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Pronation and supination analysis based on biomechanical signals from Parkinson's disease patients

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ABSTRACT

In this work, a fuzzy inference model to evaluate hands pronation/supination exercises during the MDS-UPDRS motor examination is proposed to analyze different extracted features from the bio-mechanical signals acquired from patients with Parkinson's disease (PD) in different stages of severity. Expert examiners perform visual assessments to evaluate several aspects of the disease. Some previous work on this subject does not contemplate the MDS-UPDRS guidelines. The method proposed in this work quantifies the biomechanical features examiners evaluate. The extracted characteristics are used as inputs of a fuzzy inference model to perform an assessment strictly attached to the MDS-UPDRS. The acquired signals are processed by techniques of digital signal processing and statistical analysis. The experiments were performed in collaboration with clinicians and patients from different PD associations and institutions. In total, 210 different measurements of patients with PD, plus 20 different measurements of healthy control subjects were performed. With objective values rated by several feature extraction procedures there is the possibility to track down the disease evolution in a patient, and to detect subtle changes in the patient's condition.

1. Introduction

Parkinson's disease is a neurodegenerative disorder that progresses slowly; in some people symptoms can take years to develop. According to the World Health Organization (WHO) more than 10 million people worldwide are living with Parkinson's disease. The disease itself is not fatal. However, complications are very serious and can include tremors, posture instability, stiffness and Bradykinesia (slowness of movement). It is important to note that most of these complications occur once there is brain damage from 60% to 80% and symptoms may vary from one person to another [1].

Currently the most standardized and detailed means to rate Parkinson disease (PD) is the Unified Parkinson's Disease Rating Scale (UPDRS) proposed by the International Parkinson and Movement Disorder Society (MDS) [2]. Furthermore, this rating is time consuming and still somehow subjective because it is based on human observations. Although this scale is widely used in its current form, there have been proposals of new scales for the evaluation, they present some limitations but still deserve some considerations [3,4].

On the one hand, wearable data has some advantages with respect to traditional clinical data such as less subjective scorings, large scale volume of data and it can be used in a wide variety of experiments, on the other hand traditional clinical data takes substantial time and effort to be collected [5].

Several computer evaluation tools have been proposed such as speech to predict the severity of the disease [6,7]. Most common approaches rely on, fuzzy expert systems dedicated to PD diagnosis using features such as age, amplitude, frequency, Lyapunov's exponent and adds them to the score of the MDS-UPDRS given by authorized examiners [8]. Additionally, tools such as targets for clicking on them for complication detection in fine movements [9], spiral tests are used where PD patients are asked to perform a spiral drawing task in a digitized tablet [10,11]. Likewise inertial sensors such as accelerometers and gyroscopes are used in finger tapping tests to conduct objective evaluations [12]. Similarly, tremor

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simulations are acquired by accelerometers [13]. Other researches focuses on motor exploration exercises of the MDS-UPDRS locating inertial sensors in different parts of the hands such as fingers or palms [14,15].

In addition, gait and tremor signals analysis are also evaluated for PD patients in [16]. Other works estimate the severity of tremors, Bradykinesia and Dyskinesia [17,18]. Moreover, accelerometers built in smartphones have been used to acquire tremor signals in different activities such as walking, standing and sitting [19,20]. Other classification techniques such as dynamic neural networks are used for PD severity stage classification [21,22].

Several researches have been done to quantify affectations such as tremors and Bradykinesia using different tools, but few of them are strictly attached to the MDS-UPDRS, i.e., often the quantified features are not closely related to those the examiners assess while the patient is performing the tasks proposed in the MDS-UPDRS [23]. For example, gyroscopes are used to obtain a quantitative assessment of Bradykinesia by performing a wrist pronation/supination movement after a surgical procedure in PD patients [24]. Not having a closely quantified evaluation regarding the UPDRS is somehow challenging because new evaluation proposals need to be clinically validated and tested. According to [24] the root mean square velocity of angular movement (V_{rms}) is used as an indicator of the average velocity of the wrist pronation/supination movements. However, this study is designed to only evaluate patients' performance in the pronation/supination movements, before and after a specific surgical procedure. Moreover, this work does not consider other features required by the MDS-UPDRS to rate pronation/supination exercises such as angular displacement amplitude, halts and hesitations, and how and when the amplitude decrements.

