INVESTIGATION OF CHANGES IN KINETIC TREMOR THROUGH ANALYSIS OF HAND-DRAWING MOVEMENTS

Differences between Physiological and Essential Tremors

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Abstract: Tremor is the most common movement disorder characterized by repetitive and stereotyped movements. Tremor can be classified in many ways, depending on its phenomenology, frequency and location. The data collection conducted under kinetic conditions and while performing a voluntary movement highlights the kinetic tremor. The analysis of hand-drawing movements is commonly used in the evaluation of patients with tremor. In this study, a number of features extracted from tremor activity, obtained from digitized drawings of Archimedes' spirals, were analysed. The analyses followed the sequence bellow: 1 – Linearization of the spiral of Archimedes; 2 – Estimate of tremor activity; 3 – Data pre-processing; and 4 – Feature extraction from the tremor activity. The statistical analysis of the extracted features was able to prove the differences between physiological and essential tremors collected under kinetic conditions.

1 INTRODUCTION

Tremor is an involuntary, rhythmic, oscillatory movement of a body part that can be classified in many ways, depending on is aetiology, phenomenology, frequency and location. (Mansur et al., 2007, Smaga, 2003) The movement caused by tremor can be associated to factors such as neurological disorders and natural processes. (De Lima et al., 2006, Deuschl et al., 1995) The former is called pathological tremor whereas the latter is often referred as physiological tremor. (Almeida et al., 2010) The physiological tremor occurs normally in healthy individuals and, generally, it cannot be observed by the naked eye. (Almeida et al., 2010)

An example of pathological tremor is the essential tremor. This type of tremor is a visible postural tremor of hands and forearms that may include kinetic component. (Smaga, 2003) Essential tremor is the most common movement disorder in the world.

In both essential and physiological tremors, the amplitude of tremor increases with stress, fatigue, certain medications and voluntary activities. (Smaga, 2003) Although this, both types of tremor presents a kinetic component that can be accessed through the analysis of hand-drawing movements.

Hand-drawing patterns are commonly assessed by means of visual rating scales. (Almeida et al., 2010, Louis et al., 1998) However, scales provide only crude subjective estimates of tremor amplitude. The use of digitizing tablets is common and provides the possibility of tremor activity detection under kinetic conditions. (Almeida et al., 2010) Although this, the use of this method for tremor detection is simply, versatile, non-invasive and can provide an electronically measure of tremor, reducing the subjectivity and limitation of some methods based on visual scales. (Almeida et al., 2010)

The digitizing tablet is able to inform the coordinates (x and y) of the tip of the pen on its surface while the subjects perform the drawing. In

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this study, a standard drawing pattern was fixed on the surface of the device and the subjects were asked to follow it. The selected drawing pattern is the spiral of Archimedes, used in other studies for being smooth and easily understood by subjects.

There are many studies concerning the employment of digitizing tablets for the quantification of physiological and pathological tremors. (Elble et al., 1996, Feys et al., 2007, Liu et al., 2005, Mergl et al., 1999) However, no study focusing in the use of this device for investigation of kinetic changes between physiological and essential tremor was found in our literature survey.

In order to contribute to the understanding of changes in kinetic tremor between physiological and essential tremors, this study proposes to quantify tremor by means of the analysis of digitized hand-draw drawings of a clinically healthy individual and an individual diagnosed with essential tremor.

2 MATERIALS AND METHODS

Two subjects participated in our experiments. The first subject did not present clinical evidences of suffering from any neurological disorder. The second subject was diagnosed with essential tremor.

Prior to data collection the subjects signed a Consent Form approved by the Ethical Committee of the Federal University of Uberlândia, Brazil.

The subjects were asked to sit in a comfortable chair with their feet flat on the floor and with their back straight. The digitizing tablet, shown in Figure 1, was placed on a table properly positioned in front of the subjects.

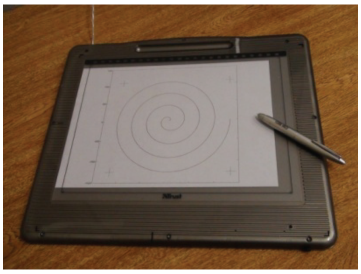

Figure 1: Digitizing tablet with the standard drawing pattern fixed on its surface. In this study, the selected drawing pattern is the spiral of Archimedes.

After verbal and written explanation about the exam the subjects were asked to draw two samples of a Spiral of Archimedes with their dominant hand. The arms of the subjects were not supported during the execution of the task. The first sample was collected with the subject drawing the spiral from its centre to its extremity (outgoing spiral - OS), whereas for the second sample the subject drew the spiral from its extremity to its centre (ingoing spiral - IS). This procedure was repeated three times for each subject. The subjects were asked to draw the spiral at their natural speed. The collected spirals were digitized at 64 Hz through a digitizing tablet (Trust, model TB-4200) with resolution of 120 lines/mm.

