Parameterization of the Tremor Signal from Accelerometers in Multiple Sclerosis

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***Abstract*—Tremor, an involuntary and rhythmic oscillatory movement of a part of the human body, is a part of complex movement disorder in multiple sclerosis (MS). This paper aims to investigate possible parametrizations of the signal from accelerometers and find the parameters that are significantly different in the group of healthy persons and MS patients. A postural tremor was measured for each patient during the experiment using our device equipped with a 3-axis accelerometer. The group of MS patients consists of 24 probands (7 males and 17 females); the average age was 49.6 ± 12.5 years (mean ± standard deviation). The group of healthy control subjects consists of 28 probands (16 males and 12 females, the averaged age is 41.8 ± 18.5 years). Several parameters were specified and evaluated in the study: the maximum value of power spectral density (PSD) of the signal, the frequency of maximum value in PSD, the total power spectral density in a specific frequency band (fixed or variable). The differences in MS patients' parameters and healthy controls were evaluated using box-plots and statistical evaluations such as a two-sample t-test, the Kolmogorov-Smirnov test, the Lilliefors of normality and the Mann-Whitney (Wilcoxon) test. The maximum value of PSD and the cumulative value of PSD in the fixed frequency range have been recognized as parameters with a significant difference between the MS patients and the healthy population ($p < 0.01$).**

Keywords—tremor, parametrization, signal processing, multiple sclerosis, accelerometer

I. Introduction

Tremor is an involuntary and rhythmic oscillatory movement of a part of the human body. In multiple sclerosis (MS), tremor is frequently a part of complex movement disorder [1]. The frequency of tremor in MS is typically in a band from 2 Hz to 10 Hz [2].

In clinical practice, there are several subjective diagnostic methods and tests to examine and evaluate the tremor, for example, a nine-hole peg test [3], a coin rotation test [4], a handgrip test [5] or a sit-to-stand test [6].

In recent years, an evaluation of tremor using accelerometers has been presented frequently. Some of these studies deal with the tremor in Parkinson's or other diseases, but there are also specific studies which concern directly with the tremor in MS [7, 8]. The typical approach to a tremor evaluation using accelerometers is to acquire signals during specified exercising, parametrize the signals and classify them to differentiate whether the signals come from healthy people or MS persons.

This paper aims to investigate possible parametrizations of the signal from accelerometers and find the parameters that are significantly different in the group of healthy persons and MS patients.

II. Methods

A. Experiment

For each patient, a postural tremor was measured during the experiment. Own device equipped with a 3-axis accelerometer and 3-axis gyroscope chip (MotionTracking sensor MPU-6050) was used for signal acquisition. Data from the sensor are received by microcontroller Atmel Mega 328 and stored on an SD card. The sampling frequency is 100 Hz. The sensor can measure acceleration up to ±16 g and rotation up to ±2000 degrees per second. The device was briefly presented in [9].

During the experiment, the sensor is placed on the arm using a ring on a finger. The resting postural tremor is measured throughout stretching the whole arm forward. The measurements were realized as one-minute experiments separately for left and right hand. Each period was repeated both for opened and closed eyes. For each patient, four signals with about 6000 samples were recorded for right/left hand and opened/closed eyes [10].

B. Signal Database

The research was done on a signal dataset acquired at the Department of Rehabilitation, Third Faculty of Medicine, Charles University in Prague, Prague, Czech Republic. The group of multiple sclerosis patients consists of 24 probands (7 males and 17 females) aged from 24 to 70 years; the average age was 49.6 ± 12.5 years (mean ± standard deviation). The group of healthy control subjects consists of 28 probands (16 males and 12 females) aged from 15 to 72 years; the average age was 41.8 ± 18.5 years (mean ± standard deviation). One record was excluded from the group of MS patients before the data processing because the proband did not correctly realize the whole experiment due to tiredness.

All the probands have been informed about the study and signed the informed consent. Each proband has filled an anamnestic questionnaire. The signal database is supplemented with anonymous data about the probands such as age, sex, height, weight, smoking, taking alcohol, visual analog scale etc.

C. Preprocessing of Signal

The Matlab program was used for signal processing. Acceleration values in each of the three axes were taken from the signal database. The total acceleration was calculated from these values. Each signal was then filtered. A 2nd order Butterworth high-pass filter was used to suppress isoline motion. The cut-off frequency of the used filter was 0.5 Hz. After this processing, signals could be visualized and compared with each other.

