Comparison of Parametric and Non-Parametric Spectral Estimation Methods for Automatic Tremor Detection against Clinical Evaluation

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Abstract: Psychogenic tremor (PT) is a condition where the person affected suffers from tremor with variable characteristics that can make it difficult to diagnose. To help in the diagnosis an automatic tremor detection method applied to long-term kinematic recordings is proposed. The recorded signal is divided in segments which are analyzed and classified automatically as "tremor" or "no tremor". The classification is done according to the location of the dominant frequency of the power spectral density (PSD) of each segment. Different PSD estimation methods are explored to determine the optimum method for segments of short length. The performance of each method is compared against a clinical assessment of tremor.

1 INTRODUCTION

Psychogenic movement disorders (PMD) are characterized by the presence of abnormal movements that cannot be attributed to an organic neurological disorder and are considered to be psychologically mediated (Kranick et al., 2011). PT is the most common form of PMD (Jankovic et al., 2006). The diagnosis of a movement disorder is mainly a clinical process where patients are interviewed and undergo clinical observation. For a diagnosis of PT the movement characteristics must be incongruent with any organic tremor and the tremor may not be fully explained by an organic disease (Jankovic et al., 2006). PT often shows variable amplitude and frequency, suggestibility and entrainment and it changes character or is suppressed when the patient is distracted (Kenney et al., 2007). While these features are useful clues the certainty of a final diagnosis largely depends on the experience of the examiner (Jankovic et al., 2006). These features can be quantified using electromyographic (EMG) (O'Suilleabhain and Matsumoto, 1998) or kinematic recordings (Salarian and Russmann, 2007). A clinician can detect episodes of tremor in these recordings by assessing the signals qualitatively (by visual inspection) and quantitatively (by using PSD estimation).

In patients with PT (where tremor symptoms are variable) long term recordings could be beneficial for accurate diagnosis.

Kinematic recordings have been used to assess tremor duration (Pareés et al., 2012). The presence of tremor was compared with a self-report from the patient from the same period resulting in an overestimation of tremor by the patient. Detailed analysis of the signals would require a large time investment of a clinician. In this study we therefore compare several automatic tremor detection methods based on PSD estimation applied to long-term accelerometry recordings. The goal is to evaluate the accuracy of the automatic detection methods in identifying tremor compared to a clinician's assessment.

2 METHODS

Kinematic recordings obtained from the diagnostic work-up of 15 patients with different disorders (12 males, 3 females, mean age=68.2, standard deviation=9.7 years, 5 parkinsonism, 4 essential tremor, 2 enhanced physiological tremor, 2 PT, 1 dystonia, 1 ataxia) at UMCG were used in this study. The signal obtained from a uniaxial accelerometer placed on the dorsal side of the hand of the most affected limb was used for analysis. Methods to estimate the PSD of a signal can be divided in

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parametric (the signal is represented by a model plus noise) and non-parametric (no model assumption). For this study both methods were used to determine the dominant frequency in the accelerometer signal.

2.1 Non-Parametric Methods

Two methods to estimate the PSD based on the Fast Fourier Transform (FFT) were used. The modified periodogram (Hann window) was used since it is one of the less computationally intensive methods. Also the Welch method (a very popular method to reduce the variance of the PSD) (Welch, 1967) was used (2, 3 or 8 windows with 50% overlap). For both methods, the dominant frequency was selected as the frequency of the peak with the highest amplitude within the 0-20 Hz frequency band.

2.2 Parametric Methods

We selected an autoregressive (AR) model because it is suited for estimating spectra that are characterized by their peaks, making it the most appropriate method for the analysis of tremor data (Spyers-Ashby et al., 1998). AR modelling of a time series is based on the assumption that each value of the series can be predicted as a weighted sum of the previous values (and posterior values for the Burg method) of the same series plus an error term (Takalo et al., 2005). The number of values used in the prediction is the model order. In this study we used the *Akaike* criterion (Akaike, 1974) and four criteria based on the evaluation of the frequency responses from the 2nd order filter to the 50th order (Fig. 1). For each response we determined the frequency of the peak with the highest amplitude (*HighAmp*) and the frequency of the peak with the highest frequency (*HighFreq*; up to 20 Hz) of all the responses. *ModeHighAmp* is the most occurring frequency in all the responses when *HighAmp* is searched. *ModeHighFreq* is the most occurring frequency in all the responses when *HighFreq* is searched (Fig. 1).

