Journal of Neuroscience Methods 198 (2011) 110–113

Contents lists available at ScienceDirect

Journal of Neuroscience Methods

journal homepage: www.elsevier.com/locate/jneumeth

Validation of a new tool for automatic assessment of tremor frequency from video recordings

Zdenka Uhríková[a,b], Otakar Šprdlík[c,d], Martina Hoskovcová[e], Arnošt Komárek[f], Olga Ulmanová[e], Václav Hlaváč[a], Chris D. Nugent[b], Evžen Růžička[e,*]

[a] Department of Cybernetics, Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic
[b] Computer Science Research Institute, Faculty of Computing and Engineering, University of Ulster at Jordanstown, Northern Ireland, United Kingdom
[c] Department of Control Engineering, Faculty of Electrical Engineering, Czech Technical University in Prague, Czech Republic
[d] Institute of Information Theory and Automation of the Academy of Sciences of the Czech Republic, Prague, Czech Republic
[e] Department of Neurology and Centre of Clinical Neuroscience, First Faculty of Medicine and General University Hospital in Prague, Charles University in Prague, Czech Republic
[f] Department of Probability and Mathematical Statistics, Faculty of Mathematics and Physics, Charles University in Prague, Czech Republic

ARTICLE INFO

Article history:
Received 2 February 2011
Received in revised form 25 February 2011
Accepted 28 February 2011

Keywords:
Tremor frequency
Essential tremor
Video analysis
Fourier transformation
Accelerometry

ABSTRACT

We present a validation study for TremAn—a tool for automatic detection of tremor and measurement of its frequency from video recordings. To assess the validity of TremAn we designed a study consisting of tremor assessment from video, by accelerometry and by clinical evaluation using Fahn–Tolosa–Marin scale. 26 patients with essential tremor and 5 healthy volunteers underwent the examination in four standardized positions with focus on the hand tremor. Results showed that the frequencies of tremor measured with TremAn and with accelerometry are closely related, attaining agreement with less than 0.1 Hz difference in 80% and less than 0.5 Hz in 94% of measured samples. The reproducibility of frequency measurements using TremAn was comparable to the accelerometry, with the TremAn/accelerometry ratio of measurement error standard deviations equal to 0.99 (95% confidence interval (0.84, 1.17)).

1. Introduction

Tremor represents the most common adult-onset movement disorder (Louis et al., 1998). It is defined as a rhythmical, involuntary oscillatory movement of a body part (Deuschl et al., 1998). The estimation of tremor properties is part of everyday neurological practice (Bain, 1998). Various tremor rating scales (Fahn et al., 1993) have been used in routine examination of patients in addition to in clinical research, based on semi-quantitative visual estimation of tremor magnitude by an experienced clinician. Nevertheless, the use of subjective scales has a number of limitations including inter- and intra-individual variability of the ratings. In addition, the scales usually evaluate the amplitude of tremor while its frequency is only roughly estimated or simply neglected. Nevertheless, the frequency of tremor is of special interest for differential diagnosis of tremor disorders as well as for their longterm follow-up (Zeuner et al., 2003; Elble et al., 1994; Elble, 2000).

A number of laboratory based methods have been proposed aiming at more precise quantification of tremor properties (Bain, 1998; Timmer et al., 1996). They include poly-electromyography (Deuschl et al., 1996), graphic tablets (Pullman, 1998; Ulmanová et al., 2007), electromagnetic tracking devices (O'Suilleabhain and Dewey, 2001), accelerometers or gyroscopes (Caligiuri and Tripp, 2004; Giuffrida et al., 2009) and optical systems (Asyali and Dalbasti, 2007). Their validity and reliability has been evaluated in a number of studies (O'Suilleabhain and Dewey, 2001; Caligiuri and Tripp, 2004; Giuffrida et al., 2009). All of the aforementioned methods depend upon elaborate technical equipment that may not be convenient for routine clinical use. Limitations for these methods exist as well, accelerometers can suffer from gravitational artifact (Elble, 2005), while electromagnetic devices are sensitive to electric or magnetic fields that may be caused by other devices (O'Suilleabhain and Dewey, 2001; Giuffrida et al., 2009; Matsumoto et al., 1999). In most of the instrumented approaches, the movement of only one point on the hand or one segment of the hand is used to represent the hand tremor.