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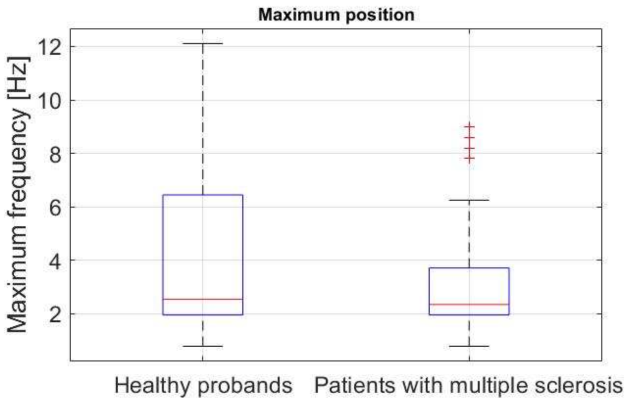

Fig. 1. Boxplot showing differences in PSD maximum positions for both tested groups

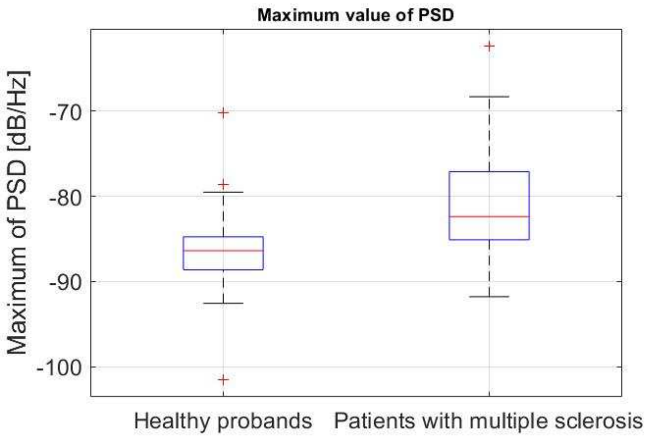

Fig. 2. Boxplot showing differences in maximum values of PSD for both tested groups

It was appropriate to determine the power spectrum of the signals for further signal processing and parameterization of those signals. The power spectral density (PSD) of the signals can be calculated using the Welch method. For calculation of power spectral density can be used a function called pwelch. This function is implemented in the Matlab library.

D. Parameterization

It was necessary to design a set of parameters and then select the best one, which will be used to determine the degree of tremor later (classification of the signal into two groups, where the first group will contain signals from healthy subjects and the second group will contain signals from patients with multiple sclerosis). The parameters are related to the power spectral densities (PSD) of signals.

The first proposed parameter that can be used to determine the degree of the tremor was the maximum value of each signal's PSD. The second parameter was related to the first one. It was the frequency of maximum value in PSD.

Another possible parameter was the total power spectral density in a specific frequency band. This band can be fixed or variable. The fixed band means constant frequency range. A parametric study was performed to determine the optimal frequency range of the fixed band. For different bandwidths (3 to 10 Hz) and different frequency ranges (0 to 25 Hz), statistical methods (described below) were used to find the best results.

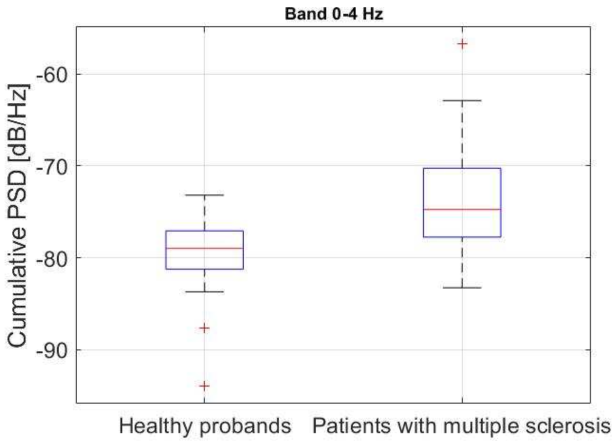

Fig. 3. Boxplot showing differences in cumulative PSD in the fixed frequency range (0-4 Hz) for both tested groups

