

Quantification of Physiological Kinetic Tremor and its Correlation with Aging *

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Abstract— Tremor is the most common movement disorder characterized by repetitive and stereotyped movements. The analysis of hand-drawing movements is commonly used in the evaluation of patients with tremor. The data collection conducted under kinetic conditions and while performing a voluntary movement highlights the kinetic tremor. Most investigations on tremor attempt to understand its relation to neuromuscular dysfunctions. Therefore, there is a lack of studies that aim to investigate the complex relation between the physiological tremor and aging, especially in kinetic conditions. In this context, the main motivation of this research was to generalize the results obtained in Almeida *et al.* [1], a study that quantified age-related changes in the kinetic tremor of clinically healthy individuals. For this, a number of features extracted from tremor activity, obtained from digitized drawings of Archimedes' spirals, were analyzed. The analyses followed the sequence : Linearization of the Archimedes' spiral; Estimate of tremor activity; Data pre-processing; Feature extraction from the tremor activity; and Application of Linear Discriminant Analysis (LDA) technique as described in Almeida *et al.* [1]. The generalization of the obtained results showed that the method based on LDA allows for a linear correlation between physiological kinetic tremor and aging.

I. INTRODUCTION

Tremor is an involuntary, rhythmic, oscillatory movement of a body part that can be classified in many ways, depending on its aetiology, phenomenology, frequency and location [2, 3]. The movement caused by tremor can be associated to many factors such as neurological disorders and natural processes [3-5]. The latter is often referred to as physiological tremor and is present in greater or lesser degree, in all humans. The physiological tremor occurs normally in healthy individuals and, generally, it cannot be observed by the naked eye [1]. The presence of severe tremor disorders causes many difficulties, and can indicate even the presence of diseases related to central nervous system. However, the dividing landmark between physiological tremor and that resulting from dysfunctions is tenuous and has not been precisely established. Thousands of people each year, begin to present some type of motor dysfunction, which interferes in their daily activities and reduces significantly the quality of life of these individuals.

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Most investigations on tremor attempt to understand its relation to neuromuscular dysfunctions [4-15]. Therefore, there is a lack of studies that aim to investigate the complex relation between the physiological tremor and aging, especially in kinetic conditions. Almeida *et al.* [1] describes a method based in LDA that is able to quantify age-related changes in the kinetic tremor of clinically healthy individuals. In this context, the main motivation of this research was to generalize the results obtained by the method described in Almeida *et al.* [1] for a new group of healthy individuals with different ages. For this, a number of features extracted from tremor activity, obtained from digitized drawings of Archimedes' spirals, were analyzed. In Almeida *et al.* [1] 59 individuals were divided into seven groups according to their ages and Linear Discriminant Analysis (LDA) was employed for the study of the correlation between age and tremor. It was found that LDA allowed for the estimate of a unique feature, so-called LDA-value, which showed to be linearly correlated with age [1]. In this study, the results obtained through LDA analysis were generalized to another group composed of 14 healthy individuals with different ages. The results presented here show that the application of the method proposed in Almeida *et al.* [1] yields a linear correlation between physiological kinetic tremor and aging.

II. MATERIALS AND METHODS

A. Hand-Drawing Patterns

Hand-drawing patterns are commonly assessed by means of visual rating scales [1, 8]. 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 [1]. Besides, the use of this method for tremor detection is simple, versatile, non-invasive and can provide an electronically measure of tremor, reducing the subjectivity and limitation of some methods based on visual scales [1].

The digitizing tablet is able to inform the coordinates (x and y) of the tip of the pen on its surface while a subject perform the drawing. In 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 Archimedes' spiral, 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 tremor [7, 10, 13, 16]. However, no study focusing upon the use of this device for investigation of the correlation between kinetic physiological tremor and aging was found in our literature survey.

B. Criteria for Recruitment of Subjects

In total, 14 healthy subjects, *i.e.*, without clinical evidences of suffering from any neurological disorder, as assessed by a neurologist, participated in our experiments. 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 divided into groups according to their ages, totaling seven groups, being: G1 = {20–29 years} (N = 2 subjects), G2 = {30–39 years} (N = 1 subject), G3 = {40–49 years} (N = 5 subjects), G4 = {50–59 years} (N = 2 subjects), G5 = {60–69 years} (N = 2 subjects), G6 = {70–79 years} (N = 1 subject), and G7 = {80–89 years} (N = 1 subject).

C. Task Definition

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 Fig. 1, was placed on a table properly positioned in front of the subjects. After verbal and written explanation about the exam the subjects were asked to draw two samples of an Archimedes' spiral 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 center to its extremity (outgoing spiral - OS), whereas for the second sample the subject drew the spiral from its extremity to its center (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.



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

D. Data Analysis

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

Linearization of Archimedes' spiral: The spiral of Archimedes is a geometrical shape that has a uniform

distance between its turns equal to $2\pi b$. This kind of spiral can be represented by (1) in polar coordinates, where r is the radius, θ the angle, a and b are constants.

$$r = a + b\theta. \quad (1)$$

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 (2) to (4).

$$x = r \cos(\theta); \quad (2)$$

$$y = r \sin(\theta); \quad (3)$$

$$r = (x^2 + y^2)^{1/2}. \quad (4)$$

The linearization of a perfect spiral results in a straight line as shown in (5), where m is the slope of the straight line.

$$r = m \theta. \quad (5)$$

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 [9].

By means of 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 [9].

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

$$S = S_{ideal} - S_{actual} \quad (6)$$

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.