2.1 Data Analysis

The analysis followed, for each data sample, the sequence of steps below:

- Linearization of the spiral;
- Estimate of the tremor activity;
- Data pre-processing;
- Feature extraction from the tremor activity.

2.1.1 Linearization of the Spiral

The spiral of Archimedes is a geometrical shape that has a uniform distance between its turns equal to 2πb. This kind of spiral can be represented by Eq. (1) in polar coordinates, where r is the radius, θ the angle, a and b are constants.

$$r = a + b\theta \tag{1}$$

The step of linearization consists in representing the original x and y coordinates of the spiral in terms of radius (r) and angle (θ) as shown from Eqs. (2) to (4).(Pullman, 1998) The linearization of a perfect spiral results in a straight line as shown in Eq. (5) and depicted in Figure 2, where m is the slope of the straight line.

$$x = r \sin(\theta) \tag{2}$$

$$y = r \cos(\theta) \tag{3}$$

$$r = \sqrt{x^2 + y^2} \tag{4}$$

$$r = m\,\theta \tag{5}$$

2.1.2 Estimate of the Tremor Activity

The estimate of the tremor activity S is carried out by Eq. (6), where S_{ideal} is the ideal spiral (template) and S_{actual} is the spiral drawn by the subject.

$$S = S_{ideal} - S_{actual} \tag{6}$$

Figure 3A shows spirals obtained from the subjects that participated on the study. In the figures the template spiral and its linearized version (Figure 3B) are in black, whereas the actual spiral and its linearization are in red. The tremor activity S (Figure 3C) is also presented for each case. Note that S is a random time-series and, therefore, it is possible to employ standard techniques for time-series analysis in order to extract information from it.

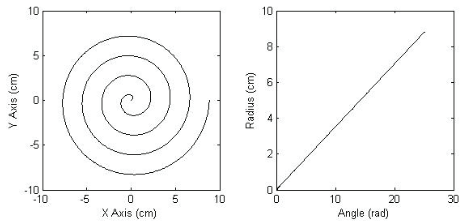

Figure 2: Illustration of the process of linearization of an ideal spiral of Archimedes. The spiral in the left panel is converted into a straight line in polar coordinates, which is shown in the right panel. This transformation eases the process of tremor estimate from hand-drawn spirals.

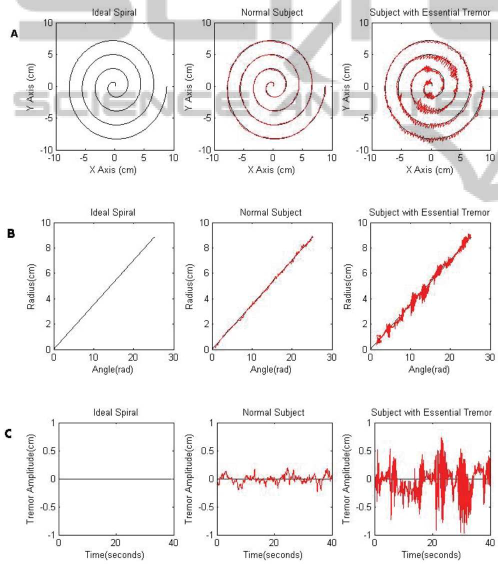

Figure 3: Example of the application of the process of linearization for an ideal spiral and two typical patterns obtained from hand-drawn spirals of normal subject and subject diagnosed with essential tremor. In (A) the spiral drawn by each subject is compared against the ideal spiral. In (B) the system coordinates are converted into polar coordinates and the results of each subject are contrasted to the ideal straight line, which represents the spiral in polar coordinates. In (C) the tremor activity obtained for each subject is shown. This activity is obtained by subtracting the ideal spiral from the hand-drawn spiral in polar coordinates.

2.1.3 Data Pre-processing

The tremor activity may be composed of: (i) the inherent noise of the digitizing tablet, which is a low-frequency noise (<0.1 Hz) as suggested by the manufacturer; (ii) voluntary movement whose energy is mostly limited to frequencies below 1 Hz; (Feys et al., 2007, Liu et al., 2005, Ulmanová et al., 2007) (iii) and the specific-task physiological tremor which is characterized by involuntary movements and energy mostly between 4 Hz and 10 Hz or the essential tremor with energy between 4 Hz and 12 Hz. (Elble et al., 1996, Miralles et al., 2006, Elble et al., 1990, Pullman, 1998, Smaga, 2003, Bhagwath, 2001)