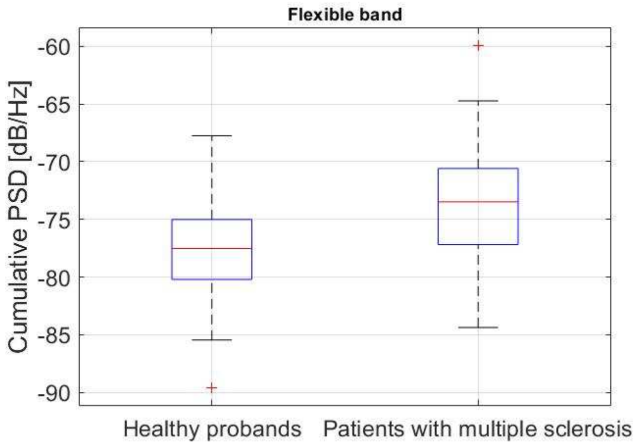

Fig. 4. Boxplot showing differences in cumulative PSD in the flexible frequency range (decrease of PSD by 3 dB) for both tested groups

The p-values of the Wilcoxon test were calculated, and the band with the lowest p-value was selected as best. The variable band is given by the frequency range for which the PSD value has dropped to a predefined fraction (for example, 0.5) of the highest value. Another parameter was bandwidth, which was based on the variable range of frequencies.

One of the possible ways to parameterize and subsequently distinguish the two groups of probands was to compare the effect of fatigue on the tremor rate of the limbs of patients and healthy individuals. For this purpose, the original measured signals were reprocessed, but only some parts of them were used for processing. Specifically, the first 15 seconds of the recording (when it is assumed that the subject does not suffer from fatigue) and then the last 15 seconds of the recording were processed. The time interval was given by the shortest measured signal, which was approximately 55 seconds long, so the signal measured between the 40th and 55th second of the measurement was processed. The signals from the beginning of the measurement and its end were parameterized by a previously selected parameter (the best parameter was selected by statistical testing, which is described below). The effect of fatigue is then presented by the difference between the parameter values obtained at the beginning of the measurement and its end.

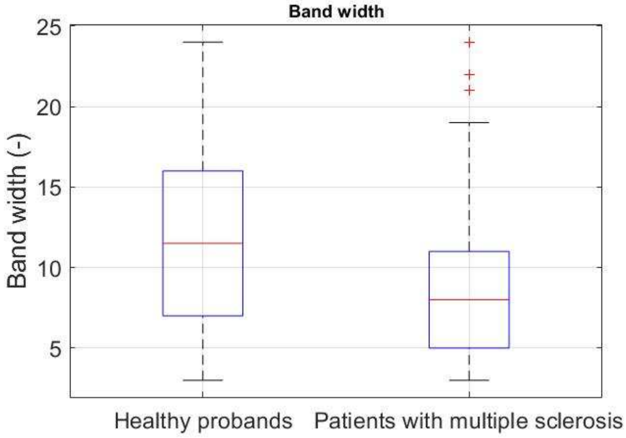

Fig. 5. Boxplot showing differences in width of flexible frequency range (decrease of PSD by 3 dB) for both tested groups

The signal database contained signals gained during the measurement with the eyes open and closed. There is a possibility that a significant reduction of limb tremor can be found when the eyes are open. This theory can be verified using one of the above parameters and then comparing the two selections (open and closed eyes) using subjective evaluation by a box-plot or an objective statistical testing method.

All participants in both groups were right-handed. Another theory was that there could be a difference between a dominant and a non-dominant limb. This theory can be verified the same way as in the case of open and closed eyes.

E. Evaluation of Significant Differences

For the initial evaluation of the functionality of individual parameters, it is possible to use subjective methods, such as evaluation using box-plot graphs. Statistical methods are used for objective evaluation. The aim was to find a parameter that can be used to distinguish between healthy people and patients. The first group (selection) contains parameters from signals measured on healthy probands (the control group). The second group contains the values of parameters for the signal from the patient's measurement. The mean values of the two groups should be significantly different. A two-sample t-test can be used to compare mean values. The null hypothesis of a two-sample t-test states that the mean values of the two samples do not differ at the chosen level of challenges. The significance level was chosen to be 5%. If the parameter should be considered applicable, the null hypothesis must be rejected.