In an effort to address some of the limitations with current approaches, we have recently presented TremAn,[1] a tool for the automatic computer analysis of tremor frequency from ordinary video sequences (Uhríková et al., 2010). This approach does not require any special equipment nor does it require anything to be

* Corresponding author at: Department of Neurology, General University Hospital in Prague, Kateřinská 30, 120 00 Praha 2, Czech Republic. Tel.: +420 224965550; fax: +420 224922678.
E-mail address: eruzi@lf1.cuni.cz (E. Růžička).

[1] Freely available at http://cmp.felk.cvut.cz/ ~uhrikz1/treman/.

0165-0270/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.jneumeth.2011.02.033

attached to the patient's body. It is simply based on changes of color intensity of the picture elements containing the oscillating body part in relation to the background.

The goal of the present study is to assess the validity of TremAn and to define its measurement range and limitations. Clinical assessment using Fahn–Tolosa–Marin scale (Stacy et al., 2007) and accelerometry have been chosen as reference methods for tremor evaluation.

2. Methods

2.1. Subjects

We examined 26 patients with essential tremor (ET): 20 M, 6 F, mean age 57.5 ± 17.5, range 19–81, ET duration 24.3 ± 15.9, range 4–54 years and 5 healthy volunteers: 2 M, 3 F, mean age 33 ± 10.7, range 26–49, without clinical features or family history of tremor.

2.2. Data collection

The subject was comfortably seated in an armchair with armrests. Inertial measurement units Xsens MTx (38 mm × 53 mm × 21 mm, weight 30 g) were attached to the subject's hand dorsa using neoprene bands with velcro strips. The leads connecting the units with a personal computer were loosely attached to the chair back in order to not restrict the subject's movements. The units measured 3D acceleration with a sampling frequency of 100 Hz.

A digital video camera (Sony Camcorder DCRPC350E) was mounted on a tripod at a distance of approximately 1 m diagonally from the left front side of the subject. The recording frequency was 25 frames/s, the resolution of the video was 720 × 576 pixels and the non-interlaced option was used. Video was recorded directly into the computer, compressed with the ffdshow codec and saved using the Audio Video Interleave (.avi) format without the audio track. Suitable field of view was chosen to cover both hands. Care was taken that no moving object was present as part of the background.

For the purpose of the validation study, four standardized positions were examined: p1. with forearms and hands resting on the armrests of the chair; p2. forearms resting on the chair's armrests with hands extended; p3. with arms stretched forward; p4. in the 'wings' position with arms horizontally elevated, elbows flexed and hands extended opposite to each other in front of the chest. Examinations lasted for 20 s in each position and were performed twice with a rest interval of at least 20 s.

2.3. TremAn performance

TremAn allows for analysis of tremor recorded in most common video formats (.avi or .mpg). The assumptions made to ensure correct analysis are as follows: the tremor is visible in the video, the area of interest is stable (the video sequence was captured with a fixed camera, with no shifting, zooming or focusing of the shot and the body part captured was not moving markedly except for the tremor itself). Patient's voluntary movements, moving background or moving camera would lead to incorrect extraction of the signal.

The length of the analyzed video sequence should be at least 5 s and the sampling frequency should be at least 25 frames/s. To increase the quality of the signal, it is better to use higher quality cameras with the resolution of at least 640 × 480 pixels. The examined body part should cover at least 100 pixels in the longer dimension in the video.

The camera's point of view should be perpendicular to the oscillation; generally the front or side views of the person are acceptable for this purpose. Optimal distance of the camera from the patient varies based on cameras parameters, but generally 1–2 m can be used, however fair measures of tremor could be obtained in archived videos acquired at longer distances. Optical zoom can be used, but it should remain fixed during the examination. If the previous conditional are met, neither distance, nor the optical zoom affects the resulting frequency.

After loading the video sequence into the TremAn application, a rectangle area encompassing the body part of interest (hands in the case of the present study) was manually labelled by a single computer mouse click on the region of interest in the video. The size of the rectangle was adjusted when required. Refer to Fig. 1 for an example of the user interface. Following identification of the region of interest, all further processing was fully automatic.

