Tremor UPDRS Estimation in home environment. (Draft)

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May 24, 2018

Abstract

In this paper, a method for evaluation of the Unified Parkinson Disease Rating scale (UPDRS) items related to tremor is presented. The method described consists of hand resting, action and posture state detection, tremor detection and tremor quantification based on accelerometer and gyroscope readings from a wrist worn sensor. The initial results on PD patient recordings on home environment indicate the feasibility of the proposed method in monitoring UPDRS tremor in patient home environment.

0.1 Introduction

Tremor is defined as a rapid back-and-forth movement of a body segment [1]. Tremor is the most common motor disorder of Parkinson's Disease (PD) and consequently its detection plays a crucial role in the management and treatment of PD patients. There are three types of Parkinsonian tremor: i) resting tremor which occurs in a body segment while this body segment is maintained at rest; resting tremor typically ranges from 3.5-7.5 Hz [1], ii) postural tremor which occurs in body segments during the maintenance of a posture, such as holding a cup, and iii) action or kinetic tremor which occurs when a body segment performs a specific action.

Tremor evaluation is based mainly on the Unified Parkinson Disease Rating scale (UPDRS) [2] performed by expert clinicians during a patient's visit at the hospital. However, during the last years there is a growing number of studies and methods focusing on continuous monitoring of PD symptoms in patient's home environment. PD_manager is a mHealth project targeting on an integrated infrastructure for monitoring and management of the disease. The monitoring is based on a combination of wrist sensors (accelerometer and gyroscope), sensors placed on a smart sole (pressure sensors and accelerometers) and mobile phone sensors. Continuous monitoring of PD symptoms allows the physicians to have a more complete picture of the patient's response to medication, and act accordingly.

Several research groups have proposed objective methods to detect and quantify tremor using accelerometers or gyroscopes [3], [4], [5], [6], [7], [8], [9]. We have also presented a method for tremor and posture recognition [10],[11]. However, the majority of the studies are relating tremor to an expert score (usually UPDRS-3.17) and not to the amplitude of the tremor, which is the quantity observed by the expert to perform the UPDRS scoring. Furthermore, in [10] at least two sensors (wrist and chest) were used for posture detection.

In this study we propose a methodology based on a wrist gyroscope and accelerometer, which provides a complete tremor UPDRS assessment (items 3.15, 3.16, 3.17, 3.18). Moreover, the method is based on a single wrist sensor (Microsoft Band [1]) and is computationally efficient, an important requirement for mHealth applications.

[1]https://www.microsoft.com/microsoft-band/en-us

0.2 Methodology

For Tremor assessment a commercially available device (Microsoft Band) was employed which includes both accelerometer and gyroscope. The accelerometer is used mainly for hand posture/rest/action detection, whereas the gyroscope is used for tremor detection and assessment. The proposed method consists of the following steps:

1. Signal Pre-processing,
2. Tremor Detection,
3. Tremor Assessment,
4. Rest/Action Posture Detection.

0.2.1 Signal Pre-processing

Four signals are produced from filtering of the original gyroscope and accelerometer.

1. A1: Low-pass ($< 0.5Hz$) accelerometer signal mainly used for posture detection.
2. G1: Low-pass ($< 0.5Hz$) gyroscope signal mainly used for tremor detection.
3. G2: Band-pass ($2-4Hz$) gyroscope signal mainly used for tremor and activity detection.
4. G3: High-pass ($3-8Hz$) gyroscope signal mainly used for tremor detection and amplitude estimation.

For tremor detection a number of features is extracted. Both detection and amplitude estimation are based on a 3sec window features. The extracted features include the energy of the G1, G2 and G3 and their ratios. The energy of a signal s is calculated as:

$$E_s = \sum_{i \in W} \left((s_i^x)^2 + (s_i^y)^2 + (s_i^z)^2 \right). \quad (1)$$

The energy ratios between different signals are calculated, namely $ER_1 = E_{G1}/(E_{G1} + E_{G2})$, $ER_2 = E_{G2}/(E_{G1} + E_{G3})$ and $ER_3 = E_{G1}/(E_{G1} + E_{G3})$.

Another important extracted feature is the distribution of the energy across the 3sec window. In the case of the tremor the energy should be uniformly distributed across the 3sec window. Therefore, the energy of 6 smaller $E_s = \{E_{0-0.5}, E_{0.5-1}, ..., E_{2.5-6}\}$ windows of 0.5 seconds is calculated and the following uniformity measure iscomputed:

$$U = \frac{\max E_s - \min E_s}{\max E_s + \min E_s}. \tag{2}$$

For the detection of tremor the C4.5 decision tree algorithm is selected [12]. The main reason for selecting decision trees for tremor detection is that the hierarchical decision allows the calculation of required features when needed and not from the beginning, thus reducing the required computational time.

