motor state and to evaluate it more accurately, in comparison with traditional scales.**

Keywords-3D sensor; assistive technology; Kinect; people with reduced mobility; physiotherapeutic evaluation;

I. INTRODUCTION

Motor deficits and reduced mobility are becoming more prevalent in our society, either due to advanced age or to diseases of neurological origin. Virtual reality and game technologies are being used in the rehabilitation of stroke, Parkinson's disease, and for patients with motor deficiencies, showing positive results [1][2]. However, we still find some loopholes in the use of such technology for the evaluation of the patients' condition before selecting the method of treatment. Recovery depends on an efficient evaluation to identify gaps and thus provide appropriate treatment [3].

Currently, the assessment of patients' motor state is mainly carried out by using qualitative clinical scales [4][5] without standardization or measuring instruments. These scales consist of surveys, trials, and questionnaires that are administered to patients to capture basic assessment of their impairments, residual functional abilities, and daily life activities. These assessments methods are most common because they are relatively inexpensive and accessible, but suffer the disadvantage of being subjective, variable, and requiring prolonged training time. These clinical scales reliability is partially dependent from the interobserver and intraobserver variability and the sensibility is affected. Therefore, they often detect only remarkable improvements or aggravations [6].

The game industry brought 3D sensors with good accuracy and low cost, such as the Microsoft Kinect, which enables the use of motion analysis to quantify the deficit or improvement of a physical therapy in a quantitative and standardized way.

We present the development and evaluation of a Kinect-based system for capturing and processing the motor state of elderly and post-stroke patients with reduced mobility, non-invasively, providing tools for the specialists in physical therapy that allow them to conduct a quantitative and objective evaluation of their patients, improving the usual assessment method based on scales.

We conducted this work in partnership with specialists in physical therapy of the SINAPSE clinic [7]. The staff of the clinic provided medical advice and participated actively in the construction of the solution.

We defined a Kinect evaluation exercises set (KEES) based on a subset of the activities of the Berg Balance Scale (BBS), an accepted standard clinical criterion by which to measure balance [4][8]. We created a dataset for each exercise in KEES. The dataset describes the motion of a healthy subject, using the Kinect as the tracking sensor. The system allows comparing unhealthy subjects with that dataset of healthy subjects and with themselves along the time. Also, it is aimed to test the coherence between the Kinect-based assessment and standardized clinical assessment.

The results of the experimental evaluation of our system show that it can give more information about patients than classical scales.

This paper is organized as follows. In the next section, we present related work. Next, we present the methodology used in the research, describing subjects, materials and algorithms. Later, we describe the proposed system to capture and process the motor state of users. Then, we expose the experimental evaluation and the obtained results. Finally, we present the conclusions of this study.

II. RELATED WORK

Motion capture system is a desirable tool for analyzing and interpreting human movement. Since the release of Kinect device and its potential to provide 3D joint positions quite accurately, an affordable solution has been increasing the interest and use in physical therapy and rehabilitation sets [9]. A considerable number of work has been done in order to evaluate the validity and/or reliability of the device [10]. However, very few studies are related to the evaluation of the patient.

Mousavi and Khademi [11] reviewed a series of articles and they concluded that Kinect was acceptable for rehabilitation purposes using techniques such as sensor fusion, calibration, and a knowledge translation [12] to overcome current limitations of the technology. Besides that, the authors listed 23 studies that clinically evaluated the use of Kinect, 17 of those clearly concluded that Kinect improved patients status in the same extent or above the control groups when applied following the authors.

Webster and Celik [13] performed a systematic review of Kinect applications for rehabilitation. They found 48 studies about Elderly Care (fall detection, and fall risk reduction) and Stroke Rehabilitation (evaluation of Kinect's spatial accuracy, and Kinect-based rehabilitation methods) applications. They concluded that the technology is still in initial development. The authors pointed promising future work directions related to improvement in patient motivation to perform proposed exercises, keeping rehabilitation records, and the development of future medical diagnostic and rehabilitation methods.