A grid was laid over the labelled part of the video, covering every fifth pixel in both the horizontal (x) and vertical (y) direction. We will refer to the intersections in the grid as points p, where $p = [x, y]$ and x, y are coordinates of the point in the grid.

Using the RGB color model, the color of each pixel can be defined as a composition of red (R), green (G) and blue (B) components. The total asset of each component can be quantified as its intensity between $\langle 0,1 \rangle$. The red intensities $R_{p,t}$ of each point p in the grid over the time $t = (1 \ldots T)$ (where T is the length of the sequence) were collected for analysis.

The more contrast background behind the moving object (examined body part), the clearer the signal which will be gathered at this stage. The moving object in front of the background causes changes from the skin color to the background color and back. Looking at changes of the R intensity in time, it will appear as a periodic signal if the body part was moving regularly.

The power spectral density (PSD) was used for analysis of the signal. Welch's method (Smith, 2007) for estimating the PSD was used, which is based on dividing the signal into blocks and averaging the Discrete Fourier Transforms (DFT) of these blocks. The length of the blocks used in TremAn is 256. Let $B_{np}, 1 \ldots T, n = 1 \ldots m$, be the nth block of the signal $R_{p,1 \ldots T}$, then we calculate the Welch PSD estimate W_p by:

$$W_p = \frac{1}{m} \sum_n \mathrm{DFT}(B^n_{p,1 \ldots T})^2 \quad (1)$$

Square of DFT magnitude is calculated in the equation above. Finally the spectra W_p for all points p in the grid are added to obtain one final spectrum, $W = \sum W_p$. If a periodic signal of tremor is detected, it results in visible peaks in the final spectrum. The sampling frequency of the camera used in this study limited the upper detectable frequency to 12.5 Hz.

2.4. Accelerometry

The PSD was computed for every component of the 3D accelerometric signal as a filtered periodogram. The frequency distribution of the signal was computed as the sum of the three PSDs. Tremor frequency was estimated as the position of the peak detected in the composite PSD (Šprdlík et al., 2010). An estimate of the PSD of the displacement was obtained by dividing each point of the acceleration PSD by $(2\pi f_i)^4$, where f_i is the frequency of the ith point in the PSD (Timmer et al., 1996). The effective value (RMS) of the displacement caused by the tremor was obtained as the square root of the integral of the displacement PSD in the interval 3.5–12 Hz. To obtain an estimate of the peak-to-peak amplitude that corresponds better to what is visually observed, the effective value was multiplied by $2\sqrt{2}$. This computation is exact in the case of a sinusoidal signal, however, may produce some error if the signal is far from being harmonic.

Due to the highly skewed distribution of amplitudes measured by accelerometry, we provide median and inter-quartile range (IQR) values rather than means and standard deviations.

