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Comparison of Wavelet Transform and FFT Methods in the Analysis of EEG Signals

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In this study, whether the wavelet transform method is better for spectral analysis of the brain signals is investigated. For this purpose, as a spectral analysis tool, wavelet transform is compared with fast Fourier transform (FFT) applied to the electroencephalograms (EEG), which have been used in the previous studies. In addition, the time-domain characteristics of the wavelet transform are also detected. The comparison results show that the wavelet transform method is better in detecting brain diseases.

KEY WORDS: wavelet; FFT; EEG.

INTRODUCTION

Brain is one of the most important organ of the body. So, its structure and functions have become a great source for the research. Although a lot of work has already been done in this field, it is still a challenging area. Furthermore, EEG is an important guide for the investigation of the physiological and psychological sutiation of participants.[1,2]

EEG signals are considered not to be deterministic and they have no special characterestics like ECG signals. In addition, when the Fourier transform is applied to successive segments of an EEG signal, the obtained spectra are observed to be time varying. This indicates that the EEG signal is also nonstationary. The spectral analysis based on the Fourier transform classical method assumes the signal to be stationary, and ignores any time-varying spectral content of the signal within a window.[3,4]

Furthermore many doctors, as a rule, determine the frequency of EEG signals by counting the number of peaks per second. From this point of view, it can be said that both frequncy and time-domain characteristics of EEG are very important.

In this study, EEG signals taken from patients in Neurology Clinic of Research Hospital of Dicle University have been used. These EEG signals were digitized by using a data processing unit (PCI-MIO-16-E4) which has been used in the previous

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studies.[2] Digitized EEG signals were analyzed using fast Fourier transform (FFT) and wavelet transform (WT) methods. The results obtained by the two techniques were eventually compared, and it was found that WT offers better spectral characteristics of EEG signals in the case of diagnosis.

MATERIALS AND METHODS

Characteristics of the EEG Waveforms

An EEG signal consists of several frequency bands, which are called δ, θ, α, and β bands. Their bandwidths are 0–4, 4–8, 8–12, and above 12 Hz respectively. In this study, two EEG signals for both healthy (normal) and pathological (abnormal) cases were recorded from subjects under relaxation, with their eyes closed. The EEG patterns recorded from subjects under relaxation show the characteristics of α waveform, which is the case for most humans.[5] This condition seems to represent a form of syncronization, almost like a natural frequency of brain.

The abnormal case is shown in Fig. 1. If one counts the number of peaks in the trace, as physicians do, it is clear that low-frequency band is dominant in the waveform. This low frequency indicates an abnormal situation to be taken under consideration.

On the other hand, Fig. 2 shows the normal case, and it can be observed that the dominant frequencies of EEG waveform are in the α range.

