A Comparative Study on FFT,STFT and WT for the Analysis of Auditory Evoked Potentials

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***Abstract* - Brainstem auditory evoked potentials (BAEPs) are the evoked potentials which are recorded in response to an auditory stimulus from electrodes placed on the scalp. They reflect neuronal activity in the auditory nerve pathway from cochlea of inner ear to brainstem, and are used in the diagnosis of neurological diseases leading to hearing loss. Fourier transform based spectral analysis of BAEPs was carried out previously to show the differences in the frequency contents of normal and abnormal signals. The time-varying nature of BAEPs calls for better techniques capable of analyzing the auditory evoked potentials (AEPs). The STFT and Wavelet Transform performed remarkably well in displaying frequency, magnitude, and time information of the AEPs. In the present paper, the comparisons of various techniques are discussed to analyze the experimental results obtained.**

***Index Terms*— Auditory Evoked Potentials (AEP), Brainstem auditory evoked potentials (BAEPs), CWT, FFT, STFT, Wavelet Transform (WT)**

I. Introduction

The Auditory Evoked Potentials are the electrical activity measured by the electrodes placed on the scalp, which are produced as a response to the application of an auditory stimulus [1].The AEP is one of the best recognized electrophysiological tools used by neurologist and audiologists for the diagnosis and assessment of hearing loss. From the AEP a neurologist is able to determine the time taken for an aural stimulus to travel from inner ear, where the physical sound is translated into a bioelectrical impulse, to the brainstem.Though traditionally the time domain AEPs are firmly used, it does not provide the most important, source of diagnostic information. There are evidences that the AEPs contain other significant information in addition to that obtained from the measurement of time domain peaks which could be used in improving the AEPs diagnostic sensitivity and specificity [2]. A pathological condition can be diagnosed more easily when frequency content of the signal is analyzed. The information that cannot be readily seen in the time domain can be seen in the frequency domain and the most popular method is Fast Fourier Transform to measure the frequency components in a signal. But, Fourier analysis has a drawback as time information is lost in transforming to the frequency domain [3]. When looking at a Fourier transform of a signal, it is impossible to tell when a particular event has taken place. The AEPs have the characteristics of changing with time along the auditory pathway as they travel from the peripheral region to the brainstem. These characteristics are often the most important part of the signal, and Fourier analysis is not suitable in detecting them. Short Time Fourier Transform (STFT) is a well known method for the time-frequency analysis of non stationary signals. For general purpose time–frequency analysis, the spectrogram remains the dominant technique in use because it is easily computed as the magnitude-squared of the STFT [4]. The output of successive STFTs can provide a time-frequency representation of the signal. To accomplish this, the signal is truncated into short data frames by multiplying it by a window [5]. The width of the window must be short enough such that inside the window the signal is assumed to be stationary. Event can be localized in time. Hence, a very short window is desired when analyzing a signal where a nonstationary event occurs over a short duration of time [6].

The Wavelet Transform permits to do the continuous analysis in the Time and Frequency domain on the AEP signal to extract the wavelet coefficients that allows the characterization of the signal. The coefficients are extracted from the different levels of decomposition giving frequency and time related details of the signal [1].

A. AEP Background

AEPs are generated by a brief click or tone transmitted from an acoustic transducer in the form of an insert earphone or headphone. The waveform response is measured by surface electrodes placed at the vertex of the scalp and mastoids. The amplitude (µv) of the signal is averaged and plotted against the time (ms). The waveform peaks are labeled as I-VII as shown in Fig.1.

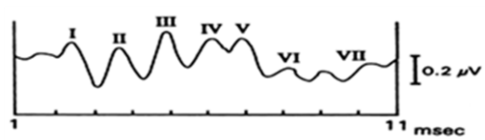

Fig.1. Typical AEP signal

Wave I is produced by the action potentials generated by the auditory nerve, wave II is generated in the cochlear nucleus, III in the superior olivery complex, IV from the lemniscus

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tracts, V is generated in the high pons and low midbrain, VI is probably produced in the medial geniculate body and wave VII corresponds to the generator activity of the auditory relations. These waveforms normally occur within a 10 ms time period after a click stimulus presented at intensities of 70-90 dB of normal hearing level in adults [7].