Therefore, we applied a linear filter in order to obtain the tremor activity signals for analysis. This activity was filtered by using a fourth-order digital band-pass Butterworth filter. As the frequency response of the filter is not ideal we set its lower and upper cutoff frequencies to 2.5 Hz and 20 Hz with the aim of preserving the bandwidth of interest. This bandwidth was carefully defined to capture the full tremor component in task-specific tremor, typically in the frequency range between 4 and 12 Hz (Elble et al., 1996, Miralles et al., 2006, Elble et al., 1990, Pullman, 1998, Smaga, 2003, Bhagwath, 2001), and also to avoid major influence of voluntary movements whose energy is normally concentrated in frequencies below 1 Hz. (Feys et al., 2007, Liu et al., 2005, Ulmanová et al., 2007)

Frequency analysis (energy estimate) was performed on the filtered signal by using the Welch's method with a 32 data point Hanning window. Figure 4 illustrates the signal before and after filtering. Figures 4a and 4b show, respectively, a signal collected from the normal subject and the subject diagnosed with essential tremor before filtering. Figures 4c and 4d are filtered versions of the signals shown in Figures 4a and 4b, respectively. The waveform depicted in Figure 4d shows an increase in amplitude when compared to the one in Figure 4c.

2.1.4 Feature Extraction from the Tremor Activity

In order to assess and quantify the tremor activity a number of traditional features were used. Each feature is described below:

- Frequency domain features: from the power spectrum of the signal, obtained from the Fourier Transform, the following features were estimated: mean frequency, peak frequency, frequency of 50% and frequency of 80%.
- Detrended fluctuation analysis (DFA): is a tool for analysis of random signals that estimates the α exponent which may characterize the nature of time-series. (Delignieres D, 2003, Norris et al., 2005)

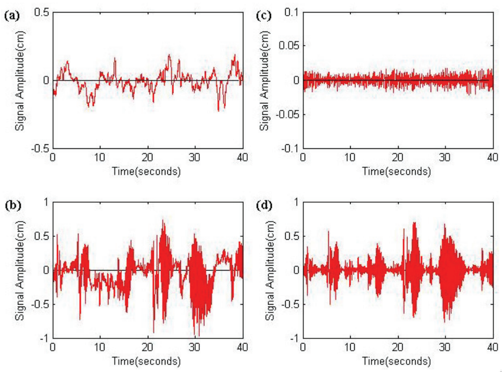

Figure 4: Illustration of the effect of filtering applied to collected signals from normal subject (a, c) and subject diagnosed with essential tremor (b, d). The non-filtered signals are depicted in (a, b) whereas their filtered versions are depicted in (c, d), respectively.

- Mean speed: is the average of the instantaneous velocity.
- Total displacement: is calculated by summing up all the distances from two consecutive samples.
- Root mean square: also known as quadratic mean, the Root Mean Square (RMS) is a statistical measure of the magnitude of a varying quantity.
- Approximate entropy: is a tool used to quantify the regularity of a signal.
- First order smoothness: This tool can characterize imperfections in spirals drawn by the subjects. The calculation of this feature is based on the overall deviation of the spiral, in such a way that an ideal spiral results in a value of the first order smoothness equal to zero. (Pullman, 1998)
- Second order smoothness: the second order smoothness can be defined as the rate of change of first order smoothness.
- Residual: this feature reflects the total distance between the spiral after the process of linearization and a line of best fit on the radius vs. angle graph. The larger this value is the more spiral changes its shape in an irregular way. (Pullman, 1998)
- Zero crossing rate: is a measure of irregularity of the signal and shows how frequently values cross their own *RMS* value.

3 RESULTS

Table 1 shows the values of extracted features for two data collection protocols, i.e., Ingoing spiral (IS) and Outgoing spiral (OS). The analysis of variance (ANOVA) was applied for each protocol and feature. A probability value (*p-value*) less than 0.05 ($p < 0.05$) was considered as a threshold for significance analysis. A 95% confidence bound were used on the value of the statistic. Features that yielded significant differences between the subjects are highlighted with an asterisk (*) in Table 1.

Table 1: Mean values obtained for each feature and protocol (ingoing and OS).