Tremor Amplitude Estimation

The UPDRS Tremor severity is based on the visual observation of the tremor's amplitude. In fact the instruction is to use the maximum observed tremor amplitude. The four amplitude scales are 0-1.5, 1.5-3, 3-10, >10 cm. In order to calculate the range of the tremor amplitude, the gyroscope readings are used after removing the low frequency component of the signal corresponding to the voluntary movements. Tremor is a quasi stationary movement across a specific rotation axis. Therefore, the first step is to find the principal rotation axis using principal component analysis (PCA). Initially, the mean of the each axis is removed; then the covariance matrix $\mathbf{C}$ of the three axis is calculated and using the eigenvector $\mathbf{v}$ corresponding to the largest eignevalue $\lambda_{\max}$ is used to get the principal component corresponding to the tremor movement

$$\mathbf{X}' = \mathbf{X}\mathbf{v}. \tag{3}$$

An example of the original gyroscope signal (with tremor) and the corresponding principal components is depicted in Fig. **??**. Then the discrete Fast Fourier Transform $\mathbf{FFT(f)}$ of the principal component is calculated. Typically tremor detection relies on the presence of a dominant frequency on the 3.5-8 Hz frequency band. To quantify the presence of a dominant frequency, the frequency, f_D, and the maximum amplitude, A_{f_D}, are calculated as:

$$f_D = \arg\max |FFT(f)|, \tag{4}$$

$$A_{f_D} = \max |FFT(f)|. \tag{5}$$

We then assume that the center of rotation is in the middle of the arm with length (L) [2]. According to the simple tremor model in Fig. **??**, the

[2] The arm length L should be calculated based on patient height. In this study for men is set to 25 cm and for women 20 cm.

maximum amplitude A^m is related to the maximum principal rotation angle ϕ_m with the following formula:

$$A^m = (L)\sin(\phi^m/2). \tag{6}$$

The maximum principal rotation angle ϕ_m can be extracted from f_D and A_{f_D} under the assumption that the FFT has a single peak, which is valid in the tremor case:

$$\begin{aligned} \phi(t) &= \phi_m \sin(2\pi f t) & (7)\\ ,\frac{d\phi(t)}{dt} &= 2\pi f \phi_m \cos(2\pi f t). & (8) \end{aligned}$$

The $\frac{d\phi(t)}{dt}$ is the observed rotation speed of the gyroscope, $2\pi f \phi_m$ is approximated by A_{f_D} and f is approximated by f_D. Based on those assumptions, ϕ_m can be approximated as:

$$\phi_m = \frac{A_{f_D}}{2\pi f_D}. \tag{9}$$

The estimated amplitude is used in a fuzzy linear function in order to obtain the UPDRS score.

$$\begin{aligned} UPDRS(x) &= tf(x; 0.1, 0.1, 0.8, 1.2) & (10)\\ &+ \; 2 \cdot tf(x; 0.8, 1.2, 2.5, 3.5]) & (11)\\ &+ \; 3 \cdot tf(x; 2.5, 3.5, 8, 12) & (12)\\ &+ \; 4 \cdot tf(x; 8, 12, 100, 100) & (13) \end{aligned}$$

where $tf(x; a, b, c, d) = \max(\min(\frac{x-a}{b-a}, 1, \frac{d-x}{d-c}, 0))$

0.2.2 Rest/Action/Posture Detection

Posture tremor could be defined as tremor while voluntarily maintaining a position against gravity [13]. In this study we aim on detecting gestures in patient activities such as: from a resting phase the subject raises his hand and holds it on the air (with no support) for a significant period of time. This could be the pattern of changing the TV channel or grasping and holding an object. The gestures are more formally described by the following actions:

A raise the hand,

B keep the hand up and still for a couple of seconds, C lower the hand.

Actions A and B are detected based on peak detection[3] (positive peak for raising and negative for lowering hand), applied on the energy of first differences of the low pass accelerometer signal (<0.5Hz) $\mathbf{E^d}$:

$$E^d(i) = \sqrt{(s_i^x - s_{i-1}^x)^2 + (s_i^y - s_{i-1}^y)^2 + (s_i^z - s_{i-1}^z)^2} \quad (14)$$

Then for each interval between pairs of consecutive positive and negative peaks three features are extracted: i) the mean value of the X axis of the low-pass accelerometer signal (P1), ii) the interval length (sec.) (P2), and iii) the percentage of time with no activity (P3) calculated as the ratio of the number of the samples of the interval where $\sum E^d(i) < 0.004$, to the total number of samples in the interval.

Then the posture was classified as posture or not, using the following fuzzy rule (product of sigmoid functions):

$$\begin{aligned} Posture(P1, P2, P3) \quad = \quad & sf(P1; 0.5, 3) \\ & \cdot sf(P1; -0.2, 30) \\ & \cdot sf(P2; -20, 0.2) \\ & \cdot sf(P3; 10, 0.6) \end{aligned} \quad (15)$$

where $sf = 1/(1 + \exp^{a\cdot(x-b)})$.

Tremor was classified in rest/posture/action according to the following rules

- **Posture**: A window where tremor was detected coinciding with an interval classified as posture.
- **Action**: A window where tremor was detected, not coinciding with an interval classified as posture and $\sum_{i \in W} E^d(i) > 0.001$.
- **Resting**: A window where tremor was detected, not coinciding with an interval classified as posture and $\sum_{i \in W} E^d(i) <= 0.001$.