B. AEP Significance

The primary clinical application of the AEP signals is the objective determination of hearing threshold in individuals, monitoring traumatic brain injury patients, and intraoperative monitoring for skull base surgery [1].

The scope of this work is to compare the FFT, STFT and Wavelet transform analysis and interpretation on AEPs.
The paper is organized as follows. Section II details the background information of AEPs. Section III details the abnormality diagnosis using FFT, Section IV details the abnormality diagnosis using STFT, Section V details the abnormality diagnosis using WT. Section VI demonstrates our experimental Result and Discussion. Eventually, in section VII we draw the conclusions.

II. METHODOLOGY

A. AEP Recording System

In the present work AEPs were recorded using a standard recording system (RMS EMG-EP MK-11 Version 1.1 from Recorders and Medicare Systems) in a sound proof chamber. The basic block diagram of the system is as shown in Fig. 2.

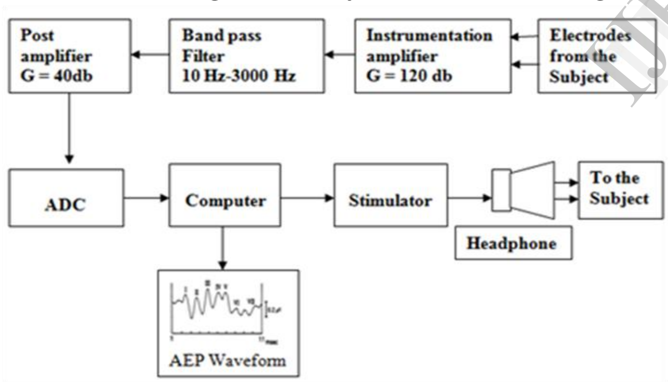


Fig. 2. Recording System of AEP

The AEPs are recorded using small disk surface electrodes made up of Ag/AgCl. The measuring electrodes are placed on the left or right mastoid, reference electrode is placed on the scalp at the vertex, and the ground electrode on the forehead. The exact position of electrodes was according to the 10-20 electrode system of EEG. To record the data, standard click stimulation generated by a computerized system is given to the ear being tested through headphones. The average response for 10 ms from 1000 to 2000 clicks is displayed on the monitor. The sampling frequency of 10 kHz for duration of 1000 clicks of 0.5µv is set. The repeated click at a frequency of 10/sec were presented binaurally or monaurally at an intensity of 85-110 dB. The magnitude of the AEP is very small, approximately 0.01 to 1 µv and amplified by instrumentation amplifier set at a gain of 120 dB. The amplified signal is passed through a band pass filter with lower and upper cut off frequencies of 10 Hz and 3000 Hz respectively as AEP is band limited in this range of frequency. The output of band pass filter which is in the order of a few hundred of µv is again amplified by a post amplifier (gain of 40 dB) to a few volts. The stimulus click frequency is restricted to 10 or 11 Hz as the auditory system shows adaptation beyond this frequency. Each ear is tested individually, and the test completes in 10-15 minutes. After averaging, data were processed using a personal computer system.

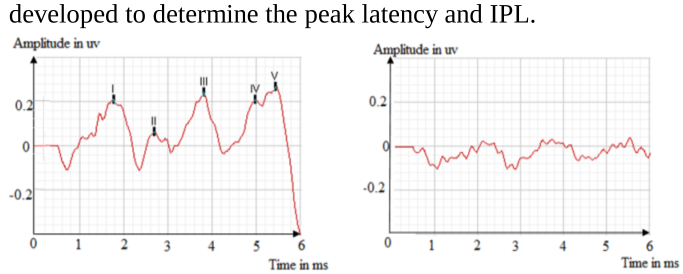
B. AEP Data Collection

The data were recorded from Paralytic Brain Stroke and Epilepsy Centre, Hubli, Karnataka. Based on the clinical symptoms and conditions, the data was also recorded for few abnormal subjects. When test shows no wave formation (peaks I-V) for the stimulation, such subjects were considered as abnormal cases. The typical test sample of AEP waveforms recorded is shown in Fig. 3. (a) Normal (b) Abnormal.