In the systematic review performed by Ruff et al. [14], the authors included studies related to orthopedics diagnostic or functional evaluations, and reported comparisons to established functional assessment criteria. They found three studies compared Kinect to gold-standard Vicon motion capture system. They reported excellent correlation and reliability when comparing Kinect to Vicon system (values between 0.84 and 0.99 R^2).

More recently, Knippenberg et al. [10] reviewed the use of markerless motion capture systems in neurological rehabilitation. They found that Kinect was the most used system and all studies reported significant improvements, mostly in favor of experimental groups using the motion capture systems. The authors emphasized the lack of client-centered solutions that do not consider the patient's interests. We highlighted that Kinect customized applications for clinical use in rehabilitation and new approaches using different setups and algorithm techniques are necessary to take advantage of its affordable cost, ease of use, and still relative high reliability and validity when compared to gold standard solutions. Due to the use of Kinect in physiotherapy area is mainly focused on assisting the rehabilitation of patients, this study brings a collaboration to the diagnostic of motor control impairments and evaluation of the patients with reduced mobility.

III. Methods

A. *Subjects*

This work was conducted in the SINAPSE clinic [7]. We performed two evaluation tests with users in the clinic. The first one involved 10 healthy voluntary individuals (6 males and 4 females, age 27+- 5 years) with no reported mobility issues to identify their balance data. The second evaluation enrolled five patients (3 females and 2 males, age 60+-15 years) of the clinic. They have reduced mobility, two of them were elderly people, and other three were post-stroke patients. All voluntaries in both tests gave voluntary and informed consent.

B. *Materials*

We used Microsoft Kinect for Xbox One with SDK 2.0. The Kinect is a camera-based sensor that tracks the position of the limbs and body, without the need for controllers. The use of a depth sensor also allows Kinect to capture the three-dimensional movement patterns.

In collaboration with the specialists in physical therapy, we designed the Kinect Evaluation Exercises Set (KEES), a set of 10 exercises (Table 1 and Fig. 1) to measure the motion performance of the participants. KEES were specified based on the Berg Balance Scale (BBS), a 14-item scale traditionally used to measure balance of people with impairment in balance function [15]. It is based on the principle that a person's balance is challenged by diminishing his/her base of support. Each item of the BBS is rated on a 5-point scale [16]. When calculating a total score for the BBS, a point of concern is that test items have different operational definitions for each of their rating categories.

Exercises in the BBS that have occlusion of joints were not included in KEES because the Kinect is not able to track those joints.

Before performing the KEES the subjects should understand that they must maintain their balance while attempting the exercises. The choices of which leg to stand on or how far to reach are left with the subject. The chair used during testing should have a reasonable height and must have arms.

TABLE I. Kinect Evaluation Exercises Set (KEES) based on BBS [15]

Item	Item description
1. Sitting unsupported	Sit safely and securely with arms folded for 2 minutes.
2. Sitting to standing	Stand up, trying not to use the hands for support and stabilize independently.
3. Standing unsupported	Stand for two minutes without holding on.
4. Standing to sitting	Sit down safely with minimal use of hands.
5. Standing unsupported with eyes closed	Close the eyes and stand still safely for 10 seconds.
6. Standing unsupported with feet together	Place feet together and stand for one minute without holding on.
7. Standing with one foot in front	Place one foot directly in front of the other. If the subject cannot put the foot directly in front, s/he must try to step far enough ahead, so that the heel of the forward foot is ahead of the toes of the other foot.
8. Standing on one leg	Stand on one leg without holding on for 10 seconds.
9. Reaching forward with outstretched arms	Lift the arms to 90 degrees, with the palms of the hands towards the Kinect. Stretch out the arms and reach forward as far as s/he can.
10. Placing alternate foot on a stool	Place each foot alternately on a step/stool; each foot should touch the step/stool four times. Try to complete eight steps in 20 seconds.

C. *Data Acquisition and Processing*

1) Skeleton Coordinate Calibration: For the data acquisition, participants were recorded in front of the Kinect performing the KEES. Before each exercise, we make a calibration of the user's skeleton recognized by Kinect to normalize the data. When recording their movements, users may get very different coordinates data for the skeleton positions, even if they make the same movement. Each user has different physical characteristics and everybody is not going to be in the same position in front of the camera at the recording time. Obtaining the skeleton calibration parameters allows each user to be in the same coordinate system.