Before using the t-test, it was necessary to test the conditions for its use. The first condition is the independence of data. Fulfilment of this condition cannot be tested, but it is fulfilment based on the way the data were measured. The data were divided from completely different probands and at different times [11, 12]. Another condition is that the data of both selections come from a normal distribution. The fulfilment of this condition can be subjectively evaluated using an N-P graph (normal probability). Tests such as the Kolmogorov-Smirnov test [13] and its modifications or the Lilliefors test of normality [14] are used for objective testing. The null hypothesis in both tests is the declaration that the data come from a normal distribution. If the normality conditions are not met, the Mann-Whitney (Wilcoxon) test [15] can be used instead of the two-sample t-test. The last condition for using the t-test is the equality of the variances of both selections. The two-sample F-test can be used for this purpose. The null hypothesis says that both populations came from a normal distribution with equal variances. If this condition is not met, it is possible to use a modified t-test for unequal variances, the Welch test [16]. If all three conditions are met, it is possible to test the equality of the mean values of the samples using a t-test.

F. Clinical Approvement

The study is approved by the institutional biomedical research ethics board of Charles University in Prague, reg. nr. EK-VP/23/0/2014.

III. RESULTS

All parameters described above were subjectively evaluated using box plots, shown in Figures 1 to 5. The two best parameters were selected for an objective evaluation using statistical methods based on the subjective evaluation.

Based on the subjective evaluation, the maximum values of PSD and cumulative PSD values for a fixed frequency range of 0 to 4 Hz (the frequency range is based on the results of the parametric study) appeared to be the most promising. These two parameters were statistically tested. The results of testing the prerequisites for using the t-test are in the following table.

TABLE I. Testing of prerequisites for t-test

Parameter	p-value from KS test of normality		p-value from Lilliefors test of normality		p-value from F-test
	Healthy probands	Patients	Healthy probands	Patient s	
Maximum of PSD	$8{,}49 \cdot 10^{-65}$	$2{,}87 \cdot 10^{-54}$	0,02	0,06	$1{,}90 \cdot 10^{-4}$
Cumulativ e PSD	$8{,}49 \cdot 10^{-65}$	$2{,}87 \cdot 10^{-54}$	0,40	0,17	$5{,}99 \cdot 10^{-6}$

The results in Table 1 show that the normality tests gave different results. Also, the null hypothesis of the F-test was rejected at the level of significance of 5%; the variances of both selections are not identical in either case. Based on the Kolmogorov-Smirnov test, we reject the null hypothesis (at the level of significance the 5%) about the origin of data from the normal distribution. To test the similarity of the mean values, it is, therefore, appropriate to use the Wilcoxon test.

However, for the cumulative PSD in the fixed frequency band, the results of the Lilliefors test say that data came from a normal distribution. In this case, we can use a two-sample t-test for unequal variances (Welch test). The results of the mean value similarity tests are in Table 2.

TABLE II. Testing of similarity of mean values

Parameter	p-value from Wilcoxon test	p-value from t-test for unequal var.
Maximum of PSD	$3{,}33 \cdot 10^{-8}$	-
Cumulative PSD	$2{,}05 \cdot 10^{-9}$	$9{,}05 \cdot 10^{-10}$

Statistical testing failed to confirm theories about the effect of eye-opening on the degree of tremor or the difference in the tremor of the dominant and non-dominant limbs. The effect of eye-opening was not observed at all. In observing the difference between limbs, Wilcoxon tests did not reject the null hypothesis of similarity of mean values (p-value for the group of healthy probands was 0.37, and for the patients, it was 0.78). The parameterization associated with evaluating the effect of fatigue also did not show convincing results, but the difference between healthy probands and patients with MS was statistically significant. The p-value from Wilcoxon test was $2{,}7 \cdot 10^{-6}$. Results are presented as boxplot on figure 6.

