

Spectral Analysis of Myoelectric Signals by Wavelet Methods

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ABSTRACT: Wavelet packet method is introduced as an alternative method for spectral analysis of surface myoelectric (ME) signals. Both computer synthesised and real myoelectric signals during static contractions are investigated, and the results show that the wavelet packet method performs equally well as Fourier method. Moreover, wavelet packets give us some advantage over the traditional methods such as multiresolution of frequency, as well as its potential use for effecting time-frequency decomposition of the nonstationary signals such as the ME signals during dynamic contractions. The wavelet shrinkage method is also introduced for improving spectral estimates by reducing the mean square errors for both Fourier and wavelet packets estimates.

1. INTRODUCTION

Spectral analysis of myoelectric signal has been widely used to determine local muscle fatigue, force production, ME signal conduction velocity, muscle fiber type proportion, and diagnosis [1]. The most intensively used method for analysis of ME signals is Fourier method, but it suffers from several limitations. For example, it is only suitable for stationary signals, which means that it is not generally an appropriate approach in the analysis of signals with transient components in time such as the ME signal.

Several methods have been used to characterise the spectral components of the ME signal including the peak spectral amplitude, spectral bandwidth, spectral band analysis, mean or median frequency (MNF or MDF), and higher order moments. However, it will be possible to rely on the evolution of a spectral parameter only if each power spectrum estimate doesn't suffer from large mean square error (bias and variance), otherwise they may mislead us in our understanding of the physiology.

Recently, time-scale methods (wavelet transform) were proposed in an effort to overcome the limitations of the traditional time-frequency methods. The time scale methods act as a "mathematical microscope" in which one can observe different parts of the signal by just adjusting the focus. This allows the detection of short-lived time components of signals. As a generalisation of the *wavelet transform* (WT), the *wavelet packets* (WP) has been recently introduced and developed, which allows a "best" adapted analysis of a signal.

In this paper we propose a new approach based on wavelet packets [2] to analyse both computer synthesised ME signals and real ME signals from six healthy subjects during sustained isometric knee extensions at 25% and 70% of a maximum voluntary contraction (MVC).

The WP method were chosen since they do not make any assumption about the statistical characteristics of signals and can be used to analyse both stationary and nonstationary signals in both time and frequency domains. Meanwhile, *wavelet shrinkage* [3], acting as a smooth operator, is introduced as a method for minimising the mean square error in spectral estimate. The idea behind thresholding is the removal of small wavelet coefficients considered being noise in the estimated spectra. In general, the wavelet shrinkage methods have a number of theoretical advantages, including near optimal mean square error and near-ideal spatial adaptation.

2. METHOD

Our investigation of comparisons among different spectrum estimation methods based on WP and FFT is divided into two parts: 1) verification of the properties of the different methods by means of computer synthesised signals with known statistical properties; 2) surface ME signals during two levels of isometric knee contractions.

The signals used were simulated by passing white noise through ARMA models of different orders (order (2,2) and (8,8)). The parameter selection was done by using the "prony-function" in MATLAB's Signal Processing toolbox with a measured surface ME signal, with a sampling rate of 2 kHz, as the given signal. A model of order (2,2) describes the ME signal well, but we also selected to use a model of higher order, (8,8), to get a more complex model to examine the properties of the methods.

Six healthy male volunteers (20-35 years of age) performed sustained isometric knee extension at 25% and 70% of MVC with the knee flexed until exhaustion. Our myoelectric signal acquisition system (MYSAS) enabled simultaneous measuring of force and surface ME signals. Surface ME signals were obtained from the right vastus lateralis, vastus medialis and rectus femoris muscles. An isokinetic dynamometer (Kin-Com 500H, Chattanooga Group, Inc., Tennessee, USA) was used to measure force. The dynamometer was equipped with its own computer monitor, which provided visual display of force. The contraction, which displayed the greatest torque, was selected as 100% of MVC and target levels of 25% and 70% of MVC were determined accordingly for each subject. Surface ME signal was recorded by a bipolar isolated amplifier (EMGAmp, Braintronics BV ISO-2104, Almere, the Netherlands).

Data analysis was performed off-line using MATLAB with the Signal Processing, Wavelet toolboxes (The MathWorks Inc., Natick, Massachusetts, USA).

3. RESULTS

Figure 1 shows the spectral estimates based on FFT and WP as well as their improved versions by wavelet shrinkage, for the two synthesised data sets. Mean square errors between true and estimated power spectra is given in Table 1 for the ARMA(8,8)-model data, where even Bartlett and Welch methods are included.