In summary, some of the problems in PD assessment:

- Weak correlation with the MDS-UPDRS [17–20,23].
- Research performed by [24] does not consider all the aspects that are assessed during the pronation/supination exercise such as halts, hesitations and decreasing amplitude.
- When expert clinicians perform an assessment, the results depend on their experience, which makes the evaluation completely subjective.

In this paper a computer model is proposed to accurately and objectively quantify eight biomechanical features using advanced digital processing techniques of signals obtained from inertial sensors woren by PD patients on the dorsal side of both hands during pronation/supination exercises. All features are strictly attached to the MDS-UPDRS. Accordingly, rating scores are also obtained herein by mathematically modelling current clinician knowledge using a fuzzy inference system. In this work, 210 measurements of PD patients during a full motor examination session are performed plus 20 measurements from healthy control subjects performing same exercises. Expert clinicians, nurses and therapists from a well-stablished National Parkinson Society monitored and participated in these sessions. All the computer model scores using objective features quantification and knowledge representation based on fuzzy inference systems are compared to the rating score assigned to the same PD patient by expert clinicians but using subjective observations.

This paper has seven sections including the introduction given herein. Section 2 reviews how the pronation/supination movements are rated in patients with Parkinson's disease (PD). Section 3 presents the data acquisition system and how it was implemented in patients with PD. Section 4 describes the feature extraction procedure. Section 5 underlines the fuzzy system design and implementation. Consequently, Section 6 discusses results, and conclusions are drawn on Section 7.

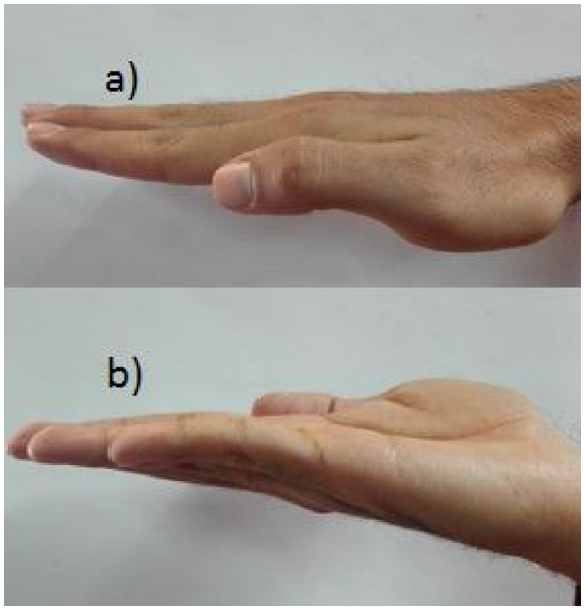

Fig. 1. Hand position at: a) Pronation and b) Supination.

2. Review

The MDS-UPDRS is divided in four parts: Part I (non-motor experiences of daily living), Part II (motor experiences of daily living), Part III (motor examination) and Part IV (motor complications) [2]. In part III, patients are asked to perform some motor exercises that are assess by an expert rater.

The exercise 3.6 consists in performing pronation/supination movements. In this task each hand is tested separately with the examiner demonstrating the task at the beginning. The patient is instructed to extend their arms out in front of their body with their palms facing down; then they turn their palm up and down alternately 10 times as fast and as fully as possible [2] as depicted in Fig. 1.

According to the MDS-UPDRS each side is rated separately evaluating features such as speed, amplitude, hesitations, halts and decrementing amplitude. Afterwards, an evaluation is given using a score from 0 to 4 where (the following evaluation weightings are exactly written as in the MDS-UPDRS) [2]:

- 0: Normal: No problems.
- 1: Slight: Any of the following: a) the regular rhythm is broken with one or two interruptions or hesitations of the movement; b) slight slowing; c) the amplitude decrements near the end of the sequence.
- 2: Mild: Any of the following: a) 3–5 interruptions during the movements; b) mild slowing; c) the amplitude decrements midway in the sequence.
- 3: Moderate: Any of the following: a) more than 5 interruptions during the movement or one longer arrest (freeze) in ongoing movement; b) moderate slowing c) the amplitude decrements starting after the 1st supination-pronation sequence.
- 4: Severe: Cannot or can only barely perform the task because of slowing, interruptions or decrements.

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