ESTIMATION OF AVERAGE VISUAL EVOKED POTENTIAL IN HEALTHY HUMANS

Meghanand Anantrao Bhamare
Department of Electronics and Communication Engineering
Amity School of Engineering and Technology
Amity University Mumbai

Abstract:- Electroencephalograph is electrical activity of brain which is small in amplitude(5 uV to 200 uV). Evoked potentials (EPs) are bioelectric signals generated by the central nervous system (CNS) when it is stimulated by a well-defined external stimulus. EP's are vey much useful in the diagnosis of visual diseases. Due to very low amplitude of EP as compared to EEG, they are hardly seen in EEG. Many algorithms have been proposed till now for the estimation of EP. A scheme is proposed named subband latency corrected average using uniform filter bank and non-uniform filter bank. The scheme is tested on healthy VEP samples and results are compared with the other schemes as ensemble average and latency corrected average. Better results are achieved compared to other schemes by limiting the frequency band as compared to full frequency band. These techniques need to be tested on the data obtained in different diseased conditions also for other EP signals like Auditory evoked potential and somatosensory evoked responses.

Keywords:- Electroencephalogram(EEG), Evoked Potential (EP), Subband Latency Corrected Average (SLCA), Visual Evoked Potential(VEP)

I. INTRODUCTION

The electroencephalogram (EEG) is a recording of the electrical activity of the brain from the scalp. EEG activity is quite small, measured in microvolt (μV) with the main frequencies of interest up to approximately 30 Hertz (Hz).

Evoked potentials (EPs) are bioelectric signals generated by the central nervous system (CNS) when it is stimulated by a well-defined external stimulus. When recorded from electrodes on the surface of the scalp these potentials are very small in magnitude, in the range of 0.5 V. These are usually recorded within the first 0.5 seconds of stimulus delivery. EP waveforms are usually characterized by constituent waves whose amplitude and latency can be analyzed for diagnostic purposes. Due to their low amplitudes in comparison with the ongoing EEG, evoked potential are hardly seen in the raw recorded signal and therefore it is common practice to average several responses in order to visualize the evoked activity. Evoked responses measure the electrophysiological responses of the nervous system to a variety of stimuli. Almost any sensory modality can be tested in theory; in clinical practice, however, only a few are used on a routine basis. The ones most often encountered are the visual evoked responses (VEP, both flash and checkerboard types).

The VEP is very useful in detecting an anterior visual conduction disturbance. However, it is not specific with regard to etiology. A tumor compressing the optic nerve, an ischemic disturbance, or a demyelinating disease may cause delay in the P100; only additional clinical history and, often, MRI are needed to uncover the etiology. The usual waveform is the initial negative peak (N1 or N75), followed by a large positive peak (P1 or P100), and followed by another negative peak (N2 or N145). Maximum value for P100 is 115 milliseconds (ms) in patients younger than 60 years; it rises to 120 ms thereafter in females and 125 ms in males.

The usual VEPs are evoked by checkerboard stimulation and, because cells of the visual cortex are maximally sensitive to movement at the edges, a pattern-shift method is used with a frequency of 1-2 Hz. The size of the checks affects the amplitude of the waveform and the latency of the P100. In addition, papillary size, gender, and age all affect the VEP. Visual acuity deterioration up to 20/200 does not alter the response significantly; large checks may be required. In some studies, women have slightly shorter P100 latencies. Sedation and anesthesia abolish the VEP. Some subjects, by "fixating" beyond the plane of stimulation, may alter or suppress P100 altogether.

II. LITERATURE SURVEY

LITERATURE SURVEY

Woody's average

In this method the individual ERP waveforms are aligned with the template signal (which is formed by ensemble average of single responses) to find out maximum latency shift using cross-correlation. Each waveform is being shifted so as to match it with template signal. One new average is find out from all these shifted waveforms which is being used as a template signal for the next procedure. This procedure continues until the product-moment correlation between the shifted single responses and the current template exceeds a certain value. This method provides improvement to the ensemble average method as it takes care of shifting in latency which is normal problem in ERP's. But still it suffers from some drawbacks as it cannot cope up with random shifts in latency and also it tries to align alpha components if it is present in the waveform [1].