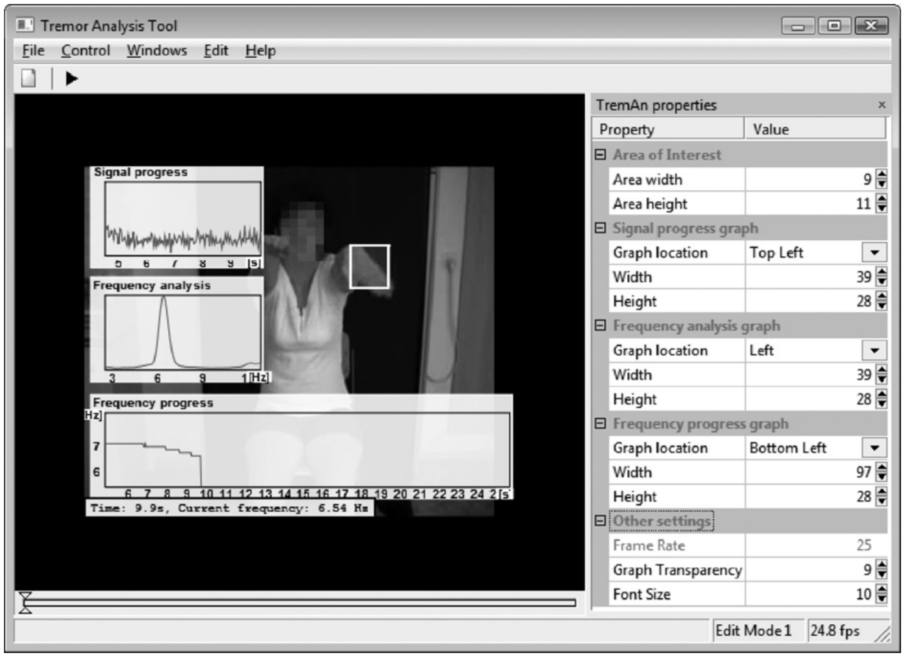

Fig. 1. User interface of TremAn, containing the selected video (the area of measurement is highlighted by the square). Three graphs displaying the processed signal, the full frequency spectrum and the principal frequency progress. Adjustable properties are listed on the right side.

2.5. Tremor rating

Complete videotaped recordings of all subjects were independently rated by two movement disorder specialists (OU and ER) using the modified Fahn–Tolosa–Marin (FTM) scale (Stacy et al., 2007) for scoring each tremor task on a 5-point scale where 0 = none; 1 = slight, barely perceivable tremor, may be intermittent; 2 = moderate tremor, amplitude < 2 cm, may be intermittent; 3 = marked tremor, amplitude 2–4 cm; 4 = severe tremor, amplitude > 4 cm. Averages of the scores were then computed and used for statistical analysis.

2.6. Statistics

Statistical analyzes were performed to evaluate (a) agreement between the frequency measurements obtained using the two methods (TremAn and accelerometry) and (b) repeatability of the frequency measurements. Concepts of Bland and Altman (1986) in connection with linear mixed models to account for repeated observations were used. In the mixed models, we controlled for the effect of the position and hand (p1.L(eft), p1.R(ight), p2.L, p2.R, p3.L, p3.R, p4.L, p4.R). Analyzes were performed using the R software (R Development Core Team, 2010), version 2.11.1.

3. Results

In total, 240 video sequences were recorded, 204 of them with patients with ET and 36 with healthy volunteers, containing both hands in the four positions. All 480 samples, with left and right hand separately, were analyzed using the techniques described above.

In 239 samples, all of them recorded in ET patients, TremAn evaluated the signal as periodic with the mean frequency 5.50 ± SD 1.11 (range 3.22–9.13) Hz. With accelerometry, the mean frequency in the same samples was 5.61 ± 1.13 (3.60–9.20) Hz. In this range, the assessment of frequency correlation between accelerometry and TremAn could be performed. The frequencies obtained by TremAn and by accelerometry were closely related; refer to Fig. 2. A more detailed analysis showed that in 80% of the samples the frequency difference between the results from accelerometry and TremAn was lower than 0.1 Hz and in 94% of the samples the difference was lower than 0.5 Hz. Statistical analysis estimated the mean difference between frequencies measured using the video based and accelerometric method as −0.11 Hz, with 95% confidence interval (−0.18, −0.04) Hz. The 95% prediction interval for the difference between the two methods was (−1.13, 0.91) Hz.

The reproducibility of frequency measurements did not significantly differ between the two methods, with the Tre-

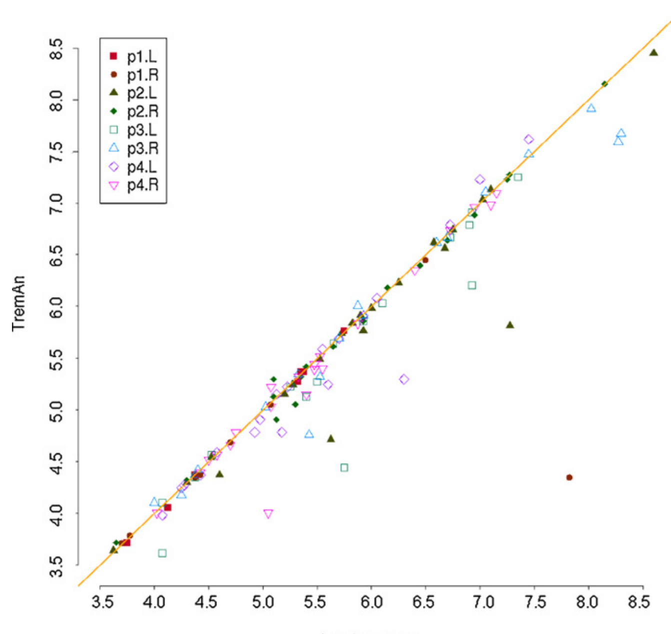

Fig. 2. Comparison of frequencies [Hz] obtained by TremAn and measured by accelerometers, for left (L) and right (R) hands, for four positions: p1. forearms and hands resting on armrests; p2. forearms resting, hands extended; p3. arms stretched forward; p4. 'wings' position.

