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Extraction of Tremor for Control of Neural Prostheses: Comparison of Discrete Wavelet Transform and Butterworth Filter

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Abstract— **Neural prostheses (NP) for tremor reduction rely on the information of tremor frequencies and their intensity and timing. Better estimation of tremor is important for reliable input to NP. In this work we compare two methods for tremor extraction. Discrete Wavelet Transform and Butterworth filter were used to decompose pathological volitional forearm movement into its slow and fast components. Slow signal is associated with volitional motion while the fast rhythmic signal is the result of involuntary muscular contraction (tremor). Our results suggest that in absence of prior knowledge about tremor frequency characteristics, Wavelet filtering has advantage over other conventional filtering methods.**

***Index Terms*— Neural prostheses, Tremor, Filtering, Wavelets**

I. Introduction

TREMOR is a rhythmic, involuntary muscular contraction of the body part, most often severely involving the upper limbs [1]. Taking into account people older than 50 years, it is estimated that more than 3% of world population show signs of upper limb tremor.

The most common method of controlling tremor is by medication therapy [2], although the results are not encouraging. There were several attempts of developing hand orthoses based on viscous friction [3, 4] or surface Functional Electrical Stimulation (FES) [5, 6]. Devices, such as joystick and computer mouse [7] or surgical instruments [8], were proposed for human-machine interface, which could filter out the undesirable movement. Risky surgical procedures, like pallidotomy and thalamotomy, were used in the past. Today, we have an alternative, called Deep Brain Stimulation (DBS). It includes an electrode placed in deep brain structures and implant in the neck area providing high frequency electrical pulses to desired brain structures [9]. Most of the people suffering from this motor disorder will not accept surgical procedure, and would rather have more benefit from a surface contact device such as FES based neural prostheses (NP). Therefore, reliable sensors and adequate processing of recorded signals for control of tremor with NPs remain as the main challenge.

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There are different types of tremor, and the most prominent characteristic is tremor frequency. Most often frequencies of tremor are: for Parkinson Disease (PD) in the range of 3-6 Hz, for Essential Tremor (ET) between 3-12 Hz [10] and for Physiological Tremor between 8-12 Hz [8], while the voluntary movement has frequencies that are less than 2 Hz. Some of these ranges overlap, but for the purpose of controlling the device for tremor attenuation, it is necessary only to establish the frequency range of pathological *vs.* voluntary movement.

Tremulous voluntary movement can be, in principal, analyzed by FFT. The fact is that tremor has frequencies that can change over time. FFT analysis will give the information about tremor frequencies, but not about their timing. For such signals we will often get better estimate with wavelets because the best correlation will be obtained when the stretched wavelet is similar in frequency to tremor and is shifted to line up with it in time. By knowing the amount of stretching and shifting we can determine both frequency and its location. Unlike the FFT, the wavelet transform allows us to remove frequency components at specific times in the data. This provides us a powerful capability to throw out the "bad" and keep the "good" part of the data in that frequency range.

The aim of this study was to investigate if tremor component could be extracted from pathological voluntary movement more accurately by using the Discrete Wavelet Transform (DWT) than by using other types of conventional filtering, and what are the benefits of DWT signal processing of tremulous movement data.

II. Material and Methods

A. Data Acquisition

Data presented in this work was obtained from one female subject suffering from Parkinson disease with observable hand tremor and one control healthy volunteer. The patient signed consent form approved by the local ethical committee in conformity with the Declaration of Helsinki. The measurements were done in the Institute of Neurology, Clinical Center of Serbia.

The subject was seated in the comfortable position with the left arm outstretched at the shoulder level in a pronated position, and fingers widespread (Fig.1, Left panel). Subject was instructed to move the forearm, in order to reach the position in which the elbow was bent over angle of 90

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degrees (Fig.1, Right panel). Subject was supposed to keep the arm in that position for a few seconds and to stretch it, wait for a few seconds, and repeat the process over and over again during the overall recording time of 30s.

