Identification of Parkinson's Disease by using Multichannel Vertical Ground Reaction Force Signals

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Abstract: **In this paper, we analyze Vertical Ground Reaction Force (VGRF) signals recorded from normal subjects as well as from subjects attained with Parkinson's disease (PD). The aim of this study is to identify abnormal gait patterns in order to detect patients who are potentially attained with PD. This is done by extracting various significant features from sensors located at 16 different positions on the right and left foot. Finally, extracted features are used to classify between health control and PD subjects and predict the Parkinson phase. Results have shown that extracting parameters based on the summation of sensors output of each foot may hide the conveyed information of VGRF signals. Moreover, frequency-related features are able to classify between PD subjects with different Hoehn and Yahr stages. Finally, results have revealed the importance of power distribution in VGRF signals that vary with PD stages.**

***Keywords*—Vertical Ground Reaction Force (VGRF); Parkinson's disease (PD); Gait analysis; Sensor location**

I. INTRODUCTION

Parkinson's disease (PD) is a chronic and progressive movement disorder that affects the central nervous system. Despite the science development, there is no standard way to test and diagnose it [1]. Till our days, clinicians estimate qualitatively the presence and severity of this disease according to the patient symptoms [2]. These symptoms may vary from patient to another, but commonly a feeling of "weakness" and fatigue may occur. Moreover, as PD progresses, primary motor signs appear through tremor of the hands, arms and legs, bradykinesia or slowness of movement, rigidity or stiffness of the limbs and postural instability [3]. These symptoms are the results of the degeneration of certain nerve cells in deep parts of the brain called the basal ganglia, and the loss of nerve cells (or neurons) in a part of the brainstem called the substantianigra, the cells that are responsible to make the neurochemical messenger dopamine. Dopamine is the chemical messenger that sends messages to the part of the brain that controls movement and coordination. With the development of disease, the amount of dopamine produced in the brain decreases, leaving a person unable to control movement normally [3].

Several research studies have worked on the quantitative gait analysis to test PD through kinetic, kinematic or temporal distance studies depending on the measurement instruments and data availability. For instance, investigating VGRF signals help achieving a significant classification results between PD and normal subjects, such as Alban-Hidalgo et al. work [1]. On the other hand, by working on kinematic parameters, Manap et al, [4] were able to show the existence of differences in the mean values of overall joint angle of hip, knee and ankle between PD patients and a group of normal subjects. As well as, Talarposhti et al, [5] explain the effect of slowness in walking pattern in PD.

The database of our research is based on VGRF recordings. According to Newton's third Law of motion, for every action there exist an equal and opposite reaction. As we maintain contact with the ground, there occur interactions between the body and the ground. Therefore, the reaction force supplied by the ground is called the ground reaction force (GRF).

The purpose of this paper is to investigate the VGRF parameters that could be used to identify abnormal gait pattern in PD over a simple straight path. First, we will extract some statistical features from time and frequency domain. Then, these features will be used as inputs to T-test and Receiver Operating Characteristic (ROC) analysis test to examine their performance in the classification between health control and PD subjects.

II. METHODOLOGY

A. Database

Database was obtained from Physionet [6]. It includes the VGRF records of elderly people walking at their usual and self-selected speed for approximately 2 minutes on level ground. Eight "Ultraflex Computer DynoGraphy, Infotronic Inc." Sensors, that measure force in function of time, were placed underneath each foot as seen in Fig1. Two additional signals that reflect the sum of the 8 sensor outputs of each foot were also available. Table I summarizes the available data recorded from the 16 sensors. Outputs have been digitized with a sampling frequency of 100 Hz.

The study was performed on 91 subjects with idiopathic Parkinson Disease and 71 healthy control subjects. The gender, weight, height, walking speed and Hoehn and Yahr information of each subject were available.

Hoehn and Yahr scale, the widely used clinical rating of PD progression, defines 5 with 2 additional stages of PD, as mentioned in Table II.

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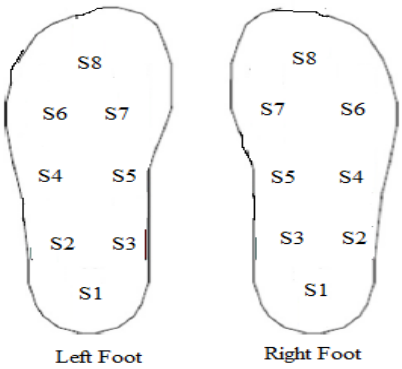

Fig. 1. Sensor location

B. *Pre-Processing*

To eliminate the influence of subject's body weight on VGRF, that is different from subject to another, the VGRF values of the 16 sensors were normalized to the percentage of their body weight by applying the following equation [5]:

$$\text{Normalized VGRF (\%)} = \frac{\text{VGRF}}{\text{Body Weight}} \times 100\% \quad (1)$$