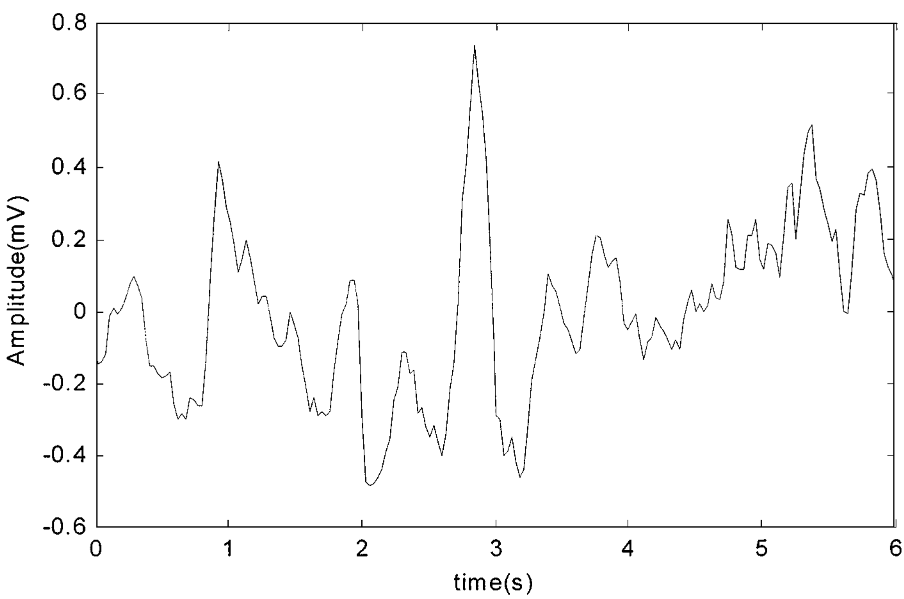

Fig. 1. Pathological EEG waveform.

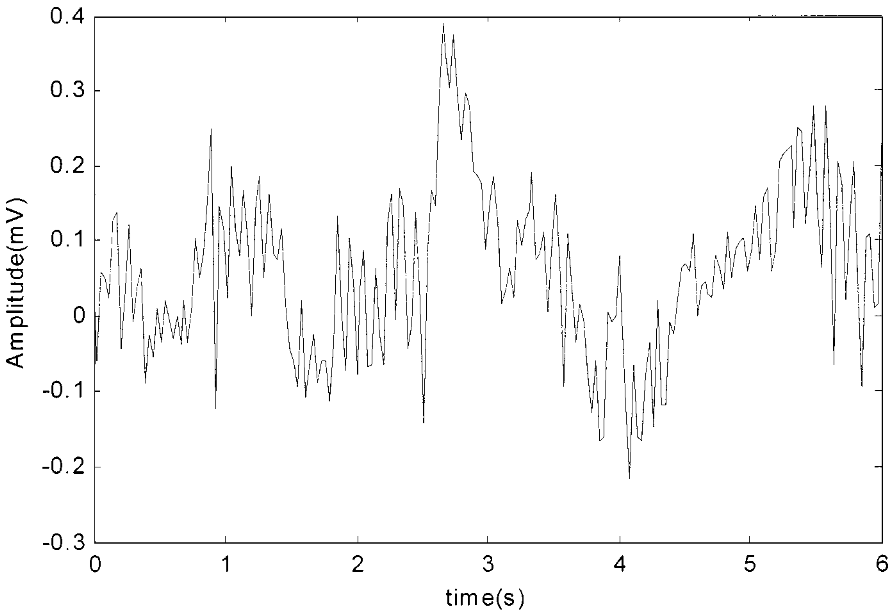

Fig. 2. Healthy EEG waveform.

Signal Analysis Methods

The basic approach to signal analysis is to get proper information from the signal by applying the best suitable method. The conditions of reversibility of the applied method and representing the original signal by the converted form should be satisfied one by one.[(6)] The methods used in this study are Fourier and wavelet transforms.

Fourier Transform

Spectral analysis of a signal involves decomposition of the signal into its frequency (sinusoidal) components. In other words, the original signal can be separated into its subspectral components by using spectral analysis methods.[(7)]

Among spectral analysis techniques, Fourier transform is considered to be the best transformation between time and frequency domains because of it being time-shift invariant. The Fourier transform pairs are expressed as[(6)]

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{kn} \tag{1}$$

$$x(n) = \frac{1}{N} \sum_{k=0}^{N-1} X(k) W_N^{-kn} \tag{2}$$

where $W_N = e^{-j(2\pi/N)}$ and $N =$ length $[x(n)]$.

The Fourier transforms of the EEG signals shown in Figs. 1 and 2 are displayed as Figs. 3 and 4.