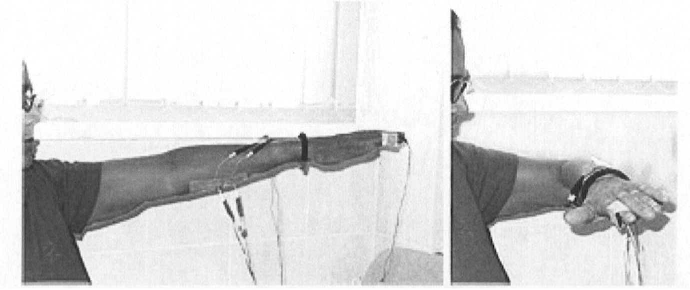

Fig. 1 Photo of the experimental setup. Movement sensor was fixed to the index finger of the arm exhibiting tremor.

Data was recorded with *Nicolet* acquisition device (VIASYS Healthcare) and built-in VikingSelect Tremor Master Software V8.3, with four-channel amplifier allowing measurement of EMG and acceleration. Data presented in this work was obtained from the movement sensor (3D accelerometer) placed on the index finger, Fig.1. The sampling frequency was set to 1 kHz.

B. Data Processing

All data processing stored during acquisition was done within MATLAB (ver. 7.3.0.267 (2006b), Matworks Inc, USA). DWT was implemented using Wavelet toolbox functions.

In order to compare results of DWT with some other type of conventional filtering, we used well known low pass Butterworth filter.

Discrete Wavelet Transform (DWT)

DWT is acting similar to filter banks, with low and high pass filters dividing signal spectrum into two equal bandwidth parts in each step (Fig. 2). These parts are called level j approximation (for LPF) and level j detail (for HPF).

In order to make a right decision about which level of decomposition is to be used for signal extraction, it is necessary to know the exact sampling frequency of the signal acquisition, and to decide which component of the signal is undesirable and needs to be extracted. The following equation introduces the relationship between the scale and the corresponding frequency (F_a) of the signal obtained on that scale:

$$F_a = \frac{F_c}{\Delta \cdot a} \tag{1}$$

- F_c - is the center frequency of a wavelet in Hz.
- F_a - is the pseudo-frequency corresponding to the scale *a*, in Hz.
- Δ - is the sampling period in seconds.
- a - is the scale, $a = 2^j$.

In this analysis we used levels of decomposition corresponding to j=6, 7, 8 and 9 because we intended to extract both slow movement and all the frequency artifacts less than the frequency of tremor from the overall signal sampled with 1 kHz.

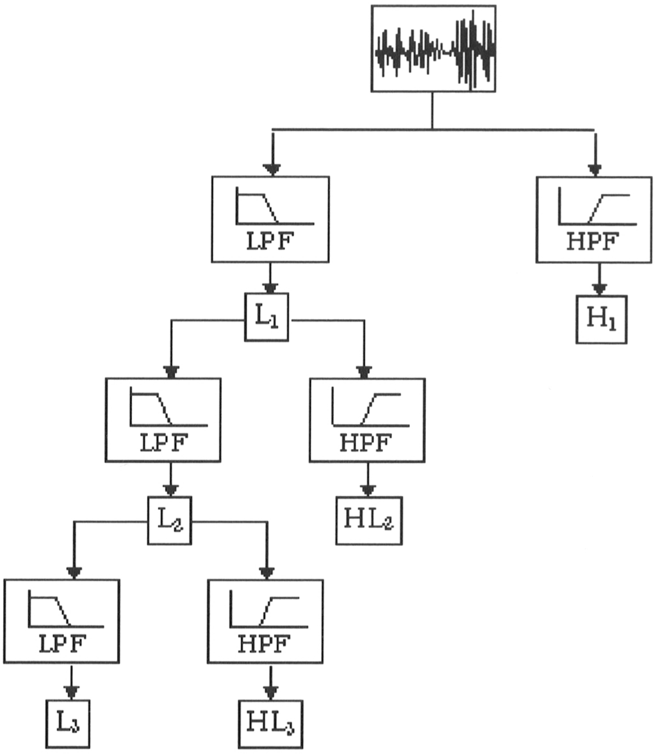

Fig. 2 Filer bank representation of DWT [11]. L_i is for low pass and HL_i is for high pass filtered signal from the previous level.