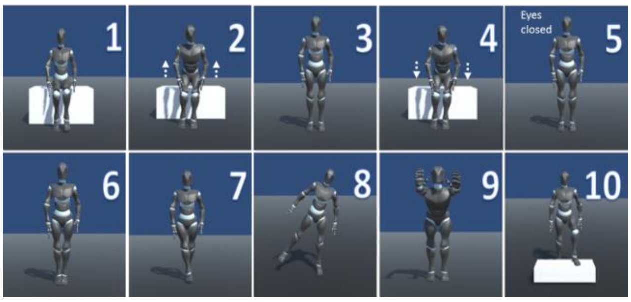

Figure 1. Kinect Evaluation Exercises Set (KEES).

The calibration system in this study is based on the algorithm by Wei, Qiao, and Lee [17], which consists in pulling the user's skeleton to the center of the Kinect sensor and then rotate it to face the Kinect sensor, so that the algorithm treats this position as the initial position in a universal coordinate system. In this way, all users' initial positions are normalized in the universal coordinate system, irrespective of their original standing position and angle. Consequently, all users' initial positions are the same in the coordinate system, wherever they stand at.

2) Skeleton Scaling: After calibration, we scale the skeleton properly to a model body to be able to make any further comparison or to extract any standard measure. In every frame a factor is used to scale the subject skeleton to the model, calculating the new positions of the joints.

Since the proportions between the center and every joint of the skeleton are different, it is necessary to find the particular scaling matrix (Fm) for every joint. For that reason, we perform a setting step before the scaling process. In the configuration phase, the subject is recorded in standing position for four seconds, and the collected data is used to calculate the scale factor to transform the skeleton of the subject to a model skeleton recorded previously in the same position.

3) Computing the angle and velocity: The angle (α) for each exercise is obtained as follows: taking three consecutive joints (e.g., hip, knee, and foot, respectively), define the vector between joints 1 and 2, and the vector between 2 and 3. After that, calculate the scalar product of these two vectors and the product of its norms. Dividing these two values, and calculating the arc cosine, the angle between the three joints is obtained:

$$\alpha = arcos\left(\frac{a \quad . \quad b}{\|a\| \quad . \quad \|b\|}\right) \tag{1}$$

where *a* and *b* are vectors connecting joints 1 and 2, 2 and 3, respectively.

The angular velocity (v) is calculated by subtracting the current angle from the previous one dividing the difference of time between each measurement. Since Kinect returns 30 frames per second, the time between each calculated value is 0.033s.

4) Dataset: To construct the dataset, ten healthy subjects were recorded while performing each exercise. To obtain the average value of one joint j at a specific frame of the exercise, the mean of the ten values of that joint at that instant is calculated.

$$Pnorm_j = \frac{1}{10}\sum_{k=1}^{10}\left(X_{c_j}, Y_{c_j}, Z_{c_j}\right)_k \quad j = 0 \dots 24 \tag{2}$$

where $\left(X_{c_j}, Y_{c_j}, Z_{c_j}\right)_k$ means the position of joint *j* of the subject *k* at that instant. Thus, the average of an instant of time of one exercise will be the set of normalized joints of the skeleton at that moment *m*.

$$Nm = Pnorm_0, \dots, Pnorm_{24} \tag{3}$$

Therefore, the average of the complete exercise will be the set of normalized joints values *N* in each moment of the exercise. Where *t* is the number of frames captured for that exercise.

$$N = N_0, \dots, N_t \tag{4}$$

To compare the data collected, we used the Dynamic Time Warping algorithm (DTW) [18]. DTW is used to compare two time series using the Euclidean distance of series' points and tries to align them with the global minimal distance path found between the points. It allows two apparently unsynchronized signals to be synchronized, finding, for example, the starting point that will align two similar signals that had been cut or captured in different moments.

