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Original Research Article

Parkinson's disease monitoring from gait analysis via foot-worn sensors

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ABSTRACT

Background: In Parkinson's disease (PD), neuronal loss in the substantia nigra ultimate in dopaminergic denervation of the stiratum is followed by disarraying of the movements' preciseness, automatism, and agility. Hence, the seminal sign of PD is a change in motor performance of affected individuals. As PD is a neurodegenerative disease, progression of disability in mobility is an inevitable consequence. Indeed, the major cause of morbidity and mortality among patients with PD is the motor changes restricting their functional independence. Therefore, monitoring the manifestations of the disease is crucial to detect any worsening of symptoms timely, in order to maintain and improve the quality of life of these patients.
Aim: The changes in motion of patients with PD can be ascertained by the help of wearable sensors attached to the limbs of subjects. Then analysing the recorded data for variation of signals would make it possible to figure an individualized profile of the disease. Advancement of such tools would improve understanding of the disease evolution in the long term and simplify the detection of precipitous changes in gait on a daily basis in the short term. In both cases the apperception of such events would contribute to improve the clinical decision making process with reliable data. To this end, we offer here a computational solution for effective monitoring of PD patients from gait analysis via multiple foot-worn sensors.
Methods: We introduce a supervised model that is fed by ground reaction force (GRF) signals acquired from these gait sensors. We offer a hybrid model, called Locally Weighted Random Forest (LWRF), for regression analysis over the numerical features extracted from input signals to predict the severity of PD symptoms in terms of Universal Parkinson Disease Rating Scale (UPDRS) and Hoehn and Yahr (H&Y) scale. From GRF signals sixteen time-domain features and seven frequency-domain features were extracted and used.
Results and conclusion: An experimental analysis conducted on a real data acquired from PD patients and healthy controls has shown that the predictions are highly correlated with the clinical annotations. Proposed approach for severity detection has the best correlation

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coefficient (CC), mean absolute error (MAE) and root mean squared error (RMSE) values with 0.895, 4.462 and 7.382 respectively in terms of UPDRS. The regression results for H&Y Scale discerns that proposed model outperforms other models with CC, MAE and RMSE with values 0.960, 0.168 and 0.306 respectively. In classification setup, proposed approach achieves higher accuracy in comparison with other studies with accuracy and specificity of 99.0% and 99.5% respectively. Main novelty of this approach is the fact that an exact value of the symptom level can be inferred rather than a categorical result that defines the severity of motor disorders.

1. Introduction

Parkinson's disease (PD) is a neurodegenerative, progressive, complex, neurological and asymmetrical disease. Among age related neurodegenerative diseases Parkinson Disease is the second most frequent one affecting 0.1–0.2% of the general population, about %2 of people over 80 [1,2]. One of the causes of the disease is the lack of sufficient dopamine in the brain. PD damages the neurons of substantia nigra pars compacta area in the brain where dopamine is produced. Pathologic examinations show that cell loss in the substantia nigra ranges between 30% and 70% [3]. Therefore therapies for PD include using drugs that activate dopamine receptors [4]. However they can be successful for a short time, these treatments could not be permanent in the long term. Dopaminergic treatment could not demonstrate adequate efficacy on motor symptoms such as postural instability and voice impairment in the disease [5]. Other motor symptoms of PD are tremor, rigidity, Bradykinesia and secondary ones including shuffling gait, micrographia and mask-like expression. While no cure for the disease yet exists, medical treatment of patients with PD is a crucial issue in order to maintain and/or improve their quality of life [6–9]. Medical treatments do not stop the progression of the disease completely but may help to slow it down.

In medical practice, determination of motor impairments of the patients is based on neurological examination performed during doctor appointments and home diaries kept by the patients or the caregivers. However, a short-time examination may not reveal enough data, and data from the everyday diaries may be subjective. To find more straight judgements, a few rating scales have been used, with the Unified Parkinson's Disease Rating Scale (UPDRS) being the most extensively used. UPDRS is a valuation system that appraises elected symptoms and signs of PD in a 5-point scoring system. Regrettably, UPDRS presents intra and inter-observer disagreements, and can only be used during a visit to the hospital. To overcome these difficulties, methods for monitoring motor symptoms of PD in an ambulatory way have been presented in the literature, like PERFORM [10], Physilog [11], Portable Motus System [12], The Kinesia [13], Opal movement monitor[14], Lift Pulse and Lift Stride [15]. There are also some going on projects investigating new technics to appraise motor performance and then construct rehabilitation programs for PD patients, by integrating auditory feedback, technologies for interactive video conference, and kinematic analysis as The Rescue Project [16], PARREHA (PARkinsonian REHAbilitation) [17], INDIGO (INDependent I GO) [18], DAPHNE (Detection of Activity Performance for Health with New Equipment) [19], The HELP (Home-based Empowered Living for Parkinson's Disease) [20], CuPiD (Closed-loop system for personalized and at-home rehabilitation of people with Parkinson's disease) [21], and REMPARK (Personal Health Device for the Remote and Autonomous Management of Parkinson's Disease) [22].

Losing of motor abilities is the key problem of PD patients. It becomes vital to monitor their conditions remotely, while providing satisfactory home care and clinical support. Current computational research on the topic has been pursued mostly in two directions. The first direction is developing systems and algorithms for recognizing the activities of daily living using motion sensors [5,23–26]. They are also widely used in gait analysis [27]. The gait analysis is important and informative for PD treatment because the disease requires continuous monitoring. To perform the analysis, PD patients should go to a hospital or a research center that has a gait laboratory. Standard gait laboratories must have an infrastructure for gait evaluation. The infrastructure consists of a video system for recording images of the patient; a motion-capture system for tracking the movements; force plates for measuring GRF and an EMG system for recording muscle activity [28]. As sensor and mobile technology become cheaper and widespread, recent studies show that it becomes easier to perform gait analysis without any need for infrastructure [29–40]. Therefore the need for a professional assistance is diminished as possible.

Tunca et al. [41] proposed a foot-mounted inertial sensor-based gait analysis system. Their proposed system is completely mobile which includes only two inertial measurement units (IMU). An IMU mainly consists of an accelerometer, a gyroscope and a magnetometer. In addition to detect straight walking, their system can detect and operate with side, back and turning steps. In their study, spatio-temporal gait metrics were extracted such as stride length, cadence, cycle time, stance time, swing time, stance ratio, speed, maximum/minimum clearance and turning rate. While the recognition of activity is helpful in a general context, it does not provide sufficient clinical assistance for therapists. The second direction is designing computational methods through different sensing modalities to diagnose the disease automatically [42–49]. Martinez et al. [42] proposed a computer-aided

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