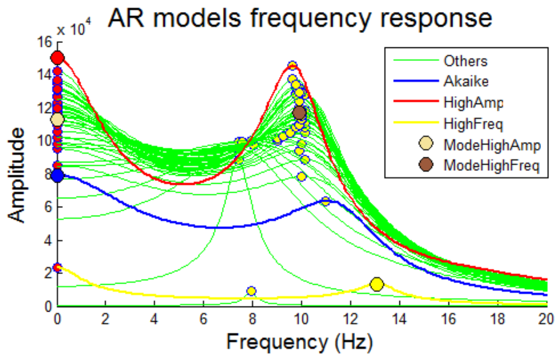

Figure 1: Frequency response of models (2^{nd} to 50^{th} order) obtained from one segment and their dominant frequencies according to five criteria (see text).

2.3 Tremor Classification

Two experienced clinicians evaluated the accelerometer signal per segments of 4 seconds. They visually assessed the signal and used a PSD estimation tool (based on FFT) to determine the dominant frequency of a specific segment, when needed. The clinicians classified the segment as tremor when the signal was dominantly sinusoidal and the frequency was consistent with a tremor. In the automatic methods, the criterion for a tremor segment was a dominant frequency between 2.5-10 Hz. To compare the methods the F1-score was used. It is an evaluation metric that combines the positive predictive value and the sensitivity in a single number.

3 RESULTS

Compared to the postulated gold standard (1^{st} clinician), the evaluation by the 2^{nd} clinician resulted in a better F1 score than the automatic methods. The performance of the automatic methods is similar, only *HighFreq* has very poor specificity due to its tendency to localize high frequency peaks (Fig. 2). The results vary depending on the patient suggesting that some conditions are more difficult to assess using solely the accelerometer signal.

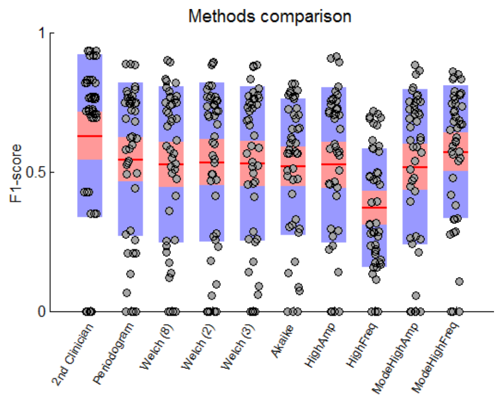

Figure 2: F1-score for each method (applied to segments of length 1, 2 and 4 s). Results are plotted with a grey circle, the mean and 95% confidence intervals are shown in red.

4 DISCUSSION

The intervals in which tremor is found are similar for almost all automatic methods (Fig. 3) These similarities may indicate that there are signal segments that contain characteristics that made them be classified as tremor by the automatic methods but not by the clinician (e.g. the clinician may classify a segment as tremor using a more constrained frequency bandwidth than 2.5-10 Hz, unconsciously). Constraining this bandwidth in the automatic methods would probably improve the results as Fig. 3 (top) suggests. This would result in a higher probability that the segment classified as tremor by the automatic methods actually corresponds to a true episode of tremor. We propose that in long term recordings having a trade-off between a high positive predictive value at the expense of an acceptable level of sensitivity is beneficial, since the detection of false positive tremor segments would be avoided and enough tremor segments could still be used. Since peak detection might not be the most accurate method to identify tremor, other methods (e.g. ratio of tremor area under the curve in frequency response) will be studied in the future.

The method selected as gold standard may not be optimal either, because it concerns a subjective interpretation. Moreover, in our current approach, neither the clinicians, nor the automatic methods incorporated other information as used in daily routine to diagnose tremor (EMG, video recordings).

REFERENCES

Akaike, H., 1974. A new look at the statistical model *identification. Automatic Control*, IEEE Transactions

Jankovic, J., Vuong, K. D. & Thomas, M., 2006. Psychogenic tremor: long-term outcome. *CNS spectrums*, 11(7), pp.501–8.