Latency Corrected Average

In this method the individual peaks in the ERP waveform are detected by filtering each waveform with minimum mean-square filter. Then a new template is being formed such that it will have general of the peaks in the ERP. After detection of the peaks they are grouped as per the latencies they occurred. Short segments of the individual waveforms in the vicinity of the identified peaks are aligned so that the peaks coincide and the average of the aligned segment is computed. The resulting average is one component of the LCA. These components are
positioned as per the average latency of the peaks. Only short segments are used to get the components[2,3].

Continuous Latency Corrected Average
This method has been developed to get continuous waveform from the disjoint segments in LCA [3]. Initially prefiltering is performed using time-invarient adaptive filter(TIAF). As it suffers few problems so care must be taken while selecting order of the filter. Then different methods are being used like a least-square fitting of power series, Chebyshev polynomials and fourier series which gives good results. But when one or more LCA components are missing it suffers some drawbacks. Hence in order to minimize such things , a weighted least square fitting was used with the continuous LCA.
Peak Components Latency Corrected Average
It is an alternative version of LCA method. This method consists of three steps[4]. Use of preprocessor such as time varying filter for enhancement of EP [5]. Then, compute latencies and amplitude with peak detection and alignment procedure. Finally superimpose mean peak component using Fast Fourier Transform (FFT).
Drawbacks of Correlation Averaging
Main problem associated with correlation method is that it is strongly affected by large amplitude responses, which is having longer duration (P300).

Weighted Average Method
Grouping single responses into different categories according to latency or amplitude characteristics and averaging them to enable comparison of different groups can obtain additional information. One similar technique is assign weights to single responses as per the magnitude of their cross correlation with the ensemble average and then re-average. The waveforms which are highly mis-matched are assigned zero weight and responses with high correlation gets better weight. For maximizing signal to noise ratio concept of weighted average is being used. With this technique SNR is improved upto 21% [6].

Subspace Averaging of Evoked Potentials
Subspace average is computed with the help of orthogonal projection of VEP. This method replaces conventional method of SNR average[7].

Nonlinear alignment and Averaging of Evoked Potentials
This is a new method which discuss about averaging of evoked potential[8] . For improving estimate of evoked potential, non linear alignment is done on average evoked potential.

Adaptive Wavelet Filtering.
This is an alternative technique for trial averaging using wavelet transform. Then align trials with evoked potentials with the help of Woody adaptive filter. This method improved the reliability [9].
Modified Adaptive Line Enhancement
Modified adaptive line enhancement (MALE)[10] is used for obtaining evoked potentials with minimum stimulus repetitions. The theory of MALE is developed and the assumptions made are tested and shown to be adequate in the case of brainstem auditory evoked potential. The signal distortion is characterized, and methods to alleviate the problem are developed. Using the weighted exact least squares lattice algorithm, the MALE method is implemented and applied to real data. It is shown that brainstem auditory evoked potentials can be obtained with less than 40 repetitions using the MALE method, compared to the 2000 required if the conventional ensemble averaging method is used.

Piecewise Prony method
This method is improvement over classic prony method [11]. With the help of this methos it is possible to study of the temporal profile of post-stimulus signal changes in single-trial evoked potentials (EPs).
Approaches with Winer Filter
Winer filter is being used for several methods in the estimation of EPs [12].One method which is called as time frequency digital filtering proposes a wavelet based post averaging winer filter for analysis .

II. DIGITAL FILTER BANK DESIGN

Filter bank are often used in signal and image processing applicationsb to reliase multiresolution decomposition of the input signal. The main role of filter bank is for signal representation and sub-band decomposition of signal. A digital filter bank is collection of digital filters, with a common input or common output. The purpose of a filter bank with a common input is to split the frequency band of a signal into several subbands and to process these sub-bands seperately.
This paper gives an estimation approach using the estimation scheme with (a) cosine modulated uniform filter bank (b) pyramidal non-uniform filter bank.
Cosine modulated uniform filter bank for VEP estimation

In a uniform filter bank, it consists of L sub filters each having the same bandwidth. let the impulse responses of these sub filters be denoted by $h_m(n)$, and the corresponding transfer functions is denoted by $H_m(f)$. To obtain $h_m(n)$, calculate $h_0(n)$ by a single low pass prototype filter. Then shift the frequency response of the prototype lowpass filter $h_0(n)$. the frequency shifting can be done by exponential modulation technique.