mAn/accelerometry ratio of measurement error standard deviations equal to 0.99 (95% confidence interval (0.84, 1.17)). The amplitudes of the periodic signals evaluated by accelerometry in the 239 samples showed a skewed data distribution, with the median 0.89 mm (interquartile range (IQR) 2.78 mm, range 0.15–57.78 mm). The median FTM score was 1.5 points (IQR 1.5 points, range 0–4 points).

Periodic signals were absent in all of the 72 video samples recorded in the healthy volunteers, while the median accelerometric amplitude of the periodic signals in the same samples was 0.20 mm (IQR 0.19 mm, range 0.04–0.50 mm). FTM ratings (mean of two raters) were equal to 0 in 63 samples, 0.5 in eight, and 1 in one sample, while none was rated higher.

Similarly, TremAn detected no periodic signals in 169 video samples from patients, in whose recordings the median tremor amplitude obtained by accelerometry was 0.18 mm (IQR 0.14 mm, range 0.03–0.67 mm). The FTM score was equal to 0 in 113 samples, 0.5 in 29 samples, 1 in 13 samples, and none was rated higher.

4. Discussion

Results of this study showed that the frequencies of tremor measured with the TremAn video based method and with accelerometry are closely related, attaining agreement with less than 0.1 Hz difference in 80% and less than 0.5 Hz in 94% of the measured samples. At the same time, TremAn featured a high reproducibility of measurement consistent with accelerometry. This is similar to the degree of concordance shown in previous studies comparing electromyography and accelerometry (Louis and Pullman, 2001), where the diagnosis concordance was equal to 94.4% with 95% confidence interval (88.3–100%).

The concordance between clinical and electrophysiological assessment (Elble, 1998) was 85% with the 95% confidence interval (78–92%). Strong correlations were also found between accelerometer, a mechanical device measuring the 3D position and velocity and clinical evaluation (Matsumoto et al., 1999). Evaluation by an electromagnetic device showed a high reproducibility as well as high correlation with clinician's measurements (O'Suilleabhain and Dewey, 2001).

In comparison with all those methods, TremAn has some advantages. It does not require any laboratory equipment and/or material attached to the patient's body. It allows to analyze tremor in video recordings acquired in a routine clinical setting or even from archived video samples, with the only condition required being that of stable view and picture background (Uhríková et al., 2010). On the other hand, the method has several limitations. In contrast to accelerometry, TremAn cannot measure the amplitude of tremor and other quantities such as angular acceleration. TremAn detects only visible tremors, with the lower amplitude limit for detecting tremor from the video approximately 0.5 mm as calculated from the accelerometry data.

From a theoretical perspective, the 3D movement of an object does not necessarily correspond to changes in image intensity. However, our practical experience tells us that changes in image intensity correspond well to tremor motion.

The upper frequency limit depends on the camera sampling frequency. Current cameras record 25 frames/s, which gives the upper frequency measurement limit of 12.5 Hz. Nevertheless, the frequency of most pathological tremors, except those associated with orthostatic tremor, does not exceed 12 Hz (Elble et al., 1994; Hallett, 1998).

In summary, the video based technique for tremor frequency measurement proved a good reproducibility and a high concordance with accelerometry. TremAn thus appears suitable for routine clinical use by virtue of its ease of application, adequate frequency range and sensitivity of tremor detection.

Conflict of interest

There is no potential conflict of interest from any author relating to the research covered in this article.