IV. PROPOSED SYSTEM

Our system is divided into three modules: Acquisition Module, Edition Module, and Analysis and Visualization Module. The acquisition module will be used by patients with the help of specialists, and editing and analysis modules will be used only by specialists.

A. *Data Acquisition Module*

The Acquisition Module provides the specialist with options to record patients' data while they perform the exercises. Internally, the acquisition process can be divided into four sub processes aimed to prepare the data for the next phases.

First, the user fills general data of the patient (e.g., id, name, age, sex, disease), and then selects an exercise of the KEES. When the exercise is selected, the system presents a tutorial on how to make the exercise (Fig. 2). Then the patient needs to be calibrated, s/he must stay in a fixed position for approximately four seconds to provide the original position and angle in reference to the Kinect. When the calibration process is finished, the specialist must initialize the recording and when the patient finishes to perform the exercise, the recording process should be manually stopped.

The specialist has the opportunity to redo the recording operation if anything goes wrong or just save the record and go back to the exercise selection. In this way, the same patient can be recorded doing the entire KEES.

Figure 2. Exercise tutorial screen.

B. *Edition Module*

In the Edition Module, the specialist can load a preview of the exercise. This module has tools for replaying the recording, watching it from different 3D views (e.g., front, left) in the animation form of an avatar that reproduces the patient's movements recorded. The specialist can delete non-useful data that is recorded, because sometimes there is a delay between the user actual beginning and end of the exercise, making the information clearer for posterior analysis.

C. *Analysis and Visualization Module*

The Analysis and Visualization Module provides to the specialist with a multiview component and a set of tools to help her/him make the diagnosis more accurately (Fig. 3). Among these tools, there are the computing and plotting of the angle, the angular speed and the position of joints.

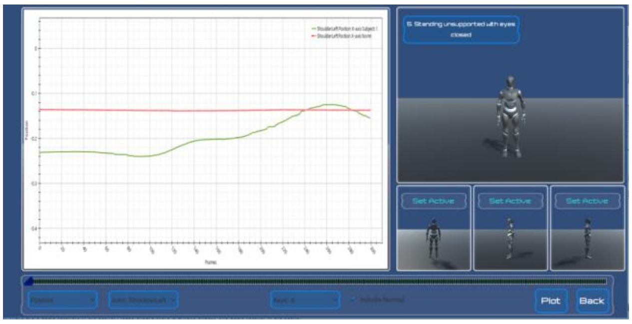

Figure 3. Analysis and visualization screen.

As in the Editing Module, the Multiview allows the specialist to have a 3D view of the records from four different perspectives, and to see the real position of the body while simultaneously analyzing the value of a metric using the options of the toolbar. It also allows to plot the same metric over the dataset of healthy subjects or previous data from the same patient, to compare with the current exercise.

V. Experimental Evaluation and Results

Two experiments were performed. The first experiment aimed to find the norm (dataset average) of each exercise in the KEES. The second experiment aimed to compare the evaluation using our system and the BBS.

A. *Experiment 1: Dataset of healthy subjects*

10 healthy individuals were instructed to perform the ten exercises of the KEES. Each exercise was processed to obtain the "correct" way to perform the activity. We considered the "norm" to the average of the movements performed by these ten individuals in the KEES' exercises.

As an example, we present a comparison between the dataset obtained and that of the healthy user, using the exercise "Standing unsupported with eyes closed" (number 5) of the KEES. The position of the left shoulder was plotted in the three axes, movement of the shoulder to the left or to the right in X-axis (Fig. 4), movement to the left or to the right in Y-axis (Fig.5), and movement forward or backward in Z-axis (Fig. 6). Results in the graphs show that, individually, there are no large deviations from the norm, which indicates that the average behavior is a good indication of what can be considered a normal movement. These results are similar for the other exercises of the KEES.

