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Gait and tremor assessment for patients with Parkinson's disease using wearable sensors☆

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Abstract

Typically, subjects with Parkinson's disease (PD) display instances of tremor at an early stage of the disease and later on develop gait impairments and postural instability. In this research, we have investigated the effect of using both gait and tremor features for an early detection and monitoring of PD. Various features were extracted from the data collected from the wearable sensors and further analyzed using statistical analysis and machine learning techniques to find the most significant features that would best distinguish between the two groups: subjects with PD and healthy control subjects. The analysis of our results shows that the features of step distance, stance and swing phases, heel and normalized heel forces contributed more significantly to achieving a better classification between the two groups in comparison with other features. Moreover, the tremor analysis based on the frequency-domain characteristics of the signal including amplitude, power distribution, frequency dispersion, and median frequency was carried out to identify PD tremor from atypical Parkinsonism tremor.

Keywords: Gait and tremor features; Linear discriminant analysis; Parkinson's disease; Wearable sensors

1. Introduction

Parkinson's disease (PD) is ranked the second most common neurodegenerative disease next to Alzheimer's disease. Parkinson Disease Foundation [1] estimates that nearly 7–10 million people worldwide suffer from PD. Deterioration of dopamine-producing neurons in the brain is the primary cause of PD, where dopamine is an essential neurotransmitter that controls both smooth and coordinated muscle function [1]. The main motor symptoms of PD include tremor at rest, bradykinesia, rigidity, and impairment of postural balance [2].

The diagnosis of PD can be difficult especially in its early stages and currently, there are no specific tests or biomarkers available to diagnose PD. Mostly, the current diagnosis is based on subjective measures derived from visual observations by clinicians/ neurologists to generate a score from UPDRS. Typically, a neurologist analyzes the patient's complete medical history and performs numerous clinical assessments to confirm the presence of PD in that subject [1,3]. Sometimes, it might take up to a year to diagnose PD after careful consideration of the subject's neurological history and clinical assessments. Moreover, due to lack of objective measures, there is also a high possibility of misdiagnosing PD. It has been found that the rate of misdiagnosis of PD is around 25%, and approximately 40% of PD cases are overlooked for other neurological disorders [1,3]. According to experts, the diagnosis of PD requires the presence of one or more of the four main PD motor symptoms. The progress of PD symptoms varies from one subject to another. For example, resting tremor occurs in only 70% of PD patients during the onset of the disease, while others might develop gait disturbances or even action tremor during their initial stages of PD [1,3]. So, an early and accurate diagnosis of PD is required for better treatment and for more efficiently control the effects of the symptoms.

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Over time, many types of research have evolved on developing a PD monitoring system, using different types of sensors, feature sets and analysis methods. Few among the many wearable sensors used in acquiring the bio-signals include accelerometers, force sensors, gyroscopes and magnetometers [4]. Patel et al. [5] worked on developing a system that measures the severity of tremor, bradykinesia (slowness of movement) and dyskinesia (motor fluctuations) using a wearable sensor platform. The resting tremor occurs during the early stages of PD and also is an essential criterion to diagnose the PD, where accelerometers are widely used to detect and record its occurrences [6,7]. Salarian et al. [8] proposed an algorithm to detect and quantify tremor and compared the measured tremor amplitude to the corresponding UPDRS score. Further, Edwards and Beuter [9] utilized tremor characteristics such as the amplitude, frequency and spectral power to identify PD tremor. Then, they combined the characteristics into a single variable to identify a PD from abnormal tremor effectively [9]. Additionally, it is vital to monitor the gait impairments in patients, to detect PD at an early stage. In the experiments conducted by Salarian et al. [10], they concluded that the stride velocity, stride length and swing time of Parkinsonian patients were lower in comparison to healthy control subjects. On the contrary, the stance time in Parkinson's patients was higher than that of healthy subjects. Additionally, Okuno et al. obtained similar results [11] using a force sensor worn by the subjects. Further, Tahir and Manap [12] extracted basic, kinetic and kinematic features based on force measurement. Then, through statistical analysis, it was found that step length, walking speed and VGRF were among the significant features that would differentiate a Parkinson's patient from healthy control subject [12]. Barth et al. [13] extracted various gait features and were classified using multiple classifiers, and their individual performances were studied. Among the classifiers used, LDA (Linear Discriminant Analysis) provided the best classification accuracy. In [14] Frenkel-Toledo et al. studied the relationship between the walking speed and gait variability in PD and healthy control subjects. Also, the investigators had performed statistical analysis (t-test) to compare the two groups. From the results, it was concluded that the patients with PD had an increased variability of stride time and swing time as compared to healthy control subjects.