In exponential modulation technique the frequency of the low pass filter is shifted as in equation

$$h_m(n) = h_0(n)e^{\{j2\pi(m-1)m/L\}}, \qquad m = 1,....,L \quad (1)$$

Cosine modulation technique:-

Derive a class of (L+1) subfilters with real coefficients, by using cosine modulation property rather than exponential one.

$$h_m(n) = \begin{cases} 2h_0(n)\cos\{2\pi(m-1)n/2L\} & if\ m = 2,.....,L \\ h_0(n)\cos\{2\pi(m-1)n/2L\} & if\ m = 1, L+1 \end{cases} \quad (2)$$

The advantages gained by using cosine modulated filter banks rather than exponentially modulated one are

1. The filter bank has real coefficient filters as they are obtained from a real coefficient prototype filter by cosine modulation. This avoids complex computations which are time consuming especially when the no of filters in the filter bank is large.
2. The estimated signal (i.e. the output of the filter bank) is real which makes further interpretation much easier.

If the application demands (forces) optimization, only the prototype has to be optimized during the design, so that the design complexity is low.

III PROPOSED SCHEMES

Ensemble Average

The traditional method for ERP estimation is to use an ensemble averaging which averages an ensemble of responses. This method is base on the premise that the underling signal is deterministic. The resultant response of averaging has a tendency to smooth out physiological peak components i.e. the variations of peak components in the ERPS are lost by averaging. This causes the improper assumption of the stationary. Previous studies have shown that the entire responses and individual peak components of the ERPS vary randomly from response to response. Mathematically it is shown as follows

$$X(k) = \frac{1}{P}\sum_{j=1}^{p} x_i(k), 0 \le k \le N \quad \textbf{(3)}$$

The number K of ERP sweeps contributing to the average for deriving the template is a compromise between suppressing the noise level and the amount of a priori information present in the template. It is possible to take a large number of trials leading to improved SNR. However, if the number of trials is too large, then smearing out some physiologically relevant information may corrupt the average re- sponse.

Latency Corrected Average

Latency shift of each segment obtained in previous section implies
the dynamic change between the reference response and observed response.

The latency shift must be corrected on the basis of p^j .segments of reference of ERP . This means that when the latency shift of observed response is r_i^j it should be corrected by $k - r_i^j$ In (3) after the correction is performed the segments of observed responses are grouped. $\bar{s}^j(k)$ is latency corrected segments of the observed responses. The single output with entire response $\bar{s}(k)'$ is obtained by

$$\bar{s}^j(k) = \sum_{i=1}^{L} \hat{s}_i^j(k - \tau_i^j), j = 1, 2, ..., D \quad (4)$$

$$\bar{s}(k)' = \frac{1}{L}\sum_{j=1}^{D} \bar{s}^j(k) \quad (5)$$

Where L is total trial number and $\bar{s}(k)'$ means the latency corrected response.

Subband Latency Corrected Average

A method for the estimation of event related evoked potential with time varying properties is presented. The procedure consist of 3 stages. it uses an lowpass filter to reduce the results of artifacts an to get an improved response. To eliminate the noise component with background EEG and physiological artifacts low pass filtering is used as a preprocesser Then the filtered response is divided into individual sub bands and the latency shifts of each segment are detected by cross correlation between the filtered response and the template formed by the average of the previous obtained responces within interval of individual segments. Finally after the detected latency shifts, the responses of each segments are corrected as much as the latency shifts respectively. The corrected segments are grouped and the whole corrected ERP is obtained by averaging.

In latency corrected average procedure the individual peak components are first detected by cross correlating observed response with a template having the general shape of peak in the ERP and then the peaks are grouped together , the resulting average is

performed. The LCA procedure are very informative about various peak components, and provide much more information than the conventional average. However there are some problems, they require us to select the template waveforms, and undesired peak components can be appeared by the discontinues intervals between the waveform within validated interval of peak components and waveforms at the else intervals. Also it is very difficult to find peak components at a response because of effect of artifacts and ongoing EEG.