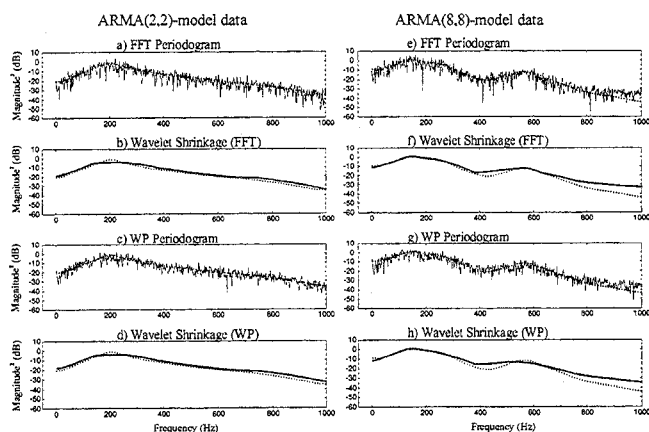


Figure 1. Spectral estimation comparison between FFT and WP and shrinkage thereof for synthesised data, where the dotted line is the true spectra.

Data set	FFT	Bartlett	Welch	WP	Wavelet Shrinkage	
					FFT	WP
0	89,10	69,70	37,06	78,90	8,41	11,64
1	130,08	88,16	59,60	106,80	14,63	13,43
2	130,31	86,40	68,43	105,30	30,16	19,19
3	114,13	83,16	73,42	125,23	22,54	14,82
4	101,78	65,56	42,44	75,99	10,62	12,56
5	91,71	66,36	44,28	70,13	15,82	19,64
6	101,39	76,01	47,63	92,36	20,58	17,07
7	104,49	76,25	36,39	91,76	12,56	12,53
8	119,15	92,10	55,95	92,04	11,72	12,98
9	96,16	66,74	42,54	89,53	9,99	12,64
10	85,48	49,30	35,27	67,65	15,73	21,75
Mean	105,80	74,52	49,37	90,52	15,71	15,30

Table 1. Relative error (percent) for different methods of spectral estimation for ARMA(8,8)-model data.

Figure 2 shows FFT, WP and wavelet shrinkage spectral estimates of real ME signals recorded during 25% and 70% of MVC, and both for unfatigued (1) and fatigued (2) states.

4. DISCUSSION

The findings in this study are that WP method performs slightly better than Fourier method for the synthesised data. However, wavelet shrinkage could significantly reduce the mean square errors. Note that results can be even better by optimising wavelet shrinkage via varying different choices of thresholds and wavelet functions.

Although there is no way to know the actual spectra of real ME signals, a number of authors have reported that the spectrum shifts to the lower frequency after sustained knee extension. The spectral estimates of the WP and FFT appear to concur with our simulated study and the literature, implying that the spectra shifts towards lower frequency band during static contractions.

Wavelet packet methods give us some advantage over the traditional methods: we can easily select different frequency resolutions for different regions in the frequency spectra and we do not need to calculate the complete spectra if only a few frequency bands of the spectra are of interest. Therefore, wavelet methods has its potential use for effecting time-frequency decomposition of the non-stationary signals such as the ME signals during dynamic contractions.

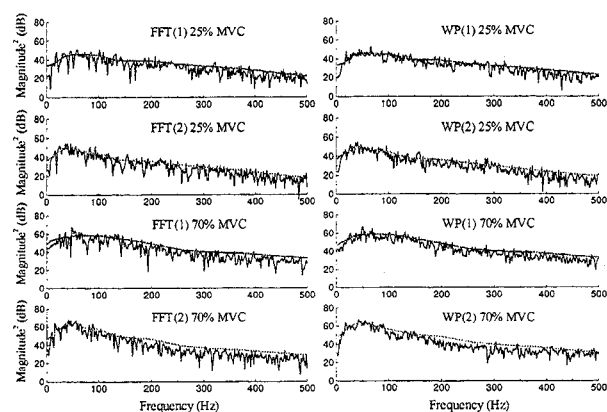


Figure 2. Spectral estimates of ME signals using FFT (left column) and WP (right column) and shrinkage (smoothed lines) thereof for two loadings at unfatigued (1) and fatigued (2) states.

5. REFERENCES

- [1] R. Merletti and L. R. Lo Conte, "Advances in processing of surface myoelectric signals: Part 1" *Med. Biol. Eng. Comput.*, vol.33, pp. 362-372, 1995.
- [2] J. Yu and S. Karlsson, "Spectrum estimation via wavelet packets," Research Report #11, Dept. of Math. Stat, Umeå University, 1997.
- [3] H. Y. Gao, "Choice of thresholds for wavelet shrinkage estimate of the spectrum," *J. Time Series Anal.*, vol.18, pp. 231-151, 1997.