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Wavelets based de-noising techniques for signal-to-noise-ratio improvements in speech-auditory Brainstem responses

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Abstract

This paper presents various Signal-to-Noise Ratio improvement techniques for EEG collected Neuro-Biomedical signals for Brainstem Speech Evoked Potentials data of Audiology. We have collected EEG data for 10 different human subjects. The de-noising techniques we developed for these Auditory Brainstem Responses are Yule-Walk multiband filters, Cascaded Yule-Walk-Comb filter, and conventional wavelet transform filters: Daubechies, Symlet, Coiflet Wavelets. After this we have designed a Translation-Invariant (TI) wavelets estimation filtering technique. In our research the idea of cascaded Yule-Walk-Comb filter is giving a considerable improvement in SNR over Yule-Walk filter; in conventional wavelets Daubechies wavelets are showing better performance than all. Ultimately, TI wavelets De-noising technique is providing us the best performance than even conventional wavelets.

Keywords: SNR, Yule-Walker filters, Comb filter, Brainstem Speech Evoked Potentials, EEG, Wavelets, Translation-Invariant Wavelets estimation

1. Introduction

There is increasing interest in recording auditory brainstem responses to speech stimuli (speech ABR) as there is evidence that they are useful in the diagnosis of central auditory processing disorders, and in particular in some children with learning disabilities (Johnson *et al.*, 2005; Dajani *et al.*, 2005; Russo *et al.*, 2004). Speech ABR is believed to originate in neural activity that is phase-locked to the envelope or harmonics of the stimulus. As a result, the recorded responses are remarkably speech-like. In fact, speech ABR is quite intelligible if played back as a sound (Galbraith *et al.*, 1995). As a result, methods used for Voice Activity Detection (VAD) may be useful for the detection of speech ABR (Ranganadh *et al.*, 2012, 2013). Once the response is detected, then other noise suppression algorithms could in principle be applied to improve the Signal-to-Noise Ratio (SNR). We found the speech like response in these brainstem speech evoked potentials collected from EEG and also we detected Voice by using VAD algorithms including our own methodology of Signal-to-Noise Ratio Peak Valley Difference Detection Ratio, which confirmedly detected Voice amazingly all the times with higher SNRs (Ranganadh *et al.*, 2012, 2013). In our research we have collected data (Dajani *et al.*, 2005; Johnson *et al.*, 2005; Russo *et al.*, 2004) from EEG signals, collected in an audiology lab of University of Ottawa. The major component evoked potential, reflects coordinated neural ensemble activity associated with an external event. Evoked potentials offer important information to study the neural basis of perception and behavior. In these signals in addition to evoked potential, potentials caused by background activity are also present. This background activity unrelated to any specific event "noise" to be suppressed and evoked potentials have to be extracted. In clinical and cognitive researches the extraction of evoked potentials is an essential task. In our research to improve the Signal-to-Noise Ratio we have designed various Filtering techniques for the Auditory Brainstem Responses of Brainstem speech evoked potentials, which successfully improved Signal-to-Noise Ratio for extracting evoked potentials. Some times cascading of filters basing on their frequency and time domain properties can develop a filter which can improve the SNR of a signal. In this research we specifically concentrated are Yule-Walk filter, Cascaded Yule-Walk-Comb-Peak filter; Wavelet filters of Daubechies, Symlet, Coiflet Wavelets; then Translation Invariant Wavelets estimation filtering.

In our research on our collected data cascaded Yule-Walk-Comb-Peak filter is giving us a considerable improvement in SNR over Yule-Walk filter; and the wavelets are performing far better than too specifically Daubechies wavelets are performing the best. Ultimately Translation Invariant (TI) wavelets are working far better than Conventional Wavelets in suppressing noise for extracting Evoked potentials; and hence a better improvement in SNR.

The paper is organized in the following way: in section II we described regarding the design of de-noising techniques, Section III talks about Result analysis and then we conclude with Section IV.