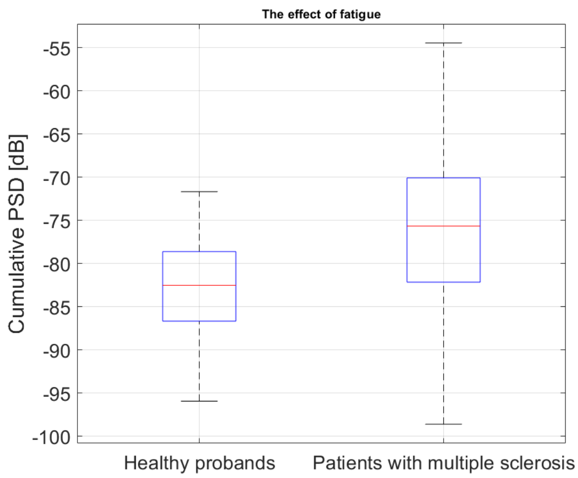

Fig. 6. Boxplot showing results of study of the effect of fatigue

IV. Discussion

The two best parameters were selected based on the subjective evaluation of parameters using box plots. Box-plots of these parameters showed a difference between a group of healthy individuals and patients with multiple sclerosis. These parameters were then objectively evaluated. The "cumulative PSD" parameter of the fixed frequency range seems more suitable because the p-value from Wilcoxon's test is lower than the p-value for the "maximum PSD" parameter. Also, it was possible to prove that values of this parameter come from the normal distribution by the Lilliefors test of normality and use a two-sample t-test for unequal variances. The similarity of the variances could not be confirmed for any of the parameters.

V. Conclusion

The optimal parameterization of the accelerometer signal obtained from MS patients and healthy controls has been studied in the paper. The maximum value of PSD and the cumulative value of PSD in the fixed frequency range have been recognized as parameters with significant difference between the MS patients and healthy population.

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References

[1] S. H. Alusi et al., "Tremor in multiple sclerosis," Journal of Neurology, Neurosurgery, and Psychiatry, vol. 66, (2), pp. 131-134, 1999.

[2] M. Koch et al., "Tremor in multiple sclerosis," J. Neurol., vol. 254, (2), pp. 133-145, 2007.

[3] P. Feys et al., "The Nine-Hole Peg Test as a manual dexterity performance measure for multiple sclerosis," Multiple Sclerosis Journal, vol. 23, (5), pp. 711-720, 2017.

[4] M. R. Heldner et al., "Coin rotation task: a valid test for manual dexterity in multiple sclerosis," Physical Therapy, vol. 94, (11), pp. 1644-1651, 2014.

[5] H. C. Roberts et al., "A review of the measurement of grip strength in clinical and epidemiological studies: towards a standardized approach," Age and Ageing, vol. 40, (4), pp. 423-429, 2011.

[6] R. W. Bohannon et al., "Sit-to-stand test: Performance and determinants across the age-span," Isokinetics and Exercise Science, vol. 18, (4), pp. 235-240, 2010.

[7] D. A. Heldman et al., "Essential tremor quantification during activities of daily living," Parkinsonism and Related Disorders, vol. 17, (7), pp. 537-542, 2011.

[8] P. Pascoal-Faria et al., "Understanding Tremor in Rapid Upper Limb Movements Using 3D Accelerometers Data," Neuroscience & Medicine, vol. 5, (5), pp. 205-213, 2014.

[9] J. Havlík, K. Řasová, Z. Horčík, J. Zeman, D. Vavrová, P. Sovka, "Monitoring of tremor: Design and realization of measuring device" in The Seventh Biomedical Engineering Conference of Young Biomedical Engineers and Researchers YBERC 2016, Ostrava: VSB - Technical University of Ostrava, 2016.

[10] J. Havlík, P. Horák, K. Řasová, J. Řezníčková, J. Zeman, "The Evaluation of the Tremor: Signal Database of Healthy Control Subjects" in World Congress on Medical Physics and Biomedical Engineering 2018 (Vol. 2), IFMBE Proceedings, vol. 68/2, p. 547-550, Springer Nature Singapore Pte Ltd., 2019

[11] P. Horák, "Objectivization of tremor with accelerometer", bachelor thesis, Third Faculty of Medicine, Charles University, Prague, 2018 (in Czech).

[12] P. Kotíková, "How related an accelerometer's examination with upper limb function in patients with multiple sclerosis?", bachelor thesis, Third Faculty of Medicine, Charles University, Prague, 2019 (in Czech).

[13] F. J. Massey, "The Kolmogorov–Smirnov test for goodness of fit," Journal of the American Statistical Association, vol. 46, (253), pp. 68-78, 1951.

[14] Lilliefors and H, "On the Kolmogorov–Smirnov test for normality with mean and variance unknown," Journal of the American Statistical Association, vol. 62, pp. 399-402, 1967.

[15] Frank Wilcoxon, "Individual Comparisons by Ranking Methods," Biometrics Bulletin, vol. 1, (6), pp. 80-83, 1945.

[16] B. L. Welch, "The Generalization of `Student's Problem when Several Different Population Variances are Involved," Biometrika, vol. 34, (1/2), pp. 28-35, 1947