The goal of this research is to analyze the features exhibited by subjects with PD during the initial phase of the disease, which would enable us to detect the presence of PD at its onset. In this study, we extracted kinetic and spatiotemporal features using data from an online database (Physionet) and found a set that best discriminates between subjects with PD (H&Y stages 2, 2.5 and 3) and healthy subjects. Also, tremor features were extracted and we performed various analyses using advanced signal processing and machine learning techniques on the extracted tremor and gait parameters to compare and distinguish between subjects with PD and healthy subjects. Majority of the studies either utilize gait or tremor features for PD monitoring. Here, we have investigated the use of both gait and tremor features and analyzed their impact on early detection and monitoring of PD.

2. Data collection

For the gait analysis, data from the Physionet online database [15] was utilized, consisting of readings from the experiments conducted on 93 patients with idiopathic PD (mean age: 66.3 years) with moderate disease severity (H & Y Stage 2–3) and 73 healthy controls, sampled at a rate of 100 Hz. The database comprises of 3 different experiments conducted by Frenkel-Toledo et al. (Group 'Si') [14], Hausdorff et al. (Group 'Ju') [16] and Yogev et al. (Group 'Ga') [17]. The forces imparted by the heel, below toe (metatarsophalangeal joint) and toe regions of the foot were analyzed. To reduce the influence of subject's body weight on the forces, the force values were normalized to the percentage of their body weight. For the tremor analysis, data from the Physionet database was utilized, resulting from the experiments conducted on a group of 16 patients with PD [18]. The patients were under minimum medications at the time of study to induce tremor and the data were recorded for a time period of 60 secs (depending on the duration of tremor occurrence in subjects) and sampled at 100 Hz.

3. Feature extraction

3.1. Gait characteristics

A gait cycle begins at the point of heel strike called as initial contact, marking the beginning of a stance phase. The stance phase ends at the toe-off period, and the swing phase terminates at the next heel strike event. The stance and swing periods of a healthy control subject varies from that of a PD patient. The stance and swing phase values are essential in identifying the individuals with PD from the healthy subjects [19]. Other spatiotemporal parameters include the step length, the linear distance in the plane of progression between two successive points of foot floor contact of the opposite feet. Also, step time is the time interval between the successive instant of foot floor contact of the opposite feet. The last feature is the kinetic feature that mainly focuses on the force acting on the ground during initial contact and toe-off positions [20].

3.2. Gait detection algorithm

Initially, the raw force data was filtered using a Chebyshev type II high pass filter with a cut-off frequency 0.8 Hz to remove noises arising from the changes in orientation of the subject's body and other factors during measurement. The filtered data was used for extracting various gait features using the peak detection and pulse duration measuring techniques. The threshold values of the gait detection algorithm were tuned to individual subjects. From the peak detection algorithm, various kinetic features including the heel, below toe, and toe forces, and their normalized values were obtained. The pulse duration algorithm was developed to extract different spatial and temporal features including the step distance, stance and swing phases, and stride time.

In Fig. 1, the force readings are plotted against time for the left foot of the subject. From the plot, points P1–P4 are marked