2. Design of De-Noising Techniques

In this research we have developed different procedures for SNR performances in the collected Neuro-biomedical auditory signals from EEG for Brainstem Speech Evoked Potentials (Dajani *et al.*, 2005; Johnson *et al.*, 2005; Russo *et al.*, 2004. M.S. John *et al.*, 2000) for 10 different human subjects. We have concentrated at the frequencies of 100Hz, 200Hz up-to a maximum of 1000 Hz for the frequency components and harmonics as at higher frequency components the speech like tones are almost rare. We have considered 1024, 2048 samples from the data for performance evaluation purposes. For these data we have implemented several different filtering techniques such as Comb-Filters, Yule-Walk multiband filters, some cascaded filters such as Cascaded Yule-Walk-Comb-Peak filters; conventional Wavelets filters: Daubechies, Symlet, Coiflet Wavelets and Translation-Invariant (TI) Wavelet estimation filtering procedures.

IIR Yule-Walk Multiband Filter: Yule-Walk (John L Semmlow *et al.*, 2004) is an IIR filter with arbitrary magnitude specifications, and this IIR filter approximates an arbitrary magnitude response, it minimizes the error between the desired magnitude represented by a vector and the magnitude of the IIR filter in the least-squares sense. This filter can be highly useful for biomedical signals such as Audiological Biomedical signals (John L Semmlow *et al.*, 2004). We can use different orders for the better approximation of the results.

IIR Comb Filter: A comb filter can be used for increasing the energy of a signal at particular frequencies basing on notch or peak; and hence possibility of improving signals amplitudes in the time domain of the signal (Mikel et Gainza *et al.*, 2005; Aileen Kelleher *et al.*, 2005. Robert W. *et al.*, 2008). Basing on their time domain and frequency domain properties Cascading of filters basing on the type of application some times gives plenty of innovative results.

We first implemented Comb filtering Comb-notch and also Comb-peak filters; Yule-Walk multiband filters. Here we implemented Cascading of Yule-Walk multiband filter with few more filters. But after Yule-Walk Filter we found that amplitude of the signal was suppressed keeping frequency same of the signal (Ranganadh *et al.* 2014). To get a good response and to improve the signal amplitude, we would like to extend this IIR Yule-Walk filter design to cascade it with a

filter which can improve the amplitude of the signal and also to improve the signal to Noise Ratio. We selected IIR Comb-filter. For this we would like to utilize the properties of Comb filtering process to enhance its time-domain for the nearest approximation. So we cascaded Yule-Walk multiband filter with Comb-Peak filter which approximated the amplitude of signal in its time domain to the simulated original signal keeping the frequency (Ranganadh *et al.* 2014). Then we observed the Signal-to-Noise Ratio for both cases of Yule-Walk multiband filter and the cascaded filter of Yule-Walk-Comb-Peak filter. It found to be there is a significant improvement in the SNR values in Cascaded filter. It's a good success. We found better improvements with different orders of the filters. We found that Yule-Walk-Comb-Peak filter is better smoothening and making the signal to the nearest approximation to the original simulated signal.

Conventional wavelets: Possesses frequency-dependant windowing, which allows for arbitrary high resolution of the high-frequency signal components; unlike STFT. A key advantage of wavelet techniques is the variety of wavelet functions available. So it allows us to choose the most appropriate one for the signal under investigation.

For the above reasons the wavelet transform has emerged over recent years as a powerful time-frequency analysis and signal-coding tool suitable for use in manipulation of complex non-stationary signals in biomedical signal processing such as in human auditory signal processing. Around 2 decades back Wavelet transforms were introduced for Evoked Potentials analysis of EEG (E.A. Bartnik *et al.*, 1992; O. Bertrand *et al.*, 1994; R.Q. Quiroga *et al.*, 1999). Recently, the wavelet transform was applied for EEG evoked potential extraction by choosing a few wavelet coefficients (R.Q. Quiroga *et al.*, 2003), requiring a priori knowledge of the time and frequency ranges of the Evoked Potential. But such knowledge is abundant in EEG. Wavelets offer higher temporal resolution at lower frequencies, so it suits well the 1/f spectral profile of evoked potentials. Wavelets filtering process includes three steps: 1. Wavelet decomposition 2. Nonlinear thresholding 3. Inverse wavelet reconstruction. Nonlinear thresholding (I.M. Johnstone *et al.*, 1997) is used in the thresholding step for separating the signal from noise. The evoked potential will be wavelet decomposed with large wavelet coefficient, whereas the ongoing background activity will be decomposed with small coefficients. So thresholding the wavelets coefficients can estimate the evoked potentials. Here we studied temporally correlated white Gaussian noise model, and we proposed level-dependant thresholding (R.R. Coifman *et al.*, 1995).