0.3 Dataset

For the purpose of this study three different datasets were used in order to evaluate the proposed method. The first dataset (Dataset I) consists of simulated tremor and hand posture movements. This dataset was employed

[3] In our experiments we used a MATLAB code by Nathanael C. Yoder, peakfinder.m.

Table 1: Results for Tremor detection

Cross validation results of decision tree L1				
Class	NoTremor	Tremor	Sens.	Spec.
No Tremor	1318	127	0.91	0.98
Tremor	22	277	0.92	0.69
Acc	**0.91**			

in order to train the tremor detection and posture detection methods. The simulated tremor is necessary in order to have all the potential combinations of tremor severity and type (resting, posture and action). This dataset was used in order to extract and evaluate the tremor detection method. The second dataset ((Dataset II) consists of 20 recordings performed in 5 PD patients. During the recordings patients have performed a specific protocol including the UPDRS evaluation of Tremor as well as a number of daily patient activities (lying on a bed, sitting on a chair, walking, drinking a glass of water etc.). This second dataset was used for comparison of an expert UPDRS assessment and the proposed method. The third dataset (Dataset III) consists of two long recordings (several hours) of one normal subject and two patients, one with significant tremor and one without. The third dataset is used in order to evaluate the method in real home environment while patient performs ordinary daily activities. All the above mentioned datasets consists of Microsoft Band accelerometer and gyroscope data as well as proper annotations (apart from Dataset III) acquired with an Android application developed by the authors.

0.4 Results

0.4.1 Tremor Detection

Tremor detection was evaluated on Datasets I and II. Two sub-datasets were created; the first one including only energy, energy ratio features and the uniformity feature U. The second feature set included also, the maximum amplitude A_D and frequency f_D, as well as, the ratio of the maximum FFT peak to the sum of all other peaks. A 10 cross-validation procedure was used to evaluate the Tremor detection accuracy for both datasets. The first dataset had accuracy of 87% and the second had accuracy of 91%. The confusion matrix of the second decision tree is depicted in Table 1.

Table 2: Results for different UPDRS items related to tremor evaluation on long home recordings.

Patient	3.15	3.16	3.17	3.18
Normal	0.1	0.2	0.1	0.5%
With Dyskinesia	0.4	0.3	0.3	0.9%
With Tremor	1.4	1.3	1.6	15%

0.4.2 Posture Recognition

The posture detection method was evaluated on Dataset I and Dataset II. The datasets include 50 hand posture regions, manually annotated by experts using video. Based on the specific parameter selection the method detects 90% (45 cases) of all the annotated postures and has 5 false positives which correspond to the 4% of the total number of postures.

0.4.3 Tremor Amplitude and Constancy

The tremor amplitude estimation described in **??** was evaluated on Dataset-II with the PD patient recordings. For each recording the tremor amplitude was calculated as described in **??** on the windows where tremor was detected. Then the distribution of the tremor amplitude estimations was calculated and the 90th percentile of estimations. This measure was compared with the experts' response to the corresponding Tremor amplitude UPDRS question. The correlation between the estimated UPDRS tremor amplitude and expert was $R^2 = 0.98$ for rest tremor, $R^2 = 0.95$ for posture tremor and $R^2 = 0.9$ for action tremor. Similar results were obtained for tremor constancy ($R^2 = 0.99$).

0.4.4 Overall Tremor Assessment

Finally the constancy of tremor was evaluated in the long recordings for the one normal subject and the two patients: one patient with tremor as typical symptom, and the other one with dyskinesia. The distribution of the tremor estimations for all subjects is presented in Table 2. Patient with tremor had a large percentage of tremor constancy and a significant higher tremor amplitude compared to a patient with dyskinesia and a normal subject.

0.5 Discussion

In this work, a method for tremor UPDRS estimation based on a wrist sensor with accelerometer and gyroscope is presented. The methodology includes tremor detection and amplitude estimation as well discrimination in resting, posture and action tremor allowing a full tremor UPDRS assessment. The tremor detection was based on a two step approach, trying to minimize the computational effort and maximize the accuracy of tremor detection. The detection accuracy on the experimental data was 91%. The methodology using the low-pass filtered accelerometer is able to discriminate tremor in action, resting and posture with relative accuracy. It should be mentioned that using a more comprehensive optimization approach for the parameters of the posture/action detection the performance could be even higher. The Tremor UPDRS assessment of the proposed method had a high correlation (> 0.9) with expert annotations in all items (amplitude and constancy). However, the number of cases for action and posture tremor are limited and in order to have more sound results more recordings are required. Moreover, the UPDRS evaluation of the long patient recording indicated that the number of false positives is very low when applying the proposed method in a real home environment. The overall solution is based on the Microsoft Band and a simple to use Android application and it is a module of the PD Manager project which targets at the development of a complete mHealth PD management solution.

As future work, we are in the process of collecting data for further evaluation of the method, and also optimizing posture detection and filtering parameters in order to further improve the obtained results. Finally, we are investigating the estimation of dyskinesia and bradykinesia related UPDRS items in order to provide a more complete solution for home based UPDRS assessment.

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