Butterworth Filter

Parameters for Butterworth filter were chosen to filter out voluntary movement from the recorded signal. For that purpose we accepted that undesirable frequency components are below 2 Hz (according to the literature). The order n=7 of high-pass filter was determined so to fulfill the following demands: stop band edge frequency of 1.6Hz with attenuation of 20dB in stop band and pass band edge frequency equal to 2.3Hz with attenuation of 3dB in the pass band (using MATLAB function [n,Wn] = buttord(Wp,Ws,Rp,Rs)).

III. RESULTS

Fig. 3 shows signals recorded with accelerometer during one trial from PD patient (Lower panel) and from healthy control (Top panel). Voluntary movement from PD patient has two imminent features: complexity and irregular pattern. Complexity of the signal is the consequence of an additional component to slow forearm movement, and that component is caused by tremor. Irregular pattern results from changes in tremor frequency and intensity over time. Signal recorded from healthy volunteer (Top panel) was shown for the comparison and further analysis consider tremulous signal only (Lower panel).

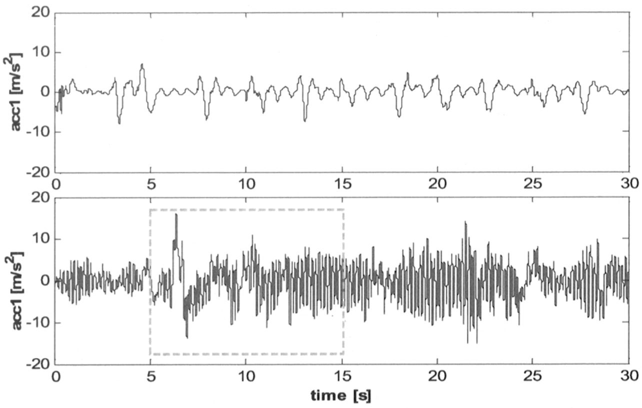

Fig. 3 Forearm volitional movement recorded with accelerometer. Top panel: healthy volunteer; Lower panel: PD patient.

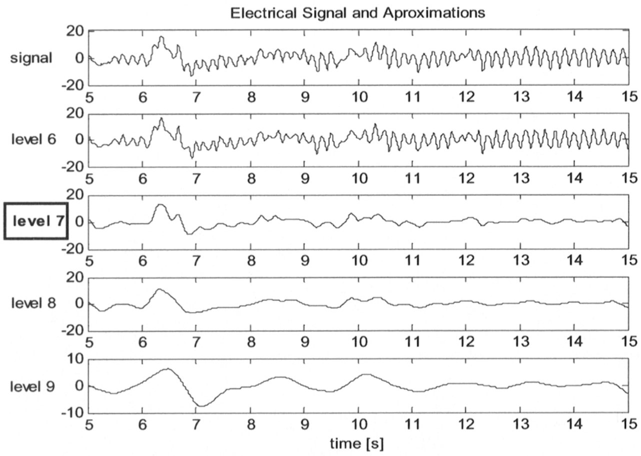

Fig. 4 From top to the bottom: part of the signal (Fig. 3, Lower panel, rectangle) and its approximations (corresponding to HL6 - HL9 in Fig. 2).