C. Analysis of AEPs

AEP abnormalities may include absence of waveforms, abnormal absolute or interpeak latencies, amplitude ratio abnormalities or right to left asymmetry. Waves I-V are seen in most of the individuals. Occasionally wave IV may be fused with wave V, in such case absence of Wave IV does not indicate abnormality. Wave II can be difficult to distinguish in some normal subjects. The subject is considered as abnormal if all waves (I-V) are absent, presence of wave I and absence of succeeding waves, and presence wave I and III and absence of wave IV and V. When waves I, III and V are clearly seen, the interpretation of abnormality might be read as follows: (1) Prolonged IPL between I-III, referred to the presence of a conduction defect in the brainstem auditory system between the eighth nerve closed to the cochlea and the lower pons. (2) Prolonged IPL between III-V, suggests the presence of a conduction defect in the brainstem auditory system between the lower pons and the midbrain. (3) Wave I is absent and III-V separation is normal, it is referred to a peripheral hearing disorder [8].

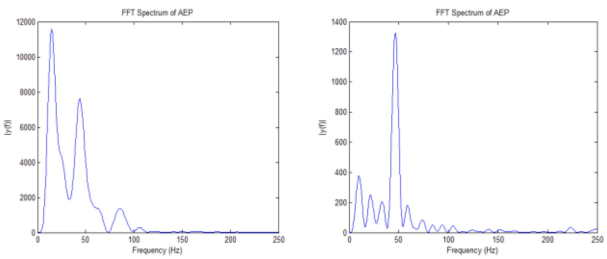
The AEP data stored in the computer are pre-processed in Matlab version 7.9, to eliminate the artifacts. The algorithm is developed to determine the peak latency and IPL.



(a) (b)
Fig. 3. Test Sample of AEPs (a) normal (b) abnormal

III. ABNORMALITY DIAGNOSIS USING FFT

The most basic technique for determining the frequency distribution of a signal is by *Fourier* transform, which decomposes signal into frequency components and determines their relative strengths [9].

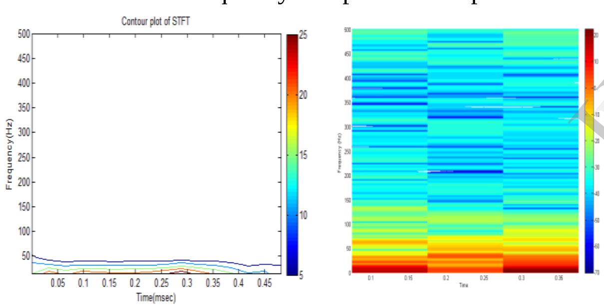


(a) (b)

Fig. 4. FFT Spectrum of AEP (a) normal (b) abnormal

A. *Result and Analysis*

To diagnose the abnormality, spectrum is obtained using a Fast Fourier Transformation (FFT) that is performed on the signal under analysis. The *Fourier* transformation of the AEP is carried out using the discrete, computationally faster, fast *Fourier* transform (FFT) algorithm in Matlab. Literature suggests that there are three main frequency components present in the AEP spectrum in the frequency analysis using FFT [10].The Fourier spectrum of the normal and abnormal signal is as shown in Fig 4. (a) and (b). The figure clearly shows the comparison between the normal and abnormal signal. The spectral analysis shows that in abnormal signal the abnormal random frequency components are present.



(a) (b)

Fig. 5. (a) Time-frequency represented via STFT contour
(b) Time-frequency representation via STFT spectrogram

IV. ABNORMALITY DIAGNOSIS USING STFT

The STFT is a modified version of the Fourier Transform. The Fourier Transform separates the waveform into a sum of sinusoids of different frequencies and identifies their respective amplitudes. Thus it gives us a frequency-amplitude representation of the signal. The STFT is the time dependent Fourier Transform for a signal, to accomplish this, the signal is truncated into short data frames, which are assumed to be stationary. This is done using a window function of a chosen width, which is shifted and multiplied with the signal to obtain the small stationary signals. The Fourier Transform is then applied to each of these portions to obtain the Short Time Fourier transform of the signal [5].

