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AN IMAGE ANALYSIS BASED METHOD FOR THE QUANTIFICATION OF TREMOR

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Abstract

In th is study, we introduce a simple and cost-effective method based on image analysis that can be used in the objective assessment/measurement of tremor. Tremor can be defined as the involuntary rhythmic movement of body parts (usually hands). Types of tremor include, but not limited to essential tremor, athetose, chorea, and flapping tremor. Objective assessment of tremor is crucial in the diagnosis of many neuromuscular d iseases. Velocity and acceleration sensors utilizing semiconductor technology a re widely used for measurement of tremor. However, one major weakness of this type of sensors is that they cannot sa tisfactorily track slow or constant speed motion, because of their poor response in the low-frequency region, where some of tremors may have some significant spectral components. Therefore, accurate measurement of tremor for the diagnosis or prognosis of movement disorders is an important issue. The method that we devise consists of an in fra-red LED that is attached to the body part whose motion to be measured and a simple CCD camera that is a ttached to a personal computer. The frames acquired by th e system first saved into a movie file, and then analyzed using a software tool that we have developed. We present the use and advantages of the devised system on a sample artificial data se t. **Keywords:** Tremor quantification, image analysis, spectral analysis.

1. Introduction

Tremor, approximately rhythmic movements of a body part due to involuntary contractions, can be associated with many neurological, muscular, and neuromuscular diseases such as Parkinson's disease [1 , 2]. Although most of its energy lies in the lo w frequencies ,

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frequency of tremor can be as high as 12 Hz [3]. Some parameters, e.g., average velocity or acceleration in the case of spatial domain analysis and weigh t of some spectral components in the case of spectral analysis, is derived from tremor measurements and then used to evaluate severity of tremor in an objective manner [1-3]. Therefore, accurate measurement or quantification of tremor is an impo rtant issue.

The widely used approach for tremor measurement involves semiconductor or piezoelectric velocity or acceleration sensors and their associated amplification circuitry [4, 5]. The major limitation of this approach is that these sensors have a poor response in the low frequency region (0 to 0.5 Hz), where some types of tremors may have significant spectral components. Furthermore, th e problems of limited linearity (i.e., different sensitivity in different frequency regions), dependency of perfo rmance on ambient temperature , and rela tively high noise in the output, makes these type o f sensors somewhat unreliable .

In th is study, we introduce an image analysis based method for tremor measurement and analysis that efficiently overcomes the many of difficulties that are associated with the currently used motion sensors. Our method involves attaching a near-infrared Light Emitting Diode (LED) to the limb, to th e tip of a finger for instance, whose tremor to be measured and capturing LED's changing position as a video/image stream using an inexpensive CCD (charge coupled device) camera whose near infrared response are known to be excellent. Once the image sequence is captured at rate suitable frame rate, the images/frames can easily be analyzed to find the position of the LED or limb and the parameters that describe the motion in spatial and frequency domains can be computed. In order to automate the analysis of captured images, we have developed a software tool called Quant-Motion.

In the methods section, we will further explain the details of our data acquisition scheme and discuss the use and features of Quant-Motion. In the discussion and conclusion section, we will make a critical comparison of our technique and existing techniques of tremor quantification.

2. Methods

2.1 Data Acquisition Scheme

We use a 850nm near-infrared (IR) light emitting diode (LED) as a pointer to be attached to the limb/location where the tremor is to be measured, using adhesive tape. Fig.1 shows an example set-up of the data acquisition scheme, to measure hand tremor. The IR LED is connected to the battery using a flexible coil cable to minimize the mechanical loading.

The camera that will capture the image or movement of the LED can be interfaced to a personal computer via either USB port or a frame grabber add-on card. In the sample hand tremor measurement application that we will this in the rest of this paper, images or frames are captured at a ra te of 24 frames per second using the USB in terface. This rate is enough to trace frequency components up to 12 Hz , according to Nyquist's Sampling Theorem [6].