We have designed wavelet filters of different orders for these brainstem speech evoked potentials collected from single electrode EEG by using different functions of Daubechies, Symlet, Coiflet Wavelets. But we found better results with Daubechies wavelets than Symlet and Coiflet wavelet functions. As a result out of all we found that conventional wavelets are outperforming and giving excellent SNR performances. In addition to conventional wavelets, we found this algorithm works better with wavelet packets.

Translation-Invariant (TI) Wavelet Filtering Estimator

In addition to the conventional wavelet based filtering estimators we are considering the TI wavelet based estimator filtering technique. Here we are choosing translation invariant wavelet evoked potential estimator, in addition to conventional wavelets. In this filtering technique problems such as pseudo-Gibbs phenomenon near the discontinuities (R.R. Coifman *et al.*, 1995) can be overcome.

To do the process with TI wavelets evoked-potential estimation filtering the steps are

1. We shift the data.
2. Threshold the shifted data.
3. Unshift the thresholded data.
4. Then average the results for all shifting.

We did this process for each individual data sets. We considered shifting and unshifting the signal in the frequency domain and we did 1, 2, 3, 4, 5 shifts for each individual data set and averaged the results. We utilized two popular thresholding techniques: hard thresholding, soft thresholding. Soft thresholding sets the wavelet coefficients with the magnitude less than the threshold to zero, but it reduces the remaining coefficients in magnitude by the threshold also when compared to hard thresholding, soft thresholding does not contain noisy spikes, so we strongly considered soft thresholding and it provides smooth estimates.

3. Result Analysis

The result analysis in terms of SNR improvements has been done for the de-noising procedures of Yule-Walk, Cascaded Yule Walk-Comb, wavelet denoising using conventional wavelets of Daubechies, Symlet, Coiflet Wavelets, and then a special and latest advanced technique of Translation-Invariant (TI) wavelets for Auditory Brainstem Responses of Brainstem Speech Evoked Potentials of EEG. The results are tabulated in Table 1 and Table 2 for 10 different human subjects. The graphical representation of the performances is given in Figure 1 and Figure 2 in the form of Bar graphs for more clarity and ease of analysis for all these 10 subjects. Spectral Analysis for all wavelets and TI wavelets and Local SNR values analysis also confirming the better performances of conventional wavelets and Wavelets and TI wavelets (Ranganadh *et al.* 2014).

Signal-to-Noise Ratio analysis

The results are given in the Tables 1 and 2. The performances are also given in the form of bar graphs in Figure 1 and Figure 2. As per the tables and Bar graphs it is clear that cascading of Yule-Walk and Comb filter is better performing than Yule-Walker de-noising technique and improves the Signal-to-Noise-Ratio. Then when it comes to conventional Wavelets it is clear that Daubechies wavelets are performing well among all the three. But Conventional Wavelets are out performing than Yule-Walk and cascading of Yule-Walk and Comb filter. When it comes to Translation-Invariant (TI) wavelets De-noising technique, it is working far better than conventional Daubechies wavelets

De-noising technique. When we observe the Figure 1 the 3rd Bar, 4th Bar, and 5th Bar are far largest showing highest SNR performances of Conventional wavelets for all the subjects, but all the three are showing nearly same performance. In the Table 2 and Figure 2 it is clear that TI wavelets are performing the best even better than Daubechies Conventional Wavelets. As per the spectral analysis given in Figure 3 (Ranganadh *et al.*, 2014); the wide lobe spectrum for TI wavelets clearly shows that TI wavelets de-noising technique is separating the noise from the Signal. But it is clear that TI wavelets method is giving sharp spectral lobes at some of the frequencies of our interest but not at all frequencies but a lot of improvement in the SNR values than conventional Daubechies wavelets. It is giving sharp edges at 100 Hz, 400 Hz, 500 Hz, 600 Hz and 700 Hz. But not sharp lobes at 200 Hz, and 300 Hz. But showing clearly all the frequencies of our interest. But SNR has been improved to a greatest level when compared to conventional wavelets. As per the spectrum we will have to further refine by doing few more shifts in the TI wavelets, which may further refine the TI wavelets and may give further SNR improvements. But as per the requirements of research it is more than sufficient if we can get clear and sharp peaks identification at one or two or three harmonics of the spectra. The same for SNR improvements case also, if it improves the SNR at one or two or three harmonics of our interest it is sufficient. From this research it is clearly be observed that Translation-Invariant Wavelets are working exceptionally well in terms of de-noising the ABR signals. It's a good sign for proceeding into the research and to develop some reference signals and spectra. Basing on application and requirement we may need to do more shifts or fewer shifts while doing TI algorithm. But it works very well.