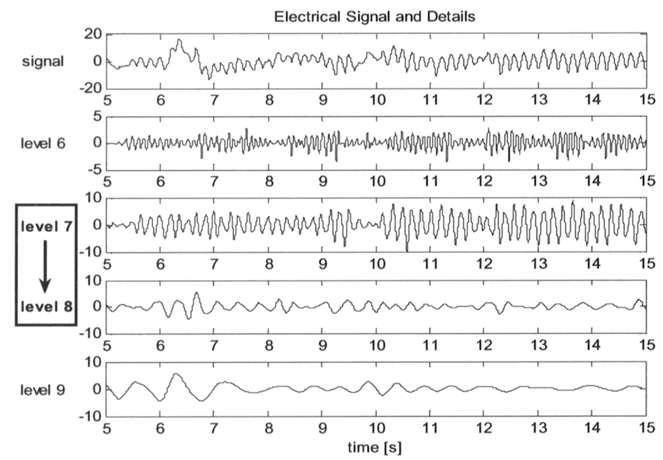

Fig. 5 From top to the bottom: part of the recorded signal (Fig. 3, Lower panel, rectangle) and its details (corresponding to L6 - L9 in Fig. 2).

Results of DWT processing are presented in Fig.4 and Fig.5. The top diagram in each figure represents part of the original signal between 5s and 15s (labeled by the rectangle in Fig.3), while the lower diagrams show the appropriate level approximation (Fig.4) or detail (Fig.5) obtained by means of the wavelet decomposition. From Fig.5 it is noticeable that there is a great change of signal frequency and intensity between levels 7 and 8. If we analyze Fig.4, indeed level 7 look like a first real slow component of the signal. Therefore level 7 can be used as the approximation of the slow component of the signal. Black line in Fig.6 representing wavelet 'coif3' (Coiflet wavelets of order 3) is approximation of level 7 that was superimposed to row signal (gray line).

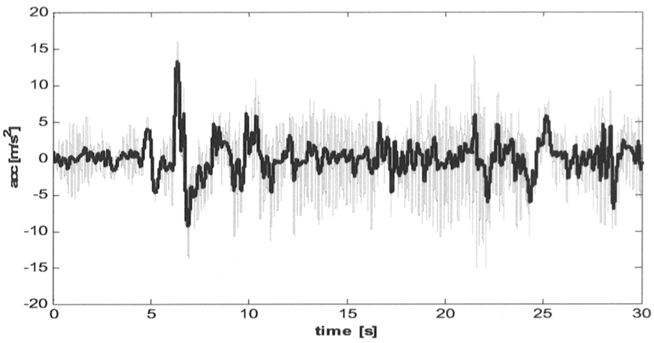

Fig. 6 Signal from Fig. 3, Lower panel gray) and its slow component extracted by wavelets, Fig. 4, approximation, level 7 (black).

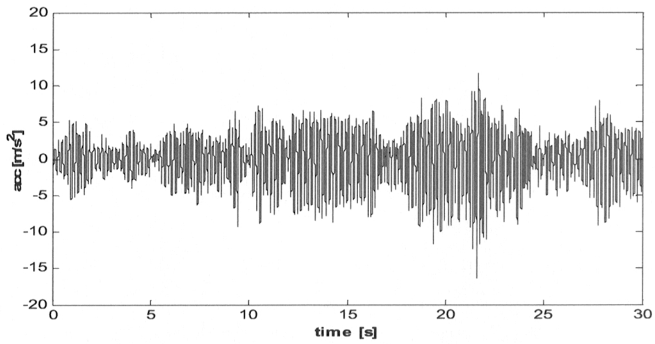

Fig. 7 Tremor: signal after extraction of the slow component (black signal in Fig.3) from row signal (gray in Fig.3).

Signal obtained after subtraction of the slow component (black signal in Fig. 6) from recorded signal (grey signal in Fig. 6) is shown in Fig. 7. Further we discuss this signal as tremor.

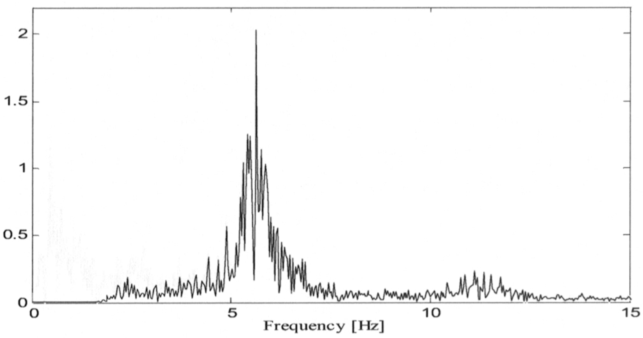

Fig. 8 FFT of tremor from Fig. 7 (black) compared to the FFT of the row signal (gray).