This simple acquisition system offers great flexibility in terms of adjustment of th e spatial resolution. Suppose, due to storage size requirements, the frame size is fixed as 100 pixels wide by 80 p ixels high. If for instance the capture area has a physical width of 10 cm, then it means we have spatial resolution of 0.1cm 1 mm per pixel, which is good enough. However if need arises, spatial resolution can easily be adjusted by moving the came ra towards or awa y from the L ED (a s the camera ge ts closer to the LED, the resolution inc reases).

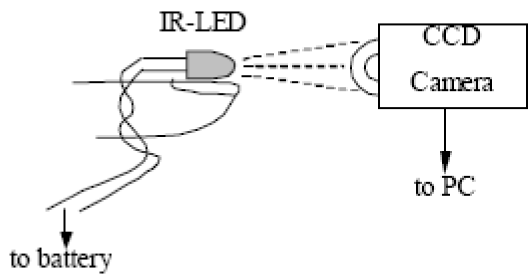

Figure 1. Schematic representation of our image/data acquisition system of tremor analysis.

The sensitivity of th e CCD cameras near the wavelength of the IR LED that we use is e xcellent [7]. Under normal circumstances, in a weakly illuminated room where we do not expect to have any IR sources other than th e LED, therefore the signal to noise ratio (SNR) fo r th e LED images are very high. In other words, detecting the LED marker, which is an approximately circular spot, in individual frames is a simple task that can be using thresholding. If needed , the SNR can be further improved by placing and IR filter, that on ly passes waves in the IR band, between the LED and the camera.

2.2 Image Analysis Software

In order to analyze captured images, we developed a se t of algorithms for th e calibration and analysis of tremor motion in space and frequency do mains in Matlab™ (The MathWorks, Inc. Natick, MA) environment. After testing th e tool on various test data sets, we built a graphical interface for easy access to the calibration and routines and compiled and packaged all the components using Matlab Compiler™. We named the resulting Windows™ stand-alone application Quant-Tremor.

2.2.1 Ca libration

We used a simple scheme fo r the ca libration the tremor analysis system. The user enters th e actual physical distance (in cm) that corresponds to th e width or height (in pixels) of the acquired frames. For instance, if the acquired image frames are 100 pixels wide, and this width corresponds to physical distance of 10 cm, then all the distances calculated on the images, i.e. on the two-dimensional pixel plane, need to be scaled by a calibration factor of 0.1 to get the actual distance in cm. (Another simple technique for calibration is to place a ruler in image capture area.)

2.2.2 Travel Analysis

With this type analysis, one can assess physical parameters of the tremor motion in two-dimensions. Among the variables that can be easily computed a re the total distance traveled, average velocity and acceleration. Our software reports these parameters along with th e x and y coordinates of the center of the spot. Travel analysis starts by selecting a suitable spot detection threshold to identify the area that corresponds to LED’s image in the frames. Once the data is loaded, the Quant-Motion lets the user select a suitable threshold fo r the detection spots (Fig.2). With simple thresholding, the LED’s location can easily be traced in different frames and the motion or travel of th e tip of limb where the LED is attached can be accurately followed in two-dimensions. Fig.3 shows a sample travel analysis result.