4. Conclusions

In this research we have collected the EEG data for Auditory Brainstem Responses for 10 different human subjects. For these Neuro-biomedical signals data we have done the De-noising process the result analysis it is clear that cascading of filters some times perform better than individual filters. Here it is proved in the case of cascading of Yule-Walk and Comb filter in terms of SNR improvement. Then it is proved that conventional Wavelets are outperforming in doing De-noising and improving SNR, especially Daubechies wavelets. The advanced technique of TI wavelets is even out performing than Daubechies Wavelets, in terms of SNR improvements. But we still have to work out for making TI to be even best performance by doing further shifts. Because at some harmonics of interest there are considerable peaks but not sharp peaks which can require further refinement by doing few more shifts, but this TI technique is surely working very well at some harmonics of interest exactly. As per most researches some harmonics perfection is sufficient. TI wavelet De-noising is successfully working also as a signal-noise separator. We found that this research is highly useful for developing some reference signals and spectra for ABR and confirming the data collection process to be a reference data collection procedure for many applications.

Table 1: The SNR performance evaluation of Different De-Noising techniques for EEG collected Speech ABR for 10 different subjects

Subject No.	Signal-to-Noise-Ratio (dB)					
	IIR Filter	Yule-Walk	Cascaded IIR "Yule-Walk Filter & Comb-Peak Filter"	Conventional Wavelets De-noising		
				Daubechies	Symlet	Coiflets
1	2.6386		7.0123	14.8412	13.9801	13.9512
2	1.9987		6.0098	13.0987	12.9087	12.9798
3	3.1428		8.5241	18.6278	18.0410	17.9801
4	2.0345		7.1243	13.9543	13.4535	13.8901
5	2.8968		6.9842	20.8543	19.9941	19.6427
6	3.9098		7.3459	15.0897	15.0587	14.9807
7	4.8211		8.9128	16.8428	16.1322	16.0329
8	3.4532		6.7891	15.8956	15.7658	15.8098
9	5.2105		7.2129	19.3214	18.7211	18.6028
10	4.7612		7.9876	17.8765	17.7567	17.6789

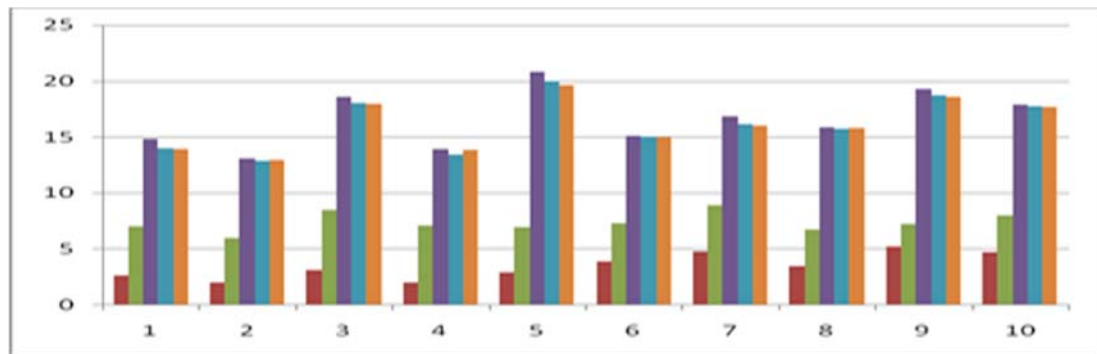


Fig 1: Bar graphical representation of performances of all de-noising techniques for all the 10 subjects. On the X-axis it is human subject number 1, 2, 3...10. Y-axis it is (in the order of first bar on the left most bar for each subject) a. Yule-Walk b. Cascaded Yule-walk & Comb c. Daubechies d. Symlet e. Coiflets SNR values in dB. It can be seen clear that Daubechies conventional wavelets are doing the best de-noising out of all.