A. *Result and Analysis*

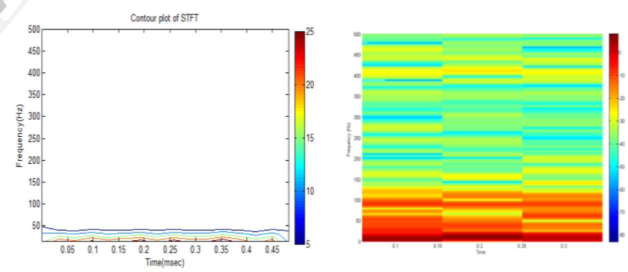
A short detail of the spectrogram and extracting the spectral distribution along the time of normal AEP is as shown in the Fig. 5 and abnormal as in Fig. 6. For the STFT analysis, Hamming window was used. The window size and the step size were defined as the percentage of the original signal.The spectrogram is used to estimate the frequency content of a signal. The magnitude squared of the STFT yields the spectrogram of the function.

The time-frequency amplitude spectrum for normal and abnormal AEPs as contour plot and spectrogram are as shown in the Fig. 5 (a) & (b) and Fig. 6. (a) & (b) respectively.

In the case of abnormal AEP as in Fig. 6, the spectrogram could be used to show the changes in frequency components with respect to time.The Figure is scaled in decibels to obtain best resolution. Here for the time-frequency plotting, color code was used to represent the amplitude of each point in the time-frequency space. The spreading of frequency components up to 100Hz can be clearly seen in abnormal AEP.

V. ABNORMALITY DIAGNOSIS USING WAVELET TRANSFORM

The Fourier transforms do not clearly indicate how the frequency content of a signal changes over time. That information is hidden in the phase, it is not revealed by the plot of the magnitude of the spectrum. The efficiency of time-frequency analysis using STFT is limited by the Heisenberg uncertainty principle.[11]



(a) (b)

Fig. 6. (a) Time-frequency represented via STFT contour
(b) Time-frequency representation via STFT spectrogram

For narrow windows good time-resolution can be achieved but for poor frequency resolution similarly for wide windows good frequency resolution can be got at the cost of poor time-resolution. The reason for the above problem is the constant width of the window. Most of the signals of practical interest are such that they have high frequency components for short durations and low frequency components for long durations. Hence Multi resolution analysis is appropriate. The Wavelet transform is a tool that cuts up data or functions or operators into different frequency components, and then studies each component with a resolution matched to its scale. The parameters in time-frequency analysis are time and frequency, while the parameters in wavelet theory are time and scales.

A wavelet is a waveform of limited duration that has an average value of zero. Wavelet Analysis is to break up the

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signal into shifted and scaled versions of Wavelets. In Wavelet analysis we move the different scaled versions of the mother wavelet and calculate the correlation between the signal and that wavelet. In this way we get wavelet coefficients. These coefficients are used to draw what is called scalogram. A scalogram is described by a time-scale plane.

The main objective of the wavelet function is to be as close as possible to the pattern of the signal. This achieves a good localization of the key structures, minimizing spurious effects during the reconstruction of the signal. The Wavelet Transform performs the analysis in the time and frequency of the AEP signal to extract the wavelet coefficients that permit the characterization of the signal [1].

These can be extracted from the different levels of decomposition a depicted in the Fig. 7.

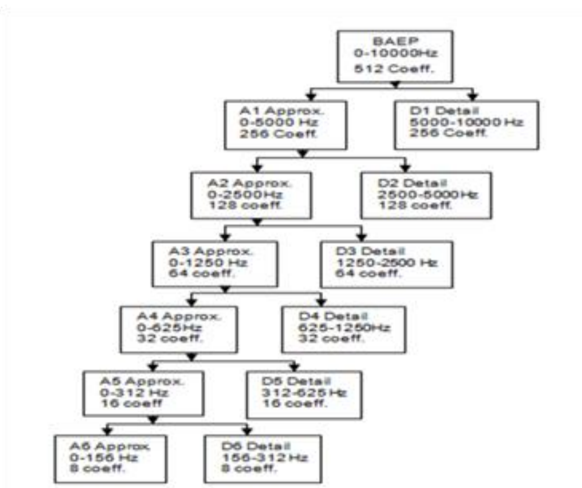


Fig. 7. Wavelet tree decomposition with 6 detail levels

The AEPs are sampled at 10 KHz. Thus, the first level has components between 0- 10 KHz (approximation 1, A1) and 5 KHz-10 KHz (Detail 1, D1), the second level components between 0-2500 KHz (A2) and 2500-5000 KHz (D2) so on as shown in the Fig. 7.