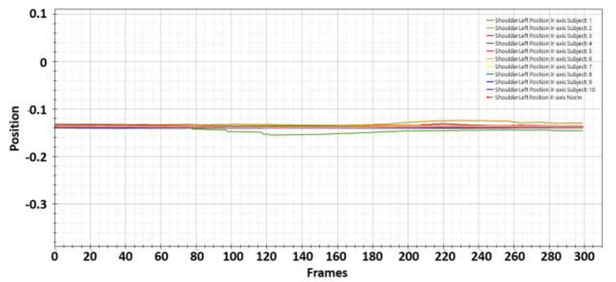

Figure 4. Results of the norm (dotted line) vs. ten healthy subjects in X-axis.

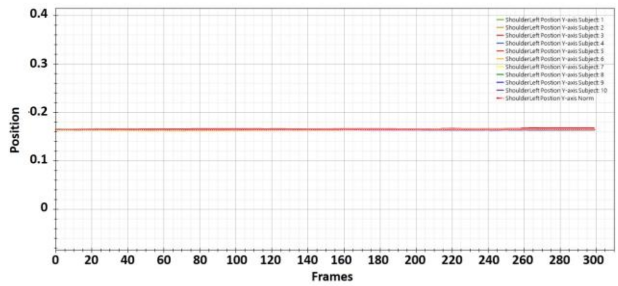

Figure 5. Results of dataset (dotted line) vs. ten healthy subjects in Y-axis.

B. *Experiment 2: Evaluation using the Kinect-based system and the Berg Balance Scale (BBS)*

Five patients with reduced mobility of the SINAPSE clinic were enrolled. The experiments were conducted by the specialists in physical therapy at the clinic using the software and the BBS. They collected the data and then provided us with this data.

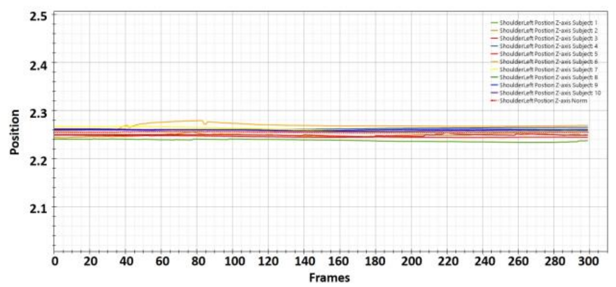

Figure 6. Results of dataset (dotted line) vs. ten healthy subjects in Z-axis.

1) Clinical Berg Balance Scale (BBS) assessment: Participants were instructed by the specialist to perform the 14 exercises of the BBS. The total score in 14-items of the BBS can range from 0 (severely affected balance) to 56 (excellent balance), which are interpreted as: high fall risk (0-20), medium fall risk (21-40) and low fall risk (41-56).

The score results of the patients are presented in table II. Three patients were evaluated as "low fall risk" and two were evaluated as "medium fall risk". Even when they were correctly evaluated using the BBS, since 8 points are required to reveal a genuine change in function between 2 assessments, it turns out to be very hard to make a precise comparison between two subjects that have the same risk of fall according to the scale. Furthermore, like in this case, there may be patients that still have issues in the movement and problems with balance, and yet they obtain the "low fall risk" result.

TABLE II. RESULTS OF THE PATIENTS IN EVALUATION USING BBS.

	Score Total	Interpretation
Subject 1 (female, 75 years)	49	low fall risk
Subject 2 (female, 60 years)	26	medium fall risk
Subject 3 (male, 50 years)	38	medium fall risk
Subject 4 (female, 56 years)	43	low fall risk
Subject 5 (male, 73 years)	50	low fall risk

2) Kinect-based system assessment: After the evaluation using the BBS, the experiment using the Kinect-based system was conducted. The Kinect was placed at 0.7 m of height. The patients were placed at 2 m of distance from the Kinect and they were recorded while performing the exercises.

For the analysis, we choose the exercises with more significant movement for the data collected from the patient, and the position of the body recommended by the specialists that were more important for the observation.

Using the same measures analyzed before in healthy users (the position of the left shoulder during the exercise "Standing unsupported with eyes closed") to compare the data obtained of the five unhealthy subjects with the computed norm, we notice a deviation from the norm even in patients with low fall risk (Fig. 7, Fig. 8, Fig. 9). This noticeable difference in the movements' graphs can be used to help the specialist in getting a more precise assessment of the patient's situation. Also, we apply DTW to achieve a quantitative analysis for each patient (table III orientation values close to zero indicate more similarity with the norm.