Lowpass filtering is performed as a preprocessing over the observed ERP. The estimation of an observed i-th response can be expressed as

$$\hat{s}_i(k) = \sum_{i=-m}^{m} h(l) x_i(k-l), 0 \le k \le N-l$$
$$= h^T X_i \tag{6}$$

where h = [h_{-m} …….h_0…….h_m]^T, X_i = [x(k-m)….. x(k)……x(k+m)]^T, and the order of filter is 2m+1. as a reference input the output of the previous M times averaging is used as

$$x_i^d(k) = \frac{1}{M} \sum_{a=1}^{M} x_{i-a}(k) \tag{7}$$

The filter response $\hat{s}_i(k)$ is divided into several intervals as express in equations which reflects latency shift correspondence to time varying properties in ERP.

$$p(k) = \sum_{j=1}^{D} p^j \hat{s}(k) = \sum_{j=1}^{D} p^j (k - \tau_i^j) \tag{8}$$

Where D, p(k) and j are the number segments of an ERP,. The reference ERP and the subscript of response in a segment. r_i^j Is the j-th segement of the i-th response. This expression provides simple calculation than LCA method, obtain peak component in response. This is because the latency shift of each segment can be obtained easily, it is possible to correct latency shifts without detection procedure of individual peak component in (7). Use a template form by average of previous obtained ERPS as a reference ERP to get the latency shifts r_i^j of each segments between the filtered response and reference ERP uses cross correlation function as

$$r_i^j(r_i^j) = \sum_{k=-\beta^j}^{\beta^j} p^j(k) \hat{s}_i^j(\tau_i^j + k), 0 \le \tau_i^j \le \beta^j \tag{9}$$

$$\tau^j = \max(r^j(\tau)) \tag{10}$$

Where β^j is the j-th segment length. Latency shift in each segment is obtained in (9). τ^j is the latency difference of each segment between the reference and measured signal. Because these variations of latency are ignored in averaging method, the resultant waveform is distorted and its amplitude is small.

Unique Features of SLCA

The following are some important unique features of the SLCA scheme that makes it more attractive:

1. As the problem addressed while devising the SLCA scheme is the estimation of an unknown signal, no assumptions were made about the signal to be estimated and noise associated.
2. The detection of features such as peaks and valleys is not necessary, neither is
it necessary to select a best VEP representative from the set of observed trials.
3. The latency correction is done within subbands. As the frequency functions of these subbands are non-overlapping, different components of the VEP signals are possibly coded within distinct basis functions. Therefore the latency correction procedure is not in or biased by a specific component of the VEP signal as usually the case with the correlation based latency correction procedures.
4. The unreliable correlation based procedures for latency correction are dropped.
5. The latency correction is achieved with the help of a coecient vector which also handles random variations in the waveform of the signal within subbands. So the nonlinear time variations such as expansion and compression in the segments are taken into account.
6. The energy based selection criterion of subbands that contribute to the SLCA, helps to remove the residual noise that may remain even after latency correction procedures are used.
7.Pre and postfilltering procedures are not necessarily required. Additionally, learning or adaptations are not required.
8. The scheme works better for all three type of VEPs without any loss of a physiologically relevant characteristic component.
9. The method is completely parameter free. No model based assumptions areneeded and does not require any explicit adjustment for the particular characteristics of the experimental setup.

IV. RESULTS AND CONCLUSION

The estimation schemes described are validated using real visual evoked potential signal.

Subjects and Experimental Setup:-

The evoked potential recordings were obtained by stimulating the visual modality: visual evoked potentials. The data was offered from Quiroga, john von Neumann Institute for computing, Forschungszentrum Julich, D-52425 Julich, Germany. Experiments were carried out on 9 voluntary subjects without any neurological deficit or medication known to affect the EEG. In an acoustically isolated and dimly illuminated room, two types of experiments were performed.

1. Single tone VEP experiment: Subjects were relaxed and watching a checkerboard pattern (side length: 50'), the stimulus being a checker reversal. The recording session consisted of 100 stimuli presentation.
2. Oddball non-target/target stimuli experiment: Subjects were watching the same pattern as above. Two different stimuli were presented in a pseudo-random order (oddball paradigm). Non-target stimuli (75%) were pattern reversal, and target stimuli (25%) consisted of pattern reversal with horizontal and vertical displacement of one-half of the square side length. Subjects were instructed to pay attention to the appearance of the target stimuli. The recording session consisted of 200 stimuli presentation.