The Discrete Wavelet Transform is the most widely used WT algorithm for multi-resolution analysis. The advantage of the DWT is its computational efficiency and its orthogonality depending on the mother wavelet used. Here the mother wavelet used was the 5th order bi-orthogonal spline wavelet (bior5.5) as it produces most accurate and reliable estimated results [12].

A. Result and Analysis

Wavelet decomposition for 5 levels is as shown in Fig. 8. From the lower decomposition levels (high frequency bands) there is less information about signal variation. While Low frequency details give much more abnormality details since they cover the frequency band corresponding to the abnormal frequency as in Fig. 8. (b). It clearly illustrates that A5 highlights the low frequency components while D5 and D4 highlights the medium and high frequency of the peak V of AEP [13].

The Continuous wavelet transform (CWT) was also used to produce the spectrum of time-scale with respect to amplitude and the spectrum is as shown in Fig. 9.The scales are inversely proportional to the frequency. Small scales correspond to higher frequency which provides the detail signal information. A larger scale corresponds to low frequency provides the global information of the signal.

VI. Result and Discussion

The common characteristics of STFT and WT are that both provide time-frequency analysis. The advantage of WT over STFT is that it uses a size adjustable window than the fixed window used by STFT [14]. For example, during the high frequency area, the window will be shorter, and for low frequency area, the window will be longer. The window is automatically adjusted by CWT according to local frequency scales. Another advantage of CWT over STFT is that it can extract the coefficients of the particular frequency.

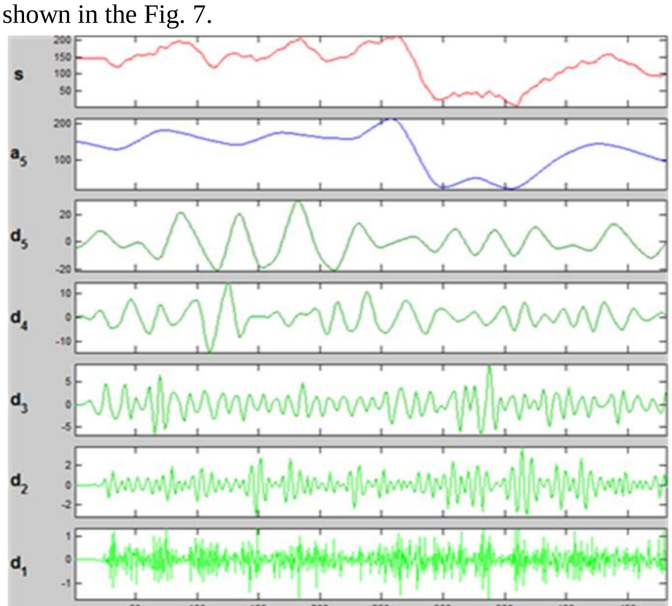
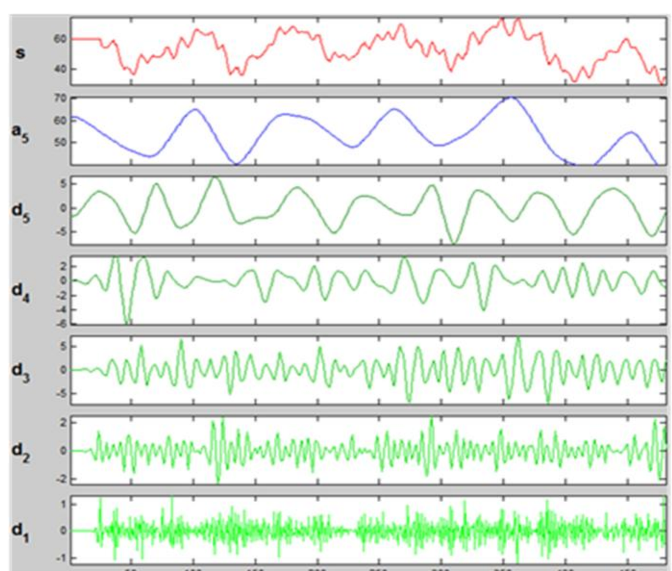