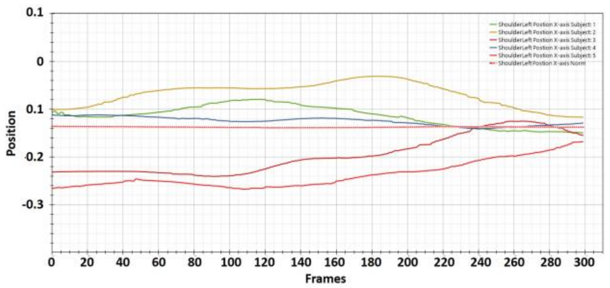

Figure 7. Results of the norm (dotted line) vs. five unhealthy subjects in X-axis.

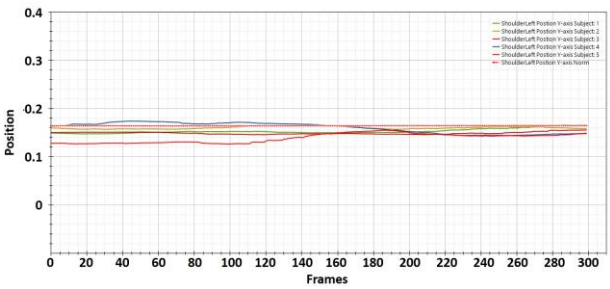

Figure 8. Results of the norm (dotted line) vs. five unhealthy subjects in Y-axis.

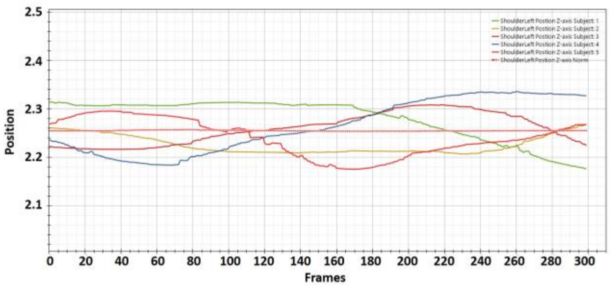

Figure 9. Results of the norm (dotted line) vs. five unhealthy subjects in Z-axis.

TABLE III. DYNAMIC TIME WRAPPING COST- STANDING UNSUPPORTED WITH EYES CLOSED-LEFT SHOULDER

DTW cost vs Norm						
Patient	Pos X	Pos Y	Pos Z	Ori X	Ori Y	Ori Z
1	1.99	0.15	1.67	0.01	0.03	0.01
2	4.75	0.39	3.74	0.11	0.02	0.00
3	3.13	0.30	1.27	0.03	0.01	0.01
4	1.10	0.12	2.21	0.01	0.01	0.00
5	2.10	0.34	2.00	0.01	0.01	0.01

We observed similar results in the measurements of other joints in other exercises performed. In some cases, even patients top ranked in the scale can have deviation from the norm, if s/he is not really a patient with good balance. One example of this is their performance during the exercise "Standing on one leg" (number 8). Fig. 10 shows the position in the X-axis of the joint of the left knee during the exercise of the five subjects comparing to the norm and table IV shows the DTW results for all the axis. In this measure a movement in the X-axis means that the subject moves the left knee to the left or to the right.

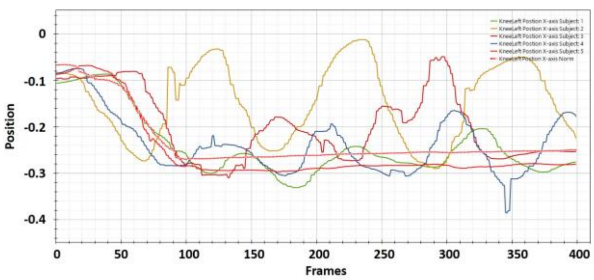

Figure 10. The norm of the Left Knee exercise (dotted line) vs. unhealthy subjects X-axis.