Kenney, C. et al., 2007. Distinguishing psychogenic and essential tremor. *Journal of the neurological sciences*, 263(1-2), pp.94–9.

Kranick, S., Gorrindo, T. & Hallett, M., 2011. Psychogenic movement disorders and motor conversion: a roadmap for collaboration between neurology and psychiatry. *Psychosomatics*, 52(2)

O'Suilleabhain, P. E. & Matsumoto, J. Y., 1998. Time-frequency analysis of tremors. *Brain : a journal of neurology*, 121 (Pt 1, pp.2127–34).

Salarian, A. & Russmann, H., 2007. Quantification of tremor and bradykinesia in Parkinson's disease using a novel ambulatory monitoring system. *Biomedical ...*, 54(2), pp.313–22.

Spyers-Ashby, J. M., Bain, P. G. & Roberts, S. J., 1998. A comparison of fast Fourier transform (FFT) and autoregressive (AR) spectral estimation techniques for the analysis of tremor data. Journal of neuroscience methods, 83(1), pp.35–43.

Pareés et al., 2012. Believing is perceiving: Mismatch between self-report and actigraphy in psychogenic

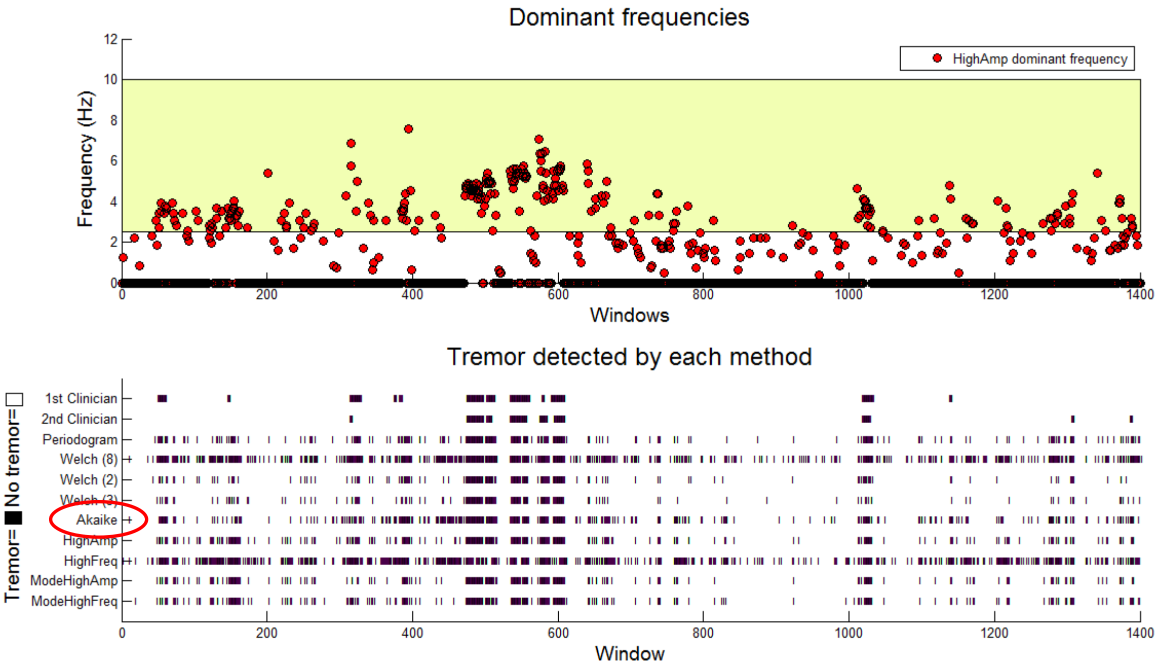

Figure 3: Results for patient 1 (Psychogenic tremor). Top: Dominant frequencies for each 1 s segment (*HighAmp* method). Yellow band: range for tremor detection. Bottom: Tremor detection by each method for each segment.

tremor. Brain 135;117-123
Takalo, R., Hytti, H. & Ihalainen, H., 2005. Tutorial on univariate autoregressive spectral analysis. *Journal of clinical monitoring and computing,* 19(6), pp.401–10.
Welch, P., 1967. The use of fast Fourier transform for the estimation of power spectra: a method based on time averaging over short, modified periodograms. *Audio and Electroacoustics,* IEEE Transactions on.