Feature	Physiological Tremor		Essential Tremor	
	Outgoing Spiral	Ingoing Spiral	Outgoing Spiral	Ingoing Spiral
Frequency of 50% *	4.417	4.417	5.750	5.667
Frequency of 80%	6.833	7.083	6.750	6.667
Mean Frequency *	4.818	4.883	5.711	5.660
Peak Frequency *	3.167	3.250	5.750	5.667
Total Displacement *	0.064	0.071	1.339	1.219
Standard Deviation *	0.007	0.007	0.165	0.163
Approximate Entropy *	0.351	0.329	0.282	0.286
First Order Smoothness	10.099	13.751	16.043	17.534
DFA *	1.661	1.652	2.024	2.030
Mean	$-4.9x10^{-6}$	$-4.1x10^{-5}$	$1.2x10^{-4}$	$5.9x10^{-5}$
Residual *	0.069	0.066	0.236	0.257
RMS Mean *	0.007	0.007	0.165	0.163
Second Order Smoothness	27.398	38.438	37.647	40.271
Variance *	$4.5x10^{-5}$	$5.4x10^{-5}$	0.027	0.027
Mean Speed *	0.175	0.195	4.077	4.055
Zero Crossing Rate	488.667	450.667	587.333	462.667

4 DISCUSSION

The linearization of the espiral of Arquimedes was performed as the first step in the data analysis. Although the linearization step does not offer any new information, it is extremely useful in the analysis of the spiral, as it is responsible for replacing the coordinates x and y by new ones, giving rise to a linear relationship between them. (Pullman, 1998)

Through this transformation, the mathematical computational operations become easier and faster, making it possible to analyze crucial aspects of the drawing of the spiral. When comparing the straight line obtained by means of the radius-angular transformation of the ideal spiral with that generated from an actual spiral, drawn by a subject, it is possible to detect irregularities. (Pullman, 1998)

After the linearization step, a linear filter was applied in order to obtain the tremor activity signals for analysis. The definition of the linear filter's bandwidth (2.5 Hz and 20 Hz) was an important step to preserve the bandwidth of interest and to avoid major influence of voluntary movements, whose energy is normally concentrated in frequencies below 1 Hz. (Feys et al., 2007, Liu et al., 2005, Ulmanová et al., 2007)

According to Elble *et al.,*(Elble et al., 1996) the acts of writing and drawing constrict the range of tremor frequencies. Furthermore, the frequency of physiological tremor quoted in several studies (8-12 Hz) refers to tremor signals collected by accelerometry. (Timmer et al., 1998, Raethjen et al., 2000, Morrison et al., 2006) Moreover, the frequency of essential tremor may suffer a constriction either, since most studies face this type of tremor as essentially postural. In both cases, the data collection made under a postural tremor protocol will present differences in frequency when compared to kinetic paradigm.

From the analysis of Table 1 is possible to conclude that the features that provided a significant difference between the two individuals in analysis, for the Outgoing Spiral (OS) and Ingoing Spiral (IS) protocols, are: frequency of 50%, mean frequency, peak frequency, total displacement, standard deviation, DFA, approximate entropy, residual, RMS mean, variance and mean speed.

The values of RMS, variance and standard deviation show that the essential tremor activity had larger displacement amplitude compared to the physiological tremor activity. As in probability theory the variance of a random variable is a measure of statistical dispersion and the results show that the essential tremor activity presented a larger value of variance, it is possible to conclude that the distribution of the essential tremor activity is more spread out than that of the physiological tremor activity.

The mean speed values were smaller for the physiological tremor signals and, consequently, the total displacement of the tremor activity was larger in the essential tremor activity. Additionally, through the analysis of the DFA and Approximate Entropy, we can observe a change in the randomness of the signal, i.e., the essential tremor activity has higher predictability than that obtained for the physiological tremor activity as suggested by the increase of the DFA coefficients and the reduction of the Entropy values.

The analysis of the features First Order Smoothness and Second Order Smoothness in Table 1 allow us to conclude that in general subjects presented more difficulty to draw the spiral towards its centre. This is based on the fact that these features can characterize imperfections in the traces made by subjects, i.e., the larger their amplitudes the more imperfect the trace is. The results depicted in Table 1 support this assumption by showing an increase in the feature amplitudes.

The main limitation of the obtained results is with regard to the number of studied subjects. However, the results show that is possible to discriminate physiological and essential tremors through the analysis of hand-draw movements, i.e., under kinetic conditions. Despite this limitation, this research introduced a way of analyzing kinetic tremor activity for the characterization of physiological and essential tremors.

5 CONCLUSIONS

In this study, different from other researches, we addressed the issues of quantifying physiological and essential tremors under kinetic conditions. For this, we investigated the tremor activity obtained from a normal subject and a subject diagnosed with essential tremor.

The study showed that digitizing tablets can be used to make the evaluation of hand-drawing movements. Moreover, the analysis of these drawings makes possible the differentiation between healthy subjects and that diagnosed with a type of pathological tremor.

The analysis of physiological and essential kinetic tremors of individuals may be an important tool for the characterization of tremors. The results obtained through this technique may be evaluated in the context of the patient's history and correlated with neurological exams.

The early diagnosis of a pathological tremor can lead to appropriate treatment, which can provide a better condition of life for individuals.

The use of this method and paradigm may be an important tool for the characterization of different types of tremors.

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