TABLE IV. DYNAMIC TIME WRAPPING COST- STANDING ON ONE LEG-LEFT KNEE.

DTW cost vs Norm						
Patient	**Pos X**	**Pos Y**	**Pos Z**	**Ori X**	**Ori Y**	**Ori Z**
1	4.35	0.23	0.77	0.17	0.71	0.15
2	16.98	5.31	2.50	1.22	0.53	0.31
3	8.67	7.39	3.66	0.19	0.04	1.07
4	5.29	3.68	1.55	0.30	0.06	0.22
5	3.04	1.67	0.80	0.03	0.21	0.39

The curve described by the norm represents that in an ideal performance when the subject raises the leg, the left knee moves from the start position to the left and it is sustained in that position.

Subjects 1, 4 and 5 have a performance closer to the norm (Fig. 11). They also obtained the "low fall risk" classification with the BBS, which is the top classification, even when they performed the exercise with some difficulties. In the BBS scale subject 1 got 49 and subject 5 got 50. According to the scale, it is necessary a difference of 8 points to have an improvement, so the subjects 1 and 5 have almost the same classification, and subject 4, that obtained 43, has a worse classification. However, in this exercise the performance of subject 1 was closer to the performance of subject 4 than the subject 5, and subject 5 was the closest to the norm. Also, subject 5 achieves the objective of raising the leg and maintaining it in the air in a better way. The curves of the subjects 1 and 4 show periodic fluctuations, consistent with their constant efforts for maintaining the leg in the air.

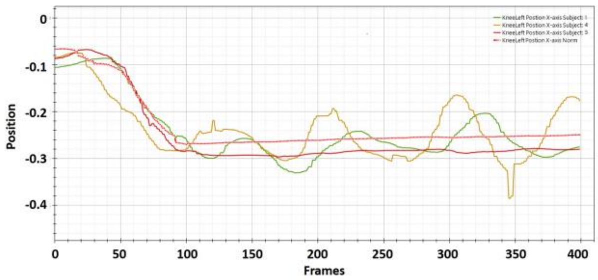

Figure 11. Subjects with low fall risk vs. the norm X-axis (red dotted line).

Subjects 2 and 3 obtained 26 and 38 points, respectively, in the BBS scale. They were classified as "medium fall risk". According to the BBS there is a significant difference between them, but the graphic of their performances using the system provides another type of understanding about their problems (Fig. 12). Subject 3 presents a few fluctuations, but still manages to keep the leg for a longer time in the air; this subject had to put the foot on the floor one time, causing the knee return to the initial position in the X-axis (yellow line in Fig. 12). On the other hand, subject 2 presents periodic fluctuations where the position of the knee returns to the initial position (green line in Fig. 12). As a result of the struggling to raise the leg, he needs to put the foot on the floor many times. So, according to the BBS, it is clear that, even when they both were classified as "medium fall risk", they present a significant difference in the performance of exercises. The measures provided by our system provide richer information about the performance in the exercises.

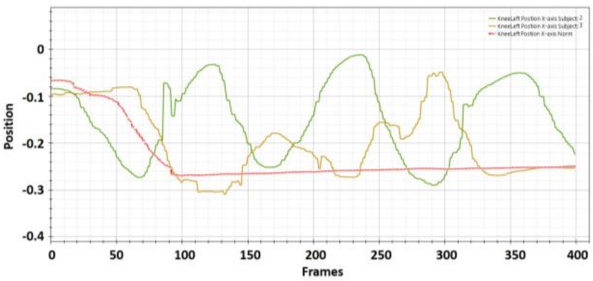

Figure 12. Subjects with medium fall risk vs. the norm X-axis (red dotted line).

This case is a good example of how we can make an analysis of the motor state of patients using the system, and how this new information can help the specialist to get a more effective assessment.