Fig. 8. (a) Wavelet decomposition of normal AEP signal



(b) Wavelet decomposition of abnormal AEP signal

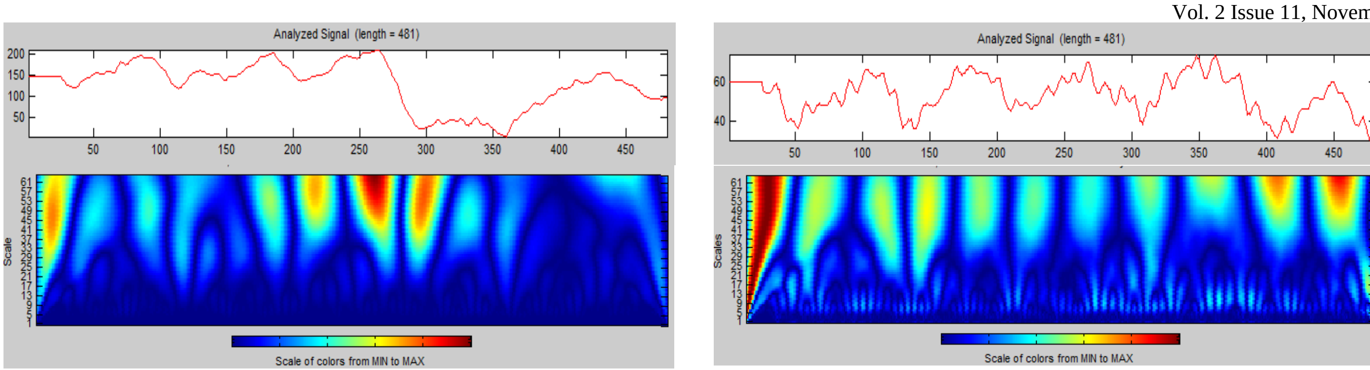


Fig. 9. (a) CWT spectrum in Time-Scale of normal AEP signal (b) CWT spectrum in Time-Scale of abnormal AEP signal

The CWT performed on the normal and abnormal AEP is as shown in the Fig. 9. The important feature of CWT is the capability to analyze the variation of the signal in time with respect particular frequency component in the signal.

The time-frequency coordinates provide the most conventional way of interpreting the data. It helps to find the amplitude peaks and their locations in the time and frequency. The limitation of STFT over CWT is that it does not provide frequency analysis for one particular frequency and the spectrogram shows more background noise due to lack of precision in programming.

VII. CONCLUSIONS

In this paper, diagnosis of AEP abnormality detection based of FFT, STFT and wavelet analysis of AEPs are discussed with some experimental results which are useful for automatic diagnosis. The automated diagnostic system detects changes in the AEPs recorded by examining the changes in the frequency components and uses the current spectrum of the signal for locating the characteristics fault frequencies. The spectrum is got by using FFT that is performed on the signal under test. The fault frequency does not give the time information. Hence this paper proposes Short time Fourier Transform and Wavelet Transform Analysis. The STFT determines the sinusoidal frequency and the phase content of the local sections of signals it changes over time. In this method spectrogram is used to estimate the frequency content of the signal with respect to time. On other hand, Wavelet transforms show changes on harmonics amplitude and distribution, and it is the suitable transform to be applied on non stationary signals. At last, we can conclude that the new methods such as Short-Time Fourier Transform (STFT) and Wavelet Transform can effectively diagnose the latency change or minor abnormalities in the AEPs. Our future work in this research is aimed to integrate all the applications of the three techniques to build an automated system in diagnosis and interpretation of the AEPs.

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