Data pre-processing: The tremor activity may be composed of: (1) the inherent noise of the digitizing tablet, which is a low-frequency noise (<0.1 Hz) as suggested by the manufacturer; (2) voluntary movement whose energy is mostly limited to frequencies below 1 Hz [10, 13, 15]; (3) and the specific-task physiological tremor which is characterized by involuntary movements and energy mostly between 4 Hz and 10 Hz [3, 7, 9, 12, 17].

According to Elble *et al.*[7], 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 [18-20].

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 [3, 7, 9, 12, 17], and also to avoid major influence of voluntary movements whose energy is normally concentrated in frequencies below 1 Hz [10, 13, 15].

Feature extraction from the tremor activity: In order to assess and quantify the tremor activity a number of traditional features were used as described in Almeida *et al.* [1].

Application of Linear Discriminant Analysis (LDA) technique: In addition to the traditional features we also employed a method inspired in LDA, which is a known method for data classification and dimensionality reduction. The main strategy of LDA is to assume that groups or classes are linearly separable and thus it is possible to estimate new features projected on optimized axes that maximizes the separability between classes. Specifically, LDA seeks a transformation matrix that maximizes the ratio of the between-class scatter to the within-class scatter [21].

The technique employed in our study follows that described by Almeida *et al.* [1] and Cavalheiro *et al.* [22] for the estimate of the LDA-value, which is a one-dimensional variable, estimated from the linear projection of features onto an optimized axis that maximizes class separability. Different from LDA, which basically uses the mean and covariance matrices of the classes for finding optimized axes, the technique used here employs genetic algorithm (GA) that is a search method used to find solutions in optimization problems.

In order to show the application of the LDA method in the quantification of physiological tremor, we used the linear model fitted to the LDA-values proposed in Almeida *et al.* [1] as a reference. The LDA-values of the tremor activity were estimated following the steps and parameters described in Almeida *et al.* [1].

III. RESULTS

The results presented in this section take into account the analysis of the data collected in Almeida *et al.* [1] and in this study. Fig. 2 depicts the LDA-values obtained for the seven groups.

The LDA-values obtained for the group of subjects investigated in this study are shown in Fig. 2. A visual inspection of this graph allows for the conclusion that the LDA-value is a feature whose value increases with age.

From the analysis of the results presented in Fig. 2 we can also observe that the estimated LDA-values follow the linear model obtained in Almeida *et al.* [1]. Fig. 2 shows a linear fit obtained through the relation between age and the LDA-value. The analysis of the parameters of the linear model shows that there is a linear trend between the two variables.

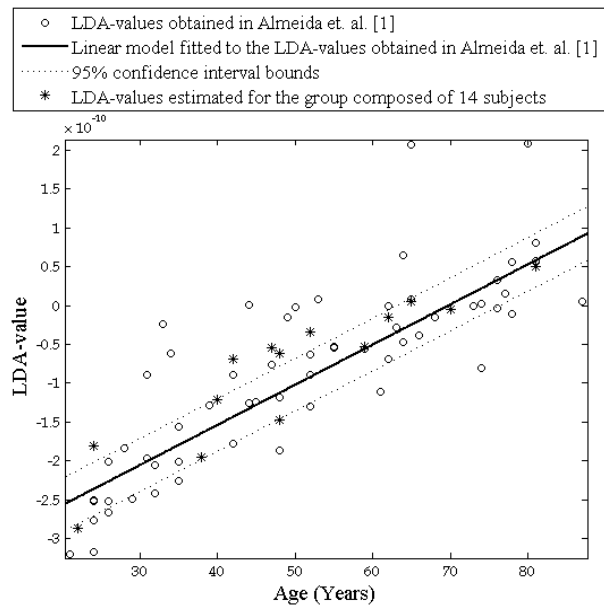


Figure 2. LDA-values calculated for the group composed of 14 subjects. In this graph this group is represented by (*), whereas the original group is represented by (o).

IV. DISCUSSION AND CONCLUSION

The possibility of obtaining a feature in a one-dimensional space, whenever possible, is relevant for easing the interpretation and visualization of results. The LDA-value was able to discriminate the groups in analysis as shown in Fig. 2, and also to characterize a linear relationship with age as depicted in the same figure.

The results also allowed us to verify that the LDA-value is a relevant feature for kinetic tremor analysis, with potential application in a number of correlated studies in areas such as Physiotherapy, Neurology, Geriatrics, and others.

In this study we addressed the generalization of the results obtained in Almeida *et al.* [1], a study that proposed a method for quantifying physiological-kinetic tremor and studied its correlation with age. For this, we investigated the tremor activity obtained from a distinct group of subjects. The subjects were grouped into classes according to their age. In the analysis, LDA was introduced as a method to analyze tremor activity through the study of hand-drawn patterns by using a digitizing tablet.

Our results indicate that the LDA-value was effective in the quantification of kinetic tremor showing a high degree of correlation with age. As the LDA-value is linearly correlated with age, this index may have great importance in future research, in particular in those related to the discrimination between physiological and pathological tremor.

Normal aging is associated with a decline in the functional capacity of the neuromuscular system, which is associated with an increase in the amplitude of physiological tremor. This situation may have severe implications in the ability of any individual to perform everyday tasks that require fine motor skills.

The analysis of physiological kinetic tremor of individuals may be an important tool for the characterization of physiological tremor. In this context, this study proved the efficiency of a new feature which showed to be correlated with the age of subjects. As this feature is in a single dimensional space it can be easily interpreted and visualized. Furthermore, the analysis of this feature may be evaluated in the context of the patient's history and correlated with neurological exams and potentially be used in the discrimination between physiological and pathological tremor. The early diagnosis of a pathological tremor can lead to appropriate treatment, which can provide a better condition of life for individuals.

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