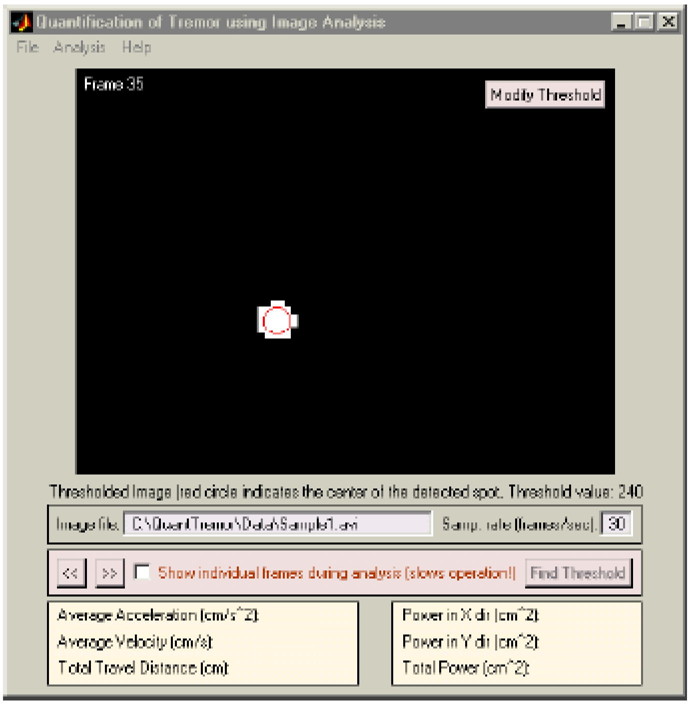

Figure 2. Determining the spot detection threshold.

2.2.3 Spectral Analysis

Power spectral density (PSD) analysis is an important tool that le ts us identify different frequency components or cyclic variations and their strength or power in signals. The PSD has been widely utilized in biomedical signal analysis [8, 9]. There are two broad classes of PSD estimation methods, parametric and nonparametric [8-14]. A detailed discussion of PSD estimation techniques is beyond the scope of this paper, we still suffice by noting that parametric methods assume that the signal is the output of a linear system driven by white noise and tries to identify the system/model that generates the signal. Once th e system parameters a re estimated, the PSD of the signal is easily obtained by evaluating the frequency response of the system at desired frequencies. Literature shows that when the da ta length of the availab le signal is relatively short, parametric methods perform better than non-parametric methods [11, 12] in terms of frequency resolution. In this application, we opted for parametric PSD estimation, since we cannot know the length of the recording or data sequence in advance.

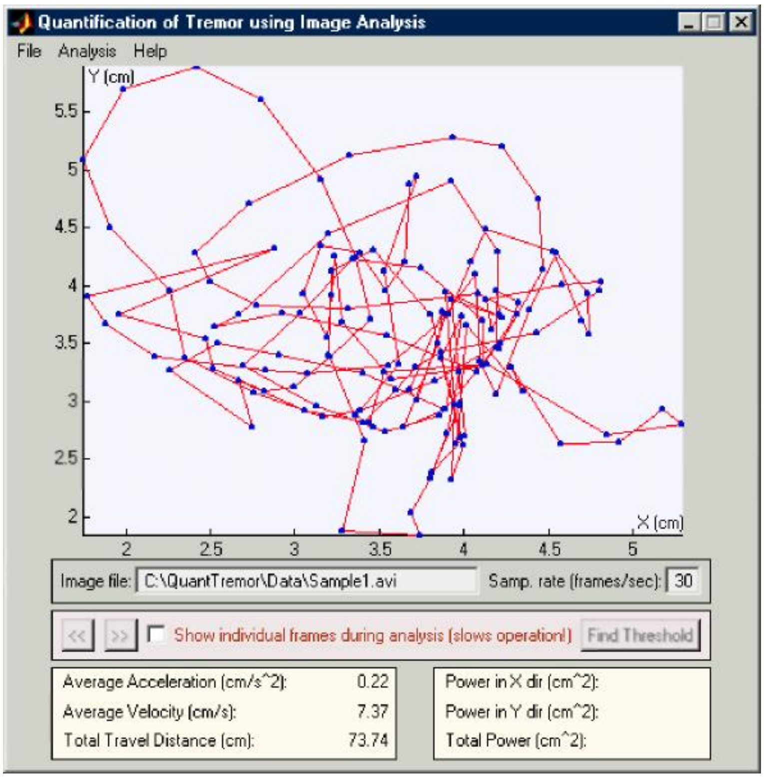

Figure 3. A sample travel analysis result.