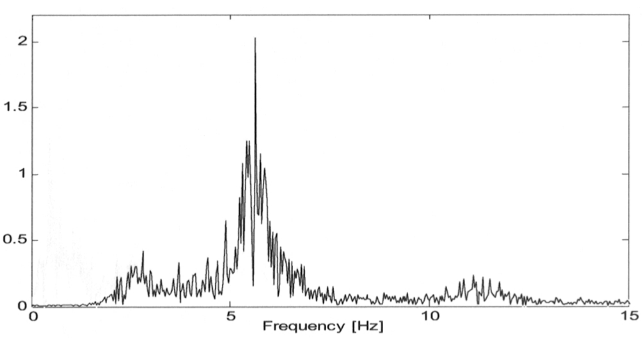

Fig. 9 FFT of the signal Butterworth high-pass filtered (black) compared to the FFT of the row signal (gray).

Results of DWT method are presented in Fig.8 where we compare spectrum of the tremor (black) with spectrum of the row signal (gray). Peak frequency of slow movement is less than 2 Hz and tremor peak is slightly above 5 Hz. These values are in agreement with data from the literature.

High-pass Butterworth filter of 7^{th} order, with cutoff frequency of 2.2Hz was applied on row signal and results are shown in Fig. 9 (black). For comparison, spectrum of row signal was superimposed (gray).

IV. Discussion

From the detailed analysis of movement recorded in this experimental setup we could expect two cyclic slow movement components. One is the result of the repetition of experimental task that consists of elbow extension, elbow flexion and pause. The second cycle comes from the repetition of elbow rotation. The first slow component, task repetition, lasts about 2.5s. This would result in peak frequency of about 0.4 Hz. Second cyclic movement (either elbow extension or flexion) lasting approximately between 500 and 300 ms would result in spectrum band between 2 and 3 Hz.

Our results suggest that both methods filtered out main frequency component of about 0.4 Hz. The second cyclic component between 2 and 3 Hz was left in tremor spectrum obtained by Butterworth filter (Fig 9, black) but not in the case of DWT processing (Fig. 8, black).

Further, when we use conventional filtering, as it was in this analysis - Butterworth filter, it is necessary to decide on cutoff frequency in advance. Therefore in such case prior knowledge of the signal frequency characteristics is essential. That may leave some other unwanted signal components, which do not belong to tremor (Fig.9, black components between 2 and 3 Hz).

In case of Wavelet Transform application, we only need to select the frequency region of interest, i.e. desired levels of decomposition. Diagrams of Details (Fig. 5) and Approximations (Fig.4) are very instructive for the decision of the right level of decomposition to be used further on.

Wavelet Transform is a powerful tool for offline analysis as it saves time and extracts preferred part of the signal only, without the neighboring components. Nevertheless, for the purpose of tremor attenuation with NP it is mandatory to develop online method. Filter banks and Wavelets might be the right solution.

The success of the method in the form presented in this paper is limited due to the fixed discrete steps of decomposition, imposed by DWT (power 2 mode). This means that for signal whose tremulous frequencies are close to some of the available pseudo-frequencies (Equation 1), we will still be able to choose the right level of decomposition according to Details diagram, but not all the undesirable frequencies will be filtered out. Instead of using the power 2 mode, the solution should be in multiple executions of frequency decomposition steps of fixed size (i.e. 0.5Hz) in the range of 2-12Hz. This should also allow for the easier estimation of the proper decomposition level to be used with signal, because the difference between frequency and amplitude of this and previous level on the Details diagram would be more visible.

The comparison of the two filtering methods in this paper was presented using one example only. Detailed analysis of various tremulous signals, as well as their conventional filtering should be completed before confirmative conclusion.

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