Another interesting result was observed during the analysis of the exercise "Reaching forward with outstretched arms" (number 9). The measure used was the position of the right hand in the Z-axis. In this exercise the subject was oriented to extend and raise the arms, move arms forward as much as s/he can. Fig. 13 shows in detail the comparison between the norm and the subjects 1, 4, and 5 classified as "low fall risk" by the BBS, and Fig. 14 shows the comparison between the norm and the subjects 2 and 3 that obtain a "medium fall risk" classification with the BBS. The distance reached by each subject will be represented in meters by the Z-axis, it can be measured by the difference between the initial position and the final position in that axis.

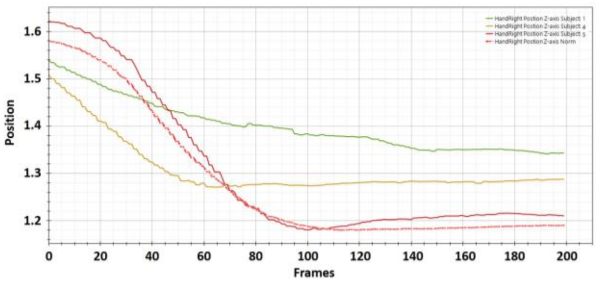

Figure 13. Subjects with low fall risk vs. the norm Z-axis.

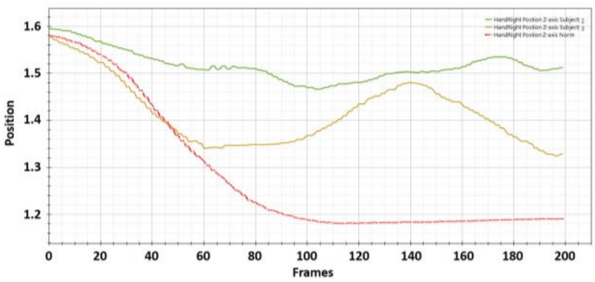

Figure 14. Subjects with medium fall risk vs. the norm Z-axis (red dotted line).

The results of DTW (Table V) show that the subjects 1, 4, and 5 classified with low fall risk have the performance closer to the norm, although subject 5 has that approach closer. Fig. 14 and Table V show that the performance of subjects with medium fall risk (subjects 2 and 3) is farther to the norm, where the performance of subject 2 is even more.

TABLE V. DYNAMIC TIME WRAPPING COST - REACHING FORWARD WITH OUTSTRETCHED ARMS- RIGHT HAND

DTW cost vs Norm						
Patient	**Pos X**	**Pos Y**	**Pos Z**	**Ori X**	**Ori Y**	**Ori Z**
1	0.07	0.24	3.44	0.01	0.03	0.01
2	0.91	0.81	8.12	0.23	0.01	0.00
3	0.66	0.90	6.53	0.03	0.01	0.01
4	0.52	0.73	2.07	0.01	0.01	0.00
5	0.03	0.56	0.53	0.01	0.01	0.01

After the tests, we asked for feedback from the specialists. In their opinion, this system greatly improves the work with the patients, since it overcomes the limitations of the most used evaluation methods: it allows to analyze the patients in a quantitative way and the exchange of information between specialists; it improves the history of the progress of the patient during the treatment and generates a large amount of data for future investigations, allowing better separation between different pathologies.

Our proposed system, and systems like this, can bring tools for the specialists in physical therapy to evaluate a patient with more objectivity.

VI. CONCLUSIONS

We presented a compact, non-invasive and low cost Kinect-based system for capturing and processing the motor state of patients with reduced mobility, providing tools to allow specialists to conduct a quantitative and objective evaluation of the patients, improving the usual assessment method based on scales.

We evaluated our system with 5 patients with reduced mobility. The significant results obtained allow us to suggest that it might be used to obtain more data of patients with balance impairments and to evaluate more precisely their motor state in comparison with traditional scales. Also, our system may facilitate the remote evaluation of patients who cannot get to hospitals or clinics.

The system may also change the interaction with patients, because patients themselves can observe their performance during rehabilitation, which contributes to the patient's psychological state, something very important during the process of rehabilitation.

As future studies, we intend to implement automatic temporal adjustment of the data recorded, to increment the number of subjects in the dataset, to make tests with patients with different pathologies, to include automatic analysis based on pattern recognition, and to include functionalities for remote assessment.

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