Table 2: The Overall SNR performances of TI wavelets for the 10 subjects over conventional wavelets of Daubechies. TI is outperforming for our data sets of 10 human subjects

Subject NO	SNR (dB) after de-noising using conventional Daubechies wavelets	SNR (dB) after de-noising using TI wavelets
1	14.8412	28.3456
2	16.1287	30.1245
3	18.6278	30.4567
4	17.0324	28.0245
5	20.8543	34.2817
6	21.2345	33.0678
7	16.8428	32.2345
8	22.1345	34.5678
9	19.3214	37.06342
10	18.1309	32.1234

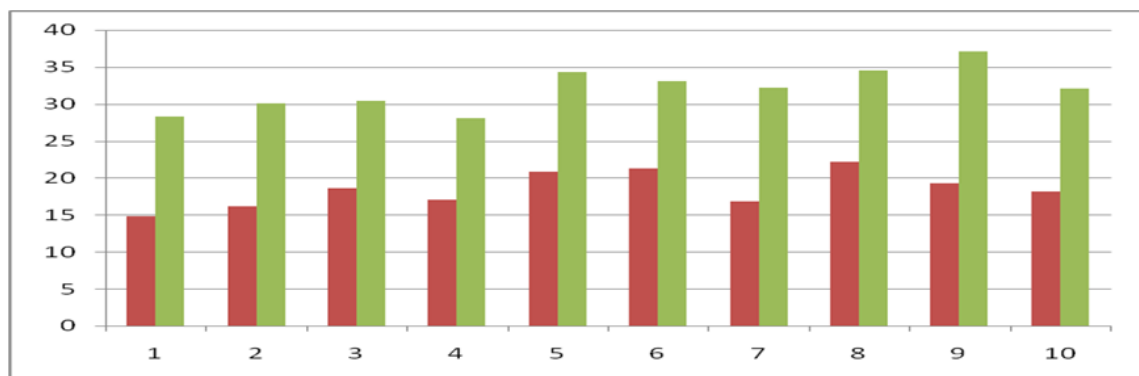


Fig 2: Bar graphical representation of de-noising performances of Daubechies conventional wavelets and TI Wavelets for all the 10 subjects. On the X-axis it is human subject number 1, 2, 3...10. Y-axis it is (in the order of first bar on the left most bar for each subject) a. Daubechies conventional wavelets b. TI Wavelets SNR values in dB. It can be seen clear that TI wavelets are outperforming.

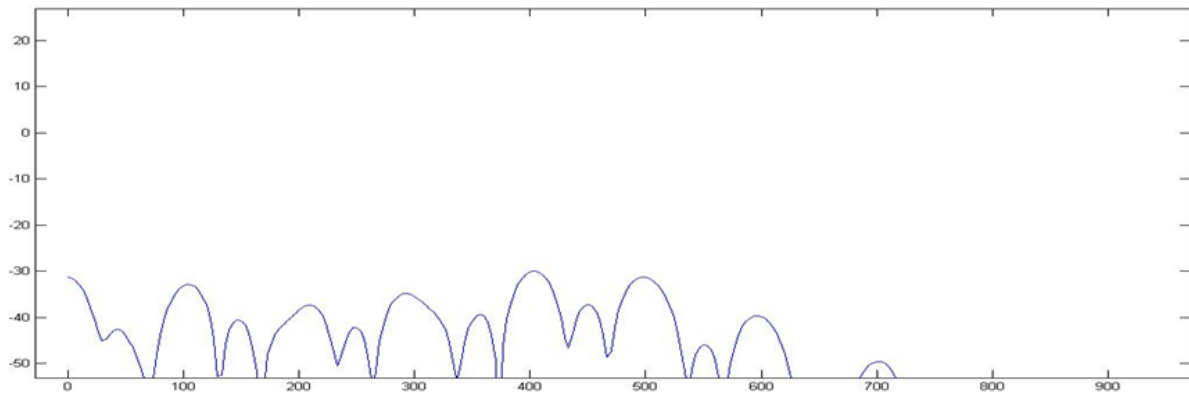


Fig 3: The frequency components in TI wavelets de-noising: the frequency components where the evoked responses concentrate strongly are the 100 Hz, 200 Hz, and so on. Which are our interested components of brainstem speech evoked potentials of our collected data. This is given for the human subject 1.

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