Memoirs of Fukui University of Technology,Vol. 32, Part1, 2002

Measurement and Wavelet Analysis of Normal EEG Spectra

Chiri Yamaguchi *

Electroencephalogram (EEG) signals from human scalp were measured using a four-channel measuring system. The measured signals were analyzed by Fourier analysis and Continuous Wavelet Transform (CWT) as well as Discrete Wavelet Decomposition (DWD) analysis. No waves except alpha rhythms were identifiable in the power spectrum densities obtained by Fourier analysis. In contrast, the low-frequency as well as high-frequency components in the EEG spectra were clearly decomposed by CWT and DWD analysis. The results demonstrated that wavelet analysis is well applicable for the time-frequency analysis of EEG spectra.

1. Introduction

Electroencephalogram (EEG) is a record of a time series of evoked potentials caused by systematic neural activities in a brain. Each signal of a typical EEG has either positive or negative amplitude of several tens of micro-volts (μV) around a reference electrode. Generally, frequencies of EEG signals range from 0.5Hz to 40Hz, and the signals are classified into four frequency bands, namely delta (δ), theta (θ), alpha (α) and beta (β). The presence of alpha waves in adults gives a basis to the judgment of normal EEG. The signals (δ and θ) whose frequencies are lower than the alpha are called the "slow-waves", and the β-signals are called the "fast-wave". Individual EEG shows quite different forms in their amplitudes, frequencies and shapes among subjects depending on their ages, especially among children, as well as their physical conditions. Even among normal EEGs large differences are recognized according to subjects' various physical conditions such as awake or asleep, eyes open or closed, excited or relaxed, medications, and so on. While normal EEGs show large diversities, abnormal EEGs show less difference among ages. Even a weak presence of clear slow-waves (> 30μV) suggests an abnormality or a border between normal and abnormal. It is considered that the lower the frequencies of the slow-waves, the lower the brain functions, and that the higher the amplitude, the stronger abnormality. Epileptic abnormalities are characterized by the presence of spikes, sharp waves, spikes and wave complexes, and sharp and slow wave complexes, making their features either diffused or

* Department of