Acknowledgements

The authors wish to thank Marie Vinopalová for her technical help. The project was funded by the Czech Ministry of Health, project IGA NS10336-3, and Czech Ministry of Education, projects MSM0021620849 and MSM6840770038 and 1M0567. Z. Uhríková has been supported by the European Commission under the Marie-Curie research training network WARTHE MEST-CT-2005-021024.

References

Asyali M, Dalbasti T. An image analysis based method for the quantification of tremor. J Yasar Univ 2007;2(7):1–7.
Bain P. Clinical measurement of tremor. Mov Disord 1998;13(3):77–80.
Bland J, Altman D. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1986;1(8476):307–10.
Caligiuri M, Tripp R. A portable hand-held device for quantifying and standardizing tremor assessment. J Med Eng Technol 2004;28(6):254–62.
Deuschl G, Bain P, Brin M. Consensus statement of the movement disorder society on tremor. Mov Disord 1998;13(3):2–23.
Deuschl G, Krack P, Lauk M, Timmer J. Clinical neurophysiology of tremor. Clin Neurophysiol 1996;13:110–21.
Elble R. Tremor in ostensibly normal elderly people. Mov Disord 1998;13(3):457–64.
Elble R. Essential tremor frequency decreases with time. Neurology 2000;55:1547–51.
Elble R. Gravitational artifact in accelerometric measurements of tremor. Clin Neurophysiol 2005;116:1638–43.
Elble R, Higgins C, Leftler K. Factors influencing the amplitude and frequency of essential tremor. Mov Disord 1994;9(6):589–96.
Fahn S, Tolosa E, Marín C. Clinical rating scale for tremor. In: Parkinson's Disease and Movement Disorders. Urban & Schwarzenberg; 1993. pp. 225–234.
Giuffrida J, Riley D, Maddux B, Heldman D. Clinically deployable Kinesia technology for automated tremor assessment. Mov Disord 2009;24(5):723–30.
Hallett M. Overview of human tremor physiology. Mov Disord 1998;13(3):43–8.
Louis E, Ottman R, Hauser W. How common is the most common adult movement disorder? Estimates of the prevalence of essential tremor throughout the world. Mov Disord 1998;13:5–10.
Louis E, Pullman S. Comparison of clinical vs. electrophysiological methods of diagnosing of essential tremor. Mov Disord 2001;16(4):668–73.
Matsumoto J, Dodick D, Stevens L, Newman R, Caskey P, Fjerstad W. Three-dimensional measurement of essential tremor. Mov Disord 1999;14(2):288–94.
O'Suilleabhain P, Dewey R. Validation for tremor quantification of an electromagnetic tracking device. Mov Disord 2001;16(2):265–71.
Pullman S. Spiral analysis: a new technique for measuring tremor with a digitizing tablet. Mov Disord 1998;13(3):85–9.
R Development Core Team. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing; 2010, ISBN 3-900051-07-0, Available from: http://www.R-project.org.
Smith J. Mathematics of the Discrete Fourier Transform (DFT). W3K Publishing; 2007.
Šprdlík O, Hurák Z, Hoskovcová M, Ulmanová O, Růžička E. Tremor analysis by decomposition of acceleration into gravity and inertial acceleration using inertial measurement unit. Biomed Signal Process Control 2010., doi:10.1016/j.bspc.2010.09.004.
Stacy M, Elble R, Ondo W, Wu S, Hulihan J, Study Group T. Assessment of interrater and intrarater reliability of the Fahn–Tolosa–Marin tremor rating scale in essential tremor. Mov Disord 2007;22(6):833–8.
Timmer J, Lauk M, Deuschl G. Quantitative analysis of tremor time series. Electroencephalogr Clin Neurophysiol 1996;101(5):461–8.
Uhríková Z, Růžička E, Hlaváč V, Nugent C. Treman: a tool for measuring tremor frequency from video sequences. Mov Disord 2010;25(4):504–6.
Ulmanová O, Homann C, Ulman R, Jech R, Čapek V, Klempíř J, Růžička E. Tremor magnitude: a single index to assess writing and drawing in essential tremor. Parkinsonism Relat Disord 2007;13(4):250–3.
Zeuner K, Shoge R, Goldstein S, Dambrosia J, Hallet M. Accelerometry to distinguish psychogenic from essential or parkinsonian tremor. Neurology 2003;61:548–50.