TABLE I. DATA DESCRIPTION

Column #	Description
Column 1:	Time (in seconds)
Column 2-9:	Vertical ground reaction force (VGRF, in Newton) on each of 8 sensors located under the left foot
Column 10-17	VGRF on each of the 8 sensors located under the right foot
Column 18	Total force under the left foot
Column 19	Total force under the right foot

TABLE II. HOEHN AND YAHR SCALE

Stage	Signs and Symptoms
0	No signs of disease
1	Symptoms are very mild; unilateral involvement only
1.5	Unilateral and axial involvement
2	Bilateral involvement without impairment of balance
2.5	Mild bilateral disease with recovery on pull test
3	Mild to moderate bilateral disease; some postural instability; physically independent
4	Severe disability; still able to walk or stand unassisted
5	Wheelchair bound or bedridden unless aided

C. *Feature Extraction*

After pre-processing phase, for each data point, 4 statistical features were extracted from time domain analysis and 2 other features were extracted from frequency domain analysis as listed below:

- Mean: Signal averaging

$$\mu = \frac{\sum_{i=1}^{n} x_i}{\text{n}} \quad (2)$$

- Standard Deviation: Measurement of the amount of variation

$$\sigma = \text{sqrt}\left(\frac{\sum_{i=1}^{n}(x_i-\mu)^2}{\text{n}}\right) \quad (3)$$

where x_i represents each value in the sample and n is the number of element in the sample

- Skewness: Measurement of lack of symmetry in a distribution

$$s = \frac{\text{E}(x-\mu)^3}{\sigma^3} \quad (4)$$

- Kurtosis: Measurement of whether the data are peaked or not

$$k = \frac{\text{E}(x-\mu)^4}{\sigma^4} \quad (5)$$

where μ is the mean and σ is the standard deviation of the elements in signal x, and E is the expected value of the element

- Power of the signal

$$P = \lim_{T\to\infty} \frac{\sum_{n=-\infty}^{\infty} |x[n]|^2}{2T} \quad (6)$$

- Mean Power Frequency: Power averaging

$$MPF = \frac{\sum_{i=1}^{n} I_i \cdot f_i}{\sum_{i=1}^{n} I_i} \quad (7)$$

where n represents the number of frequency components in the power spectrum, f_i the value of the frequency and Ii the intensity of the power spectrum corresponding to the frequency f_i [7].

D. *Feature Selection*

In order to evaluate how well the extracted features can separate between control and PD subjects, and between patients with different stages of PD, feature selection techniques were applied. T-test and Receiver Operating Characteristic (ROC) Curve techniques were used to check the performance of the time and frequency features.

T-test, a comparison study of the means of two independent samples, proof that two means are significantly different when ρ value is less than 0.05 [5]. On the other hand, ROC curve, a fundamental tool for diagnostic test

evaluation, plots the true positive rate (sensitivity) in function of the false positive rate (100-Specificity) with different cut-off points of parameters: Area Under the Curve (AUC), accuracy (ACC), sensitivity (True positive rate), specificity (1-False positive rate) and the Matthews correlation coefficient (MCC) [7]. These measures from the curves are calculated as follows:

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \times 100 \qquad (8)$$

$$\text{MCC} = \frac{\text{TP} \times \text{TN} - \text{FP} \times \text{FN}}{\sqrt{(\text{TP} + \text{FN})(\text{TP} + \text{FP})(\text{TN} + \text{FP})(\text{TN} + \text{FN})}} \qquad (9)$$

$$\text{True Positive Rate (TPR)} = \frac{\text{TP}}{\text{TP} + \text{FN}} \times 100 \qquad (10)$$

$$\text{False Positive Rate (FPR)} = \frac{\text{FP}}{\text{FP} + \text{TN}} \times 100 \qquad (11)$$

Here *TP*, *FN*, *FP*, and *TN*, respectively, represent the numbers of true positives, false negatives, false positives, and true negatives.

III. RESULTS

The statistical time and frequency domain parameters were extracted from each of the 16 VGRF signals and from the 2 signals representing the summation values of each foot sensors. After applying the T-test analysis between normal and PD subjects, Tables III and IV illustrate the ρ-values of some sensor for the mean, STD and power studies. The examination shows that these parameters can be extracted from three common sensors; the 1st, 2nd and 5th sensors of both feet; to provide significant information for classification. However, extracting statistical parameters from the summation of total left and total right sensors hide the conveyed information of VGRF signal. Then, ROC analysis corresponding to the power feature of sensor 1 was applied. Fig3 shows the ROC curves generated from a) left and b) right foot sensors number 1.

Finally, the average of power distribution shown in Fig4 and the box plot presented in Fig 5 prove that the power exerted on sensor number 1 decreases when moving from a health control to a PD subject, as well as moving from a PD of first stage to another subject with higher stage.