There are many alternatives within the class of parametric PSD estimation techniques. We have chosen to use autoregressive (AR) modeling based approach to implement the spectral estimation feature of Quant-Tremor. The issue of model order selection is critical fo r the proper estimation of PSD using model-based, i.e. parametric, techniques. This issue has been dealt with extensively in system identification literature and various criteria based on information theoretical results have been proposed. The most commonly used of such criteria a re Akaike's Information Criterion (AIC) [13, 14], Final Prediction Error (FPE) [8] and Minimum Descriptive Length (MDL) [15, 16]. All of these criteria involve two terms acting in opposite sense, the variance of the estimation error that monotonically decreases and another expression that increases with th e number of model parameters. In this paper, we selected the order fo r AR modeling based PSD estimation of as 15, based on literature. However, once we collect a large number of data sets, we will further look in to this issue and confirm the suitability of our selection. Fig.4 shows one sample spectral analysis result.

3 Discussion and Conclusion

In this study, we have introduced a digital image analysis based method for tremor measu rement and/or quantification. Applicability of this technique is not limited to the upper limbs, e.g., to the hand. Tremor of any body part can be measured by placing the small IR LED on it. Our proposed method of tremor measurement is totally non-invasive, as there a re no cables, electrodes, etc. attached to the subject. Another advantage of this technique is that it is very cost e ffective. Simple USB cameras are widely available and the construction of the marker part of the acquisition system is very easy, as it consists of only the LED and its power supply, e.g. the battery. Furthermore, our method presents an integrated approach fo r both measurement and analysis of tremor. The Quant-Tremor software that we have developed as a part of this study, can analyze the captured tremor image sequence in both time and frequency domains.

As for th e drawbacks of our approach, it is evident from th e use of a single camera that our method can trace the motion in on ly two dimensions. However, this limitation can easily be overcome by using another camera and making simu ltaneous recording with tw o cameras. For instance, one camera can capture the motion in the frontal plane and the other in th e horizontal plane.

In a future study, we will collect real data from subjects with differen t types of tremors and try to identify an optimal recording length/duration for our method so that different conditions can be accurately classified based on the estimated spectrums. We will also confirm whether a model order of 15 is a good choice fo r autoregressive model fitting based power spectral density estimation.

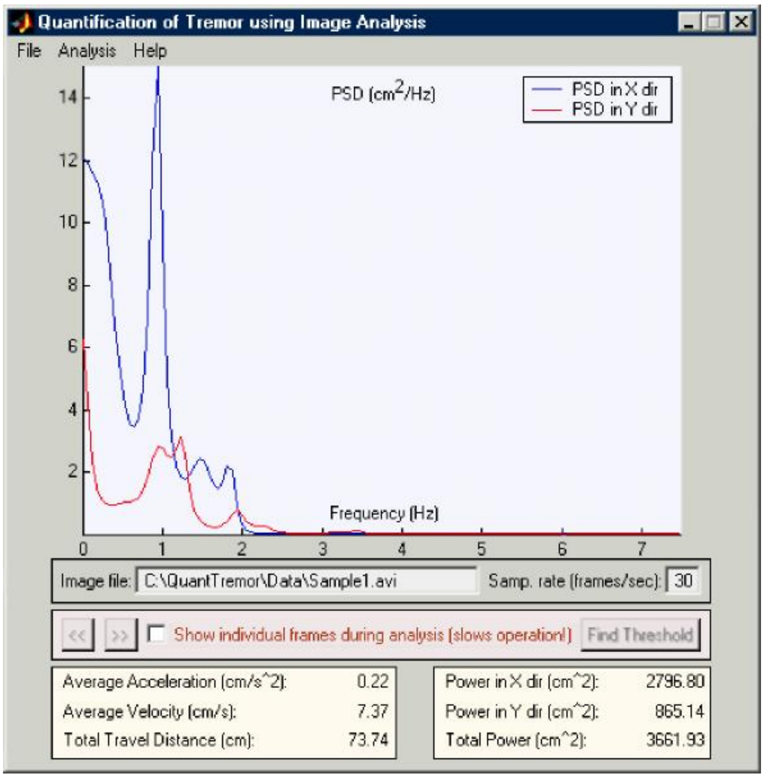

Figure 4. A sa mple sp ectral ana lysis result.

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