The inter-stimulus interval varied pseudo-randomly between 2.5 to 3.5 seconds. After each pattern reversal, the reverted pattern was shown for 1 sec, then the pattern was re-reverted. Scalp recording were made following the international 10/20 system in 7 different electrode positions [central (CZ), frontal (F3, F4), occipital (O1, O2) and parietal (P3, P4)] referenced to linked earlobes. Sampling rate was 500 Hz and after bandpass filtering in the range 0.1 to 70 Hz, approximately 2 seconds of data (512 pre- and 512 post-stimulus data samples) were recorded. So, each single sweep consisted of 1024 samples which corresponds to slightly more than 2 seconds recording interval. Note that the length of the post stimulus EEG corresponds to the time during which the reverted pattern was visible.

After visual inspection of data, trials free of artifacts were selected for type of stimulus (VEP, non-target and target) and stored in separate files. So, data is being provided with $9 \times 3 \times 7 = 189$ different data files in 'plain text' format. Each data file contains minimum 16 and a maximum of 30 signal trials and each trial is composed of 1024 data samples (512 pre- and 512 post-stimulus) at the sampling rate of 500 Hz.

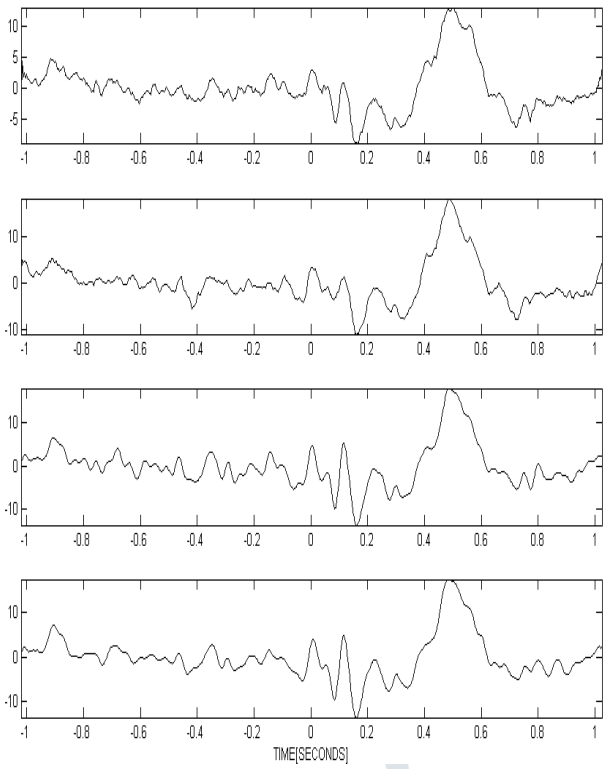
Final result shows positive peak at about 100 ms after stimulation (P100) followed by a negative peak (N200).

Data preprocessing and organization:-

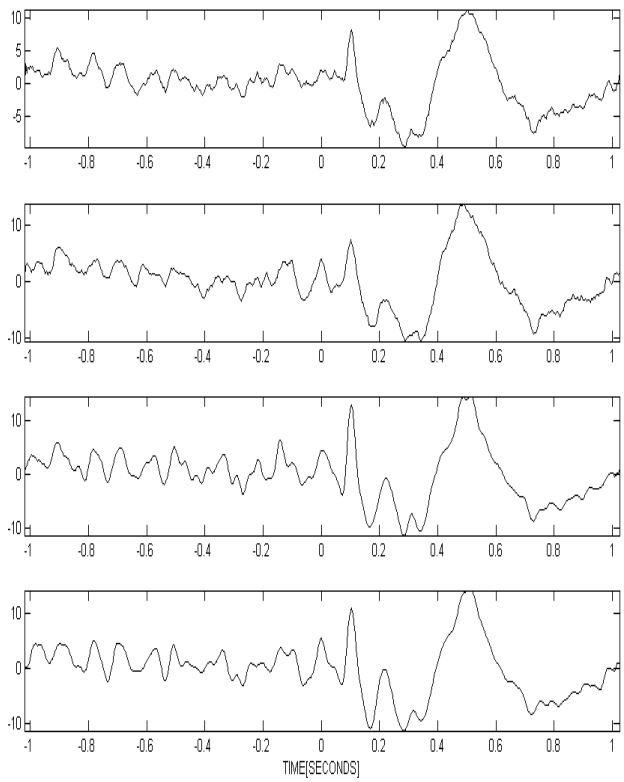
To reduce the computational overhead and the execution time downsample data by factor of 2 after passing it through an antialiasing lowpass filter having 125 Hz cutoff frequency. The downsampled data is stored in another set of files (in 'mat', i.e. MATLAB format). Thus, now the data files contains minimum 16 and a maximum of 30 signal trials and each trial consists of 512 data samples (256 pre- and 256 post-stimulus) at the sampling rate of 250 Hz. The data in such files is considered for the further estimation process. The file names used to store the data corresponds to e.g. DAA95O1T:

DAA95 Subject and experimental session.
O1 Electrode position
V/N/T:
V Visual single tone experiment,
N Non-target, oddball experiment,
T Target, oddball experiment

DAA95O1T			
P-100	0.9229	1.313	4.9
N-200	-8.727	-11.03	-13.66
P-300	13.06	18.4	19.74
DAA95O2T			
P-100	8.042	7.652	14.74
N-200	-6.486	-7.964	-10.79
P-300	11.19	13.98	14.82



SAMPLE-:*DAA95O1Td* (EA, LCA, SLCA Using UFB, SLCA Using NUFB)



SAMPLE-:*DAA95O2Td* (EA, LCA, SLCA Using UFB, SLCA Using NUFB)

V. CONCLUSION

Although this study has focused on applying the estimation scheme to visual evoked potentials, there is no reason why they cannot be employed any kind of event related signals. Advantage of filter bank scheme is the simpler design requirements with both uniform and non-uniform filter bank schemes. One has to design only a single prototype filter. In filter bank methods the NUFB does not show a clear advantage over the UFB, in most of the cases it has produced better results than UFB method. More clear results can be achieved by using limited frequency band 0-16 Hz (in case of limited SLCA).

REFERENCES

1. J. I. Aunon and R. W. Sencaj, "Comparison of different techniques for processing evoked potentials," *Med. Biol. Eng. Comput*., vol. 16, pp. 642-650, Nov. 1978.
2. C. D. McGillem and J. I. Aunon, "Measurements of signal components in single visually evoked brain potentials," *IEEE Trans. on Biomedical Engineering*, vol. 24, pp. 232-241, May. 1977.
3. C. D. McGillem, J. I. Aunon, and C. A. Pomalaza, "Improved waveform estimation procedures for event-related potentials," *IEEE Trans. on Biomedical Engineering*, vol. 32, pp. 371-379, June 1985.
4. X.-H. Yu, Y.-S. Zhang and Z.-Y. He, "Peak component latency-corrected aver- age method for evoked potential waveform estimation," *IEEE Trans. on Biomedical Engineering*, vol. 41, pp. 1072-1082, Nov. 1994.
5. X.-H. Yu, Z.-Y. He and Y.-S. Zhang, "Time-varying adaptive filters for evoked potential estimation," IEEE *Trans. on Biomedical Engineering*, vol. 41, pp. 1062-1071, Nov. 1994.
6. T. Gasser, J. Mocks, and R. Verleger, "A method to deal with trial-to-trial variability of evoked responses," *Electroenceph. Clin. Neurophysiol*., vol. 55, pp. 717- 723, 1983. 244
7. C. E. Davila and R. Srebro, "Subspace averaging of steady-state visual evoked potentials," *IEEE Trans. on Biomedical Engineering*, vol. 47, pp. 720-728, June 2000.
8. L. Gupta, D. L. Molfese, R. Tammana, and P. G. Simos, "Nonlinear alignment and averaging for estimating the evoked potential," *IEEE Trans. on Biomedical Engineering*, vol. 43, pp. 348-356, Apr. 1996.
9. M. Browne and T. R. H. Cutmore, "Adaptive wavelet filtering for analysis of event-related potentials from the electro-encephalogram," *Med. Biol. Eng. Comput*., vol. 38, pp. 645-652, Nov. 2000.
10. P. G. Madhavan, "Minimal repetition evoked potentials by modified adaptive line enhancement," *IEEE Trans. on Biomedical Engineering*, vol. 39, pp. 760-764, July 1992.
11. Violet Garoosi and Ben H. Jansen, "Development and evaluation of the Piecewise Prony Method for Evoked Potential analysis," *IEEE Trans. On Biomedical Engineering*, vol 47, pp. 1549-1554, Dec. 2000
12. O. Bertrand, J. Bohorquez, and J. Pernier, "Time-frequency digital filtering based on an invertible wavelet transform: an application to evoked potentials," *IEEE Trans. on Biomedical Engineering*, vol. 41, pp. 77-88, Jan. 1994.