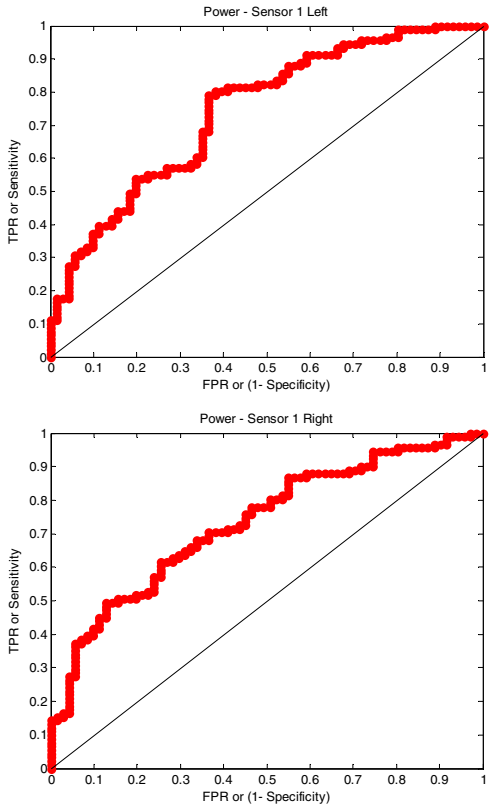

Fig 3. ROC curves calculated from the power of sensor 1 under a) left and b) right foot.

TABLE III. T-TEST ANALYSIS FOR LEFT FOOT SENSORS

	ρ-Values		
Sensor	Mean	STD	Power
1	1.99E-06*	2.935E-08*	7.65E-08*
2	0.001523*	0.00018*	0.000531*
5	0.00043*	0.009494*	0.036437*
Total	0.64193	0.79874	0.90931

* Significant difference (t-test, $p<0.05$)

TABLE IV. T-TEST ANALYSIS FOR RIGHT FOOT SENSORS

	ρ-Values		
Sensor	Mean	STD	Power
1	6.684E-06*	7.174E-08*	5.68E-07*
2	0.03994*	0.007128*	0.0144*
5	0.000484*	0.008429*	0.01618*
Total	0.106725	0.909822	0.81189

* Significant difference (t-test, $p<0.05$)

IV. DISCUSSION

From our study, as well as previous researchers work, investigating VGRF signals allows classifying between health control and PD subjects. As it is known, choosing the correct parameters improves this classification.

First, through our study of time and frequency domain parameters, our results attest that not only the extracted parameters affect the results, but as well, the location from where the feature is extracted has a significant role. We observed that certain sensors located underneath each foot hold significant information that allow their usage in classification between health control and PD subjects, rather than focusing on the summation of VGRF outputs of the 8 sensors of each foot.

Moreover, we noticed the discrimination of VGRF power over the sensors depending on the severity of PD, which is symbolized by Hoehn and Yahr stages.

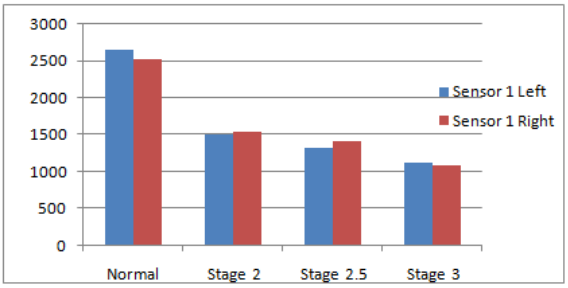

Fig.4 Comparison of VGRF power average between health control and PD subjects with different Hoehn and Yahr stages

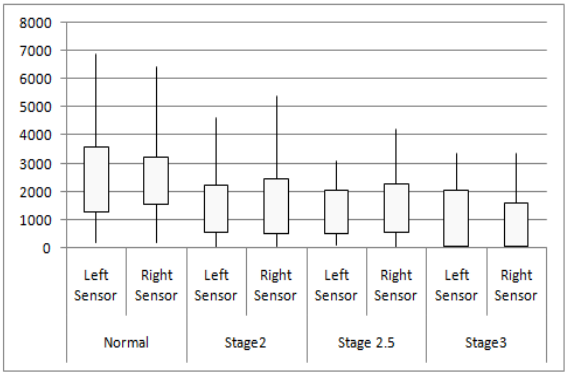

Fig 5. The Difference between power distribution over sensor number1 for normal and PD subjects of different stages.

V. CONCLUSION

In this paper, we presented the VGRF signals analysis done based on statistical and frequencies parameters. Results have shown the importance of some sensors that varies according to the extracted feature. Unlike some of researchers work, investigating only the summation of VGRF signals prevents the capability of classifying between health control and PD subjects. Furthermore, through our research, we were able to confirm that the power distribution over the foot alters between subjects of different stages of PD.

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