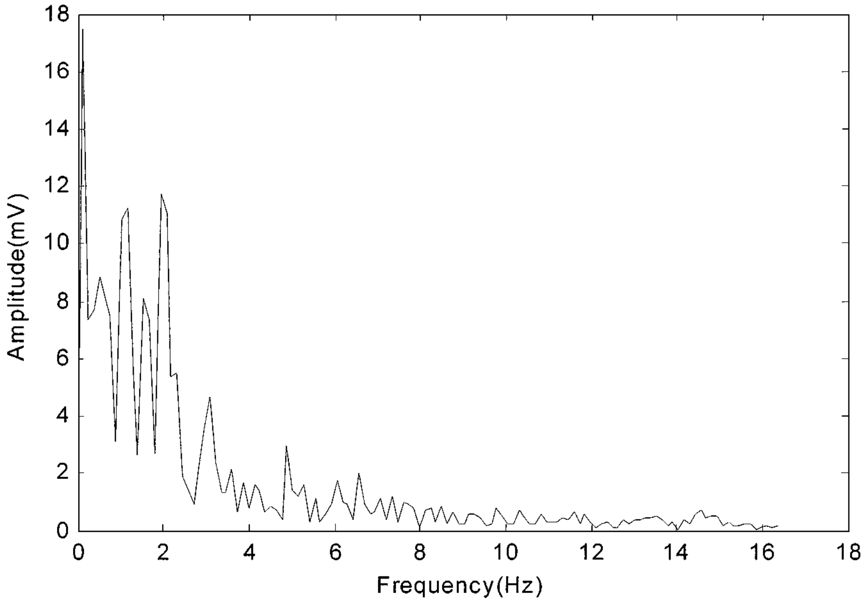

Fig. 3. Spectrum of the pathological waveform.

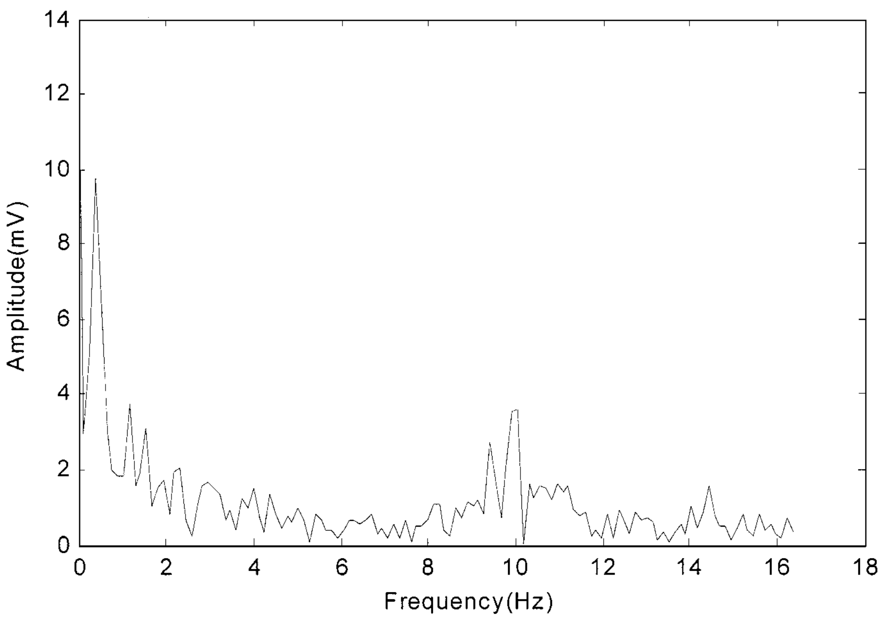

Fig. 4. Spectrum of the normal EEG signal.

In Fig. 3 it can be observed that there are several peaks which have abnormal amplitudes in the δ and θ frequency bands. These peaks may indicate a pathological case such as epilepsy, tumors, and traumas.

In these two figures, the difference of the dominant frequencies can easily be seen. This means that by using Fourier transform, the frequency components that the signal includes can be estimated.

Wavelet Transform

Wavelet transform decomposes a signal onto a set of basis functions called wavelets. These are obtained from a single prototype wavelet, called mother wavelet, by dilatations and contractions, as well as by shifts.(8)

The first recorded mention of the term "wavelet" was in 1909, in a thesis by Alfred Haar. The concept of wavelets in its present theoretical form was first proposed by Jean Morlet and the team at the Marseille Theoretical Physics Center, working under Alex Grossmann in France. The methods of wavelet analysis have been developed mainly by Y. Meyer and his colleagues, who have ensured the methods' dissemination. The main algorithm dates back to the work of Stephane Mallat in 1988. Since then, research on wavelets has become international. Such research is particularly active in the United States, where it is spearheaded by the work of scientists such as Ingrid Daubechies, Ronald Coifman, and Victor Wickerhauser.(9)

On the basis of the input signal $x(t)$, WT may be continuous WT (CWT) or discrete WT (DWT). The CWT is expressed as

$$\text{CWT}\ (a, b) = \int x(t)\Psi^*_{a,b}(t)dt \tag{3}$$

where * denotes the complex conjugate, $a \in R^+$ represents the scale parameter, and $b \in R^+$ represents the translation. The function $\Psi_{a,b}(t)$ is obtained by scaling the prototype wavelet $\Psi(t)$ at time a and scale b, and is defined as

$$\Psi_{a,b}(t) = \frac{1}{\sqrt{a}}\Psi\left(\frac{t-b}{a}\right). \tag{4}$$

Generally in wavelet applications, orthogonal dyadic functions are chosen as the mother wavelet. This transform is often discretized in a and b on a dyadic grid, with the time remaining continuous. The commonly used mother wavelet is defined as

$$\Psi_{j,k}(t) = 2^{-j/2}\Psi(2^{-j}t - k) \tag{5}$$

where $\{\Psi_{j,k}(t),\ j, k \in Z\}$ is for $L^2\ (R)$.

Wavelet transforms of the EEG signals in Figs. 1and 2 are shown in Figs. 5 and 6.

In these figures EEG signal is separated into its δ, θ, α, and β bands by using WT. Observing these figures, it can be easily seen that the amplitudes of signals in the δ and θ ranges of Fig. 5 is greater than those of Fig. 6. Thus in Fig. 5 the amplitude values of the δ subspectral component are significantly high. This means that an abnormality occurs in this section of the EEG signal.

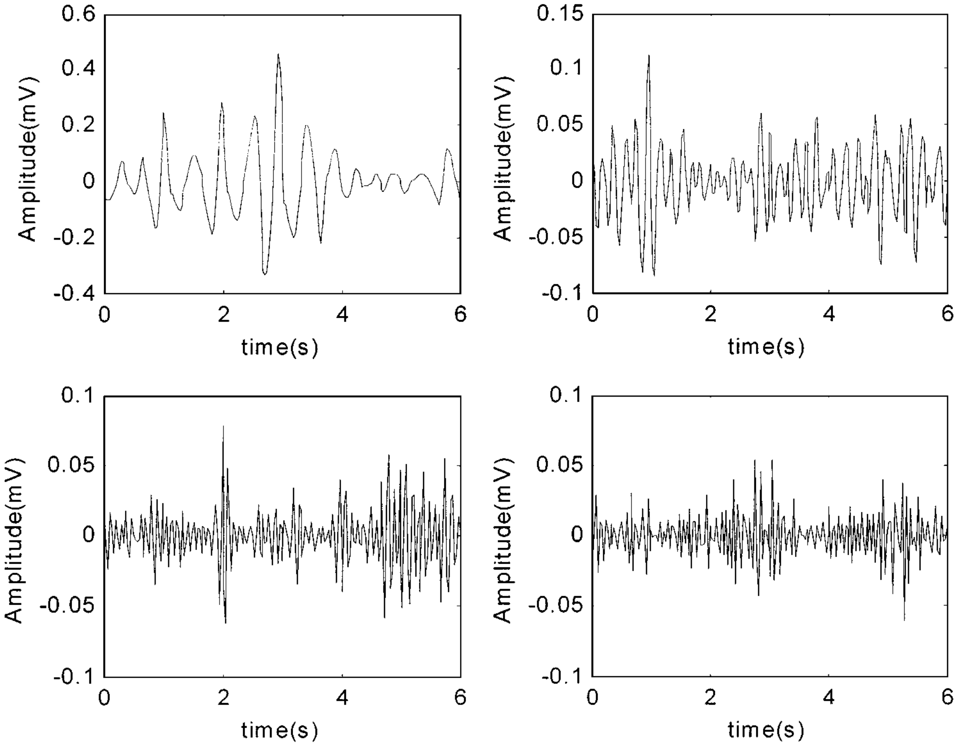

Fig. 5. Wavelet transform of the pathological EEG signal.

Also by using WT, one can view the shapes of the subspectral components of the EEG signal in time domain to be different from those in Fourier transform.

RESULTS AND CONCLUSIONS

This study is aimed at the comparison of the FFT and WT. Therefore, a better-suited method for the analysis of EEG signals is investigated.

The fact is that EEG signals are nonstationary, and by the use of the Fourier transform, small changes may not be realized and the analysis my change depending on the length of data. So, for spectral analysis, it can be said that WT is more suitable than Fourier transform. The reason of this success depends on the scaling and the shifting properties of the mother wavelet.

Another advantage of the wavelet transform is 3D representation of signals as amplitude, frequency, and time. The 3D representation is more convenient for pathological cases, as the epileptic discharges using WT subspectral components can also be represented as shown in Figs. 5 and 6.

In addition to these above expressions we can say that WT is a newer technique, and also that WT has been developed depending on the short-time Fourier transform. Namely, WT uses the FFT by adding the time-domain viewment.

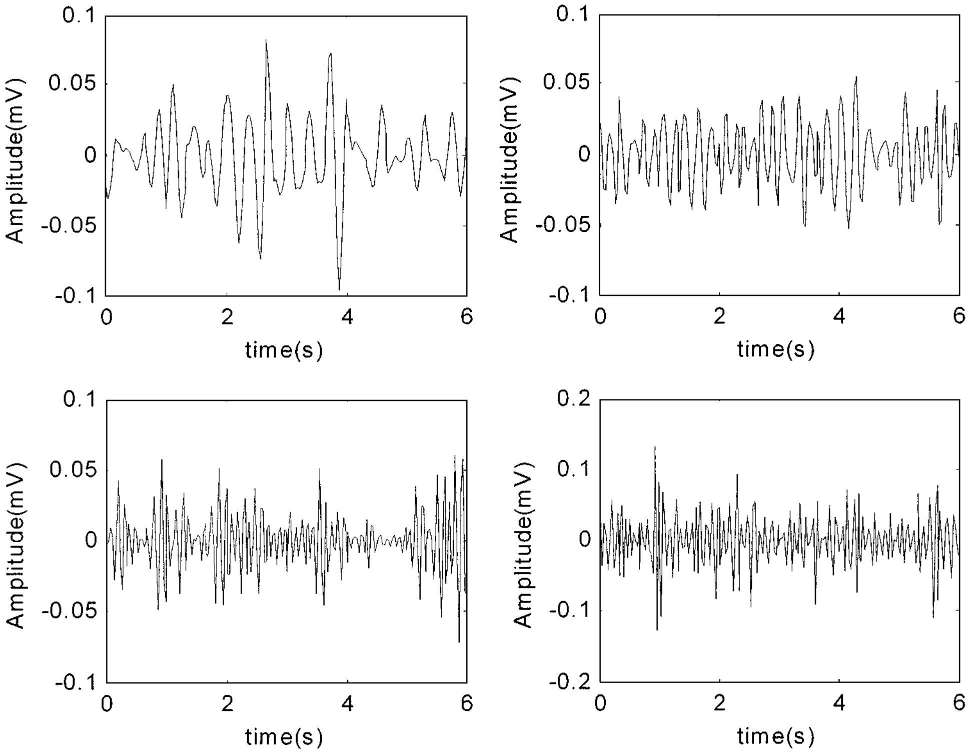

Fig. 6. Wavelet transform of the normal EEG signal.

As a result, one can say that in the spectral analysis, WT is much more efficient than the FFT.

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