Virtual reality and hand tracking system as a medical tool to evaluate patients with Parkinson's

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ABSTRACT
In this paper, we take advantage of the free hand interaction technology as a medical tool, either in rehabilitation centers or at home, that allows the evaluation of patients with Parkinson's. We have created a virtual reality scene to engage the patient to feel in an activity that can be found in daily life, and use the Leap Motion controller tracking to evaluate and classify the tremor in the hands. A sample of 33 patients diagnosed with Parkinson's disease (PD) participated in the study. Three tests were performed per patient, the first two to evaluate the amplitude of the postural tremor in each hand, and the third to measure the time to complete a specific task. Analysis shows that our tool can be used effectively to classify the stage of Parkinson's disease.

ACM Classification Keywords
J. Computer Applications: J.3 Life and Medical Sciences–Medical Information Systems

Author Keywords
Parkinson's Evaluation; Healthcare Assistant; Virtual Reality; Leap Motion Controller; Hand Tracking.

INTRODUCTION
In the last decade, free hand interaction systems have reflected a positive increase in their use for various applications. A free hand interaction system and virtual reality together could serve as a great healthcare assisting tool to remotely assess people with Parkinson's disease (PD). PD is characterized by symptoms of bradykinesia associated with tremor, stiffness and postural instability [16]. Tremor is one of the most recognized symptoms of the disease, which is rhythmic and involuntary oscillatory movement in certain parts of the body [18]. The most common type of tremor is rest tremor, and tremor can re-emerge a few seconds after voluntary movement [6]. The study of tremors in patients with PD, have focused on measuring amplitude, frequency components, and quantified data using statistical methods [11]. The use of the above metrics can provide useful medical information to the therapist or physician to provide better insight into the clinical data. The measurements generated from these metrics can be compared with the clinical scales used in assessing PD [3]. In past years, many conventional methods have been developed to monitor the tremor associated with PD. Examples include electromyography (EMG) [14], microelectromechanical (MEMS) system such as gyroscopes [2], accelerometers [4], graphonometric spiral on digitizing tablets [17], and laser line triangulation method (LLTM) systems. EMG provides additional useful information about the activity of the involved muscles, but due to the use of wire electrodes, or more typically surface electrodes on active muscles, the application remains limited due to the potential damage to the patient's tissue [7]. Gyroscopes are considered as presenting long term stability. However, a disadvantage is the presence of a low frequency bias, mainly due to temperature effects [5]. The accelerometer system may be accurate to track the tremor, but in turn involves placing the device on a part of the body [12]. On the other hand, Kinetic tremor assessed by spiral drawing is not quantified by alternative approaches so far and is not even considered by most rating scales [10]. Therefore, the implementation of a non-invasive, portable, quantifiable, economical method that is effective to monitor and classify the severity of tremor is important for the study of PD.

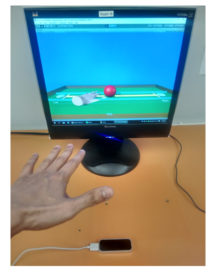

Figure 1. Performing the task of moving a virtual sphere.

In this sense, we used the USB peripheral device Leap Motion sensor that detects gestures. This sensor uses infrared light to accurately and fluidly track hands, fingers and small objects. It is also a low-cost, non-invasive, non-contact, portable, easy to use, compact sensor and provides hand readings with sub-millimeter precision [1]. Since many patients are exposed to various stressful situations in their lives, it is important to understand and systematically examine the impact on the patient's condition at a stage of stress or mind concentration, which may be able to characterize the tremor. Rest tremor is a well recognized cardinal feature of PD, but many patients have a postural tremor that can be more impairing and disabling

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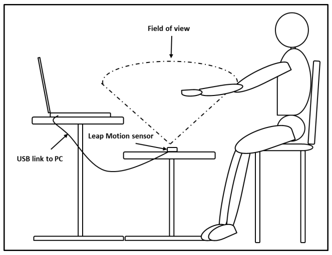

Figure 2. Schematic drawing of the elements and position of the patient in the experiment.

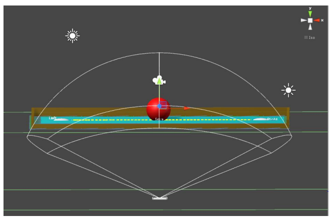

Figure 3. Field of view captured by the sensor on the scene.

the classic rest tremor [8]. In fact, virtual reality is a new paradigm that delivers an innovative modality of therapy or rehabilitation, allowing clients to enter a computer-generated virtual environment in order to be exposed to fear-provoking stimuli similar to their real world stress [15]. We use a simple virtual reality application created in Unity 5.4.0f3 (64 bits) version for Windows 10 SOS to encourage the patient to perform a specific activity (Fig. 1). Note that for the virtual model of the human hand in the virtual scene, the Leap Motion assets package provided by the sensor manufacturer was used. In this study, a number of distance metrics were tested between sets of vectors. Square euclidean distance, Chi square distance, Earths movers distance, Shannon Entropy and Log energy Entropy were compared between resting-state and stress-state conditions during both kinetic and postural tremor.

The study was conducted at the Edmonton Kaye Alberta Clinic, and all patients provided informed consent prior to participating in the study. The total population of the study was 33 patients (21 males and 12 females), aged 30-87 (mean is 65.36, and standard deviation is 12.19) with PD were recruited for the study. The sensor (Leap Motion Sensor v2.3.1, Leap Motion Inc., San Francisco, California) was placed on an ergonomically adjustable non-movable table at a height of 60 cm above the ground surface (Fig. 2). The effective range of the hand visualization in the virtual Unity scenario extends from approximately 125 to 500 mm (millimeters) on the device, and a maximum of 600 mm wide from each side as show in Fig. 3.The patients were comfortably seated in a chair opposite the sensor, where the application could be clearly seen on the laptop screen at another nearby table.

PARTICIPANTS AND MATERIALS

Three tasks per patient were performed, during the measurement of postural tremor (Task 1) the patient was instructed to stretch the left arm out in front of the body with palm down. The wrist was straight and the fingers comfortably separated

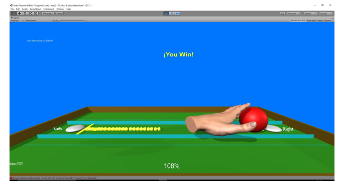

Figure 4. A snapshot of the game interface for Task 2.

so that they did not touch each other. The hand was detected in the area of coverage of the sensor for 15 sec, as shown in Fig. 1. Task 2 was the same as the previous one but this time it was done with the right hand. In Task 3 during the measurement of kinetic tremor, the virtual reality interface was also used, but this time the scene showed a table and on it a small red sphere. The objective was to extend the left hand at the initial position indicated on the screen and try to push or move the sphere located in the center of the scene to the final goal on the right. At the same time, the patient received points when the virtual rigid sphere collided with yellow rotating objects along the path as shown in Fig. 4.

EXPERIMENTAL PROCEDURE FOR TASK 3

Once the red sphere had reached the goal position, the patient moved the hand back to the center of the scene to complete the task. The task has a time restriction of 15 seconds. The idea is to induce the patient a situation of stress and focus when performing a specific activity that can be found in daily life. For each of the tasks performed, the 3D (X,Y,Z) data obtained by the sensor includes: position and velocity of the fingertips and the center of the palm of the hand, and the rotation of the hand. Once the data were obtained, MATLAB 2016b (MATLAB,Mathworks, USA) was used for signal processing.

DATA ANALYSIS

The sensor worked at a refresh rate of 40 fps, so that 600 samples (S) were obtained for each test. The data obtained represent a total of 40 variables in the 3D space. The displacement between each plot of the point located in the center of the palm with the position coordinates (X, Y, Z) was calculated for the analysis of the tremor. However, by plotting the signals, atypical values could be observed which may have a disproportionate effect on the statistical results. Because of these atypical values, a sliding window was used to study the signal sequences. After evaluating different window sizes, we find a window of 15 frames performs best in our experiments.

Distance metric features

The measurement of the distance between objects or individuals allows to interpret geometrically many classic techniques of multivariate analysis, equivalent to represent these objects as points in a suitable metric space [13]. We used two feature vectors to represent the hand movement of a PD and a non-PD individuals respectively, and implemented a variety of metrics to measure the distance between these two vectors. The goal is to identify which metrics distinguish better characteristics of the tremor signal and most effective to classify the PD subject. The subject's hand is represented by six joints: one at each finger tip and the sixth on at the center of the palm. The positions

			Score task[1]		Score task[2]	
n°	*Gender*	*Age*	*Medical*	*System*	*Medical*	*System*
1	F	66	1	1	1	1
2	F	67	0	0	0	2
3	F	48	0	0	1	1
4	M	60	0	0	0	0
5	M	65	1	1	1	1
6	M	86	0	0	0	0
7	F	85	0	2	0	0
8	F	73	0	2	0	2
9	M	72	0	2	1	1
10	M	66	0	0	0	2
11	F	57	0	0	0	0
12	F	68	0	2	0	0
13	F	72	0	2	0	2
14	M	78	0	2	1	1
15	M	62	0	0	0	0
16	M	81	2	2	1	1
17	F	82	1	1	1	1
18	M	72	3	3	2	3
19	M	83	1	1	1	1
20	M	87	1	1	2	2
21	M	30	1	1	1	1

Table 1. Comparison between medical results and the system for the Action/Posture of the Hands.

of each joint at all time steps form a signal sequence. The metrics used for measuring the signal displacement of each PD subject, compared to normal movement (without tremor), are formulated as follows: Square euclidean and Chi Square distance [9], Earth Mover's Distance (EMD), the Manhattan distance, The Shannon Entropy and the Log Energy Entropy.

Experimental Results and Discussion

In order to verify the usefulness of our system, we compare the system generated scores with the Unified Parkinson's Disease Rating Scales (UPDRS) part III scores, which were given to the patients during rehabilitation sessions based on a clinical expert's observation. UPDRS has a range from 0 to 4, where 4 means the patient is in a severe stage and may need assistance for daily activities, while 0 means very minor observed symptom of PD. Patients were asked to perform Task 1 (right hand) and Task 2 (left hand) with our system separately.

Table 1 compares the system scores and UPDRS scores of the first two tasks. 21 patients had UPDRS scores available. The fourth and fifth columns report patient's postural tremor score of the right hand, and the sixth and seventh columns report left hand postural tremor score. It can be seen that there is agreement between the patients' medical scores and system scores, 71.42% of patients show the same result for Task 1 (correlation of 0.45), and 76.19% of patients show the same result for Task 2 (correlation of 0.43). We also noticed that occasionally the virtual hand disappeared from the scene because the subject lower their hand beyond the visible spectrum. This caused the subject to suddenly raised the hand to make the virtual hand reappeared. This sudden movement accounts for the deviation in Subject 2, 7-9 and 12-14 when performing the tasks. Since we only use one clinical expert's subjective assessment for comparison, it is possible that higher correlation can be obtained if more clinical symptoms, e.g., blood pressure and observation of other movements, are taken into account in order to establish a reliable ground truth.

n°	*Time(s)*	*D(mm)*	*Game (%)*	*Velocity(mm/s)*
1	15.0	563.7	45.5	37.6
2	15.0	802.8	64.8	53.5
3	6.5	1,237.8	100.0	190.4
4	10.9	914.1	73.8	83.8
5	10.7	913.9	73.8	85.6
6	14.7	393.6	31.8	26.7
7	14.2	616.6	49.8	43.3
8	15.0	620.9	50.2	41.4
9	15.0	531.3	42.9	35.4
10	9.2	1,230.0	99.4	133.3
11	9.6	1,176.2	95.0	122.5
12	6.8	1,230.0	99.4	180.2
13	10.7	680.0	54.9	63.7
14	9.0	1,210.0	97.7	133.7
15	7.1	445.0	35.9	62.8
16	5.8	1,230.5	99.4	211.2
17	15.0	306.0	24.7	20.4
18	5.8	1,230.5	99.4	211.2
19	15.0	158.2	12.8	10.5
20	10.3	1,232.0	99.5	119.9
21	8.8	1,231.7	99.5	139.6
22	9.6	1,180.0	95.3	122.6
23	9.6	642.0	51.86	66.9
24	15.0	267.8	21.6	17.8
25	7.9	1,209.0	97.6	151.6
26	14.7	513.0	41.4	34.8
27	15.0	1,231.0	99.4	82.1
28	9.3	1,188.7	96.0	127.5
29	14.9	570.9	46.1	38.3
30	15.0	671.2	54.2	44.7
31	8.6	643.1	51.9	74.5
32	7.8	687.1	55.5	87.5
33	8.7	1,229.7	99.3	140.9

Table 2. Characteristics of each patient in the test to move the red sphere.

While Task 1 and Task 2 test the hand tremor at rest position, Task 3 tests the hand during a focused activity. Table 2 shows the observations in Task 3, that involves completing the game of moving a sphere and earning award points. The completion time, total displacement and average speed of each patient were measured. We set Tier 1 >= 75%, Tier 2 >= 50%, Tier 3 >= 25% and Tier 4 less 25% of the game completion. Patients were assessed based on how many of the 50 rotating objects they could catch in this game. At the end, 42.42% were in Tier 1, 27.27% were in Tier 2, 21.21% were in Tier 3, and 9.09% were in Tier 4. Using Table 1 as a cross reference, we are able to compare a patient's hand conditions at rest position and when the brain is in a focused state. It is possible that the tremor appears when the hand is at rest but not when engaging in a focused task. The % of game completed indicates whether the patient can achieve the goal satisfactory within the 15 seconds. By providing suitable advice based on this observation will benefit the patients. Due to the limited time of a rehab session, we were not able to collect further information such as "rate your satisfaction in this game." Some recent finding suggests that sports, e.g., boxing, can improve PD condition. Our system has the advantage for patients who are less mobile or lack of transportation to visit rehab facility, because they can monitor their conditions at home and submit the statistics for expert evaluation if needed. Due to the shortage of rehab personnel and facility, our system of using smart sensor technology and vritual games contributes to the quality of life by decentralizing health services.

CONCLUSION

In this paper we have implemented a natural interaction system, using smart sensor technology and virtual reality game, to evaluate patients with Parkinson's disease. The system is non-invasive and can be used by the patient in the absence of rehab personnel, which is an advantage given the shortage of rehab resources. We have conducted a study with 33 patients to evaluate certain tremor conditions in the hands and compare the system assessment with the UPDRS. The results show a significant correlation between the system scores and the provided UPDRS. Currently, there is no single biomarker, which is confirmed reliable for such diagnosis. For future work, we propose to investigate more hand motor activities assessed in rehab sessions. By assessing different tasks, the system will be able to obtain more accurate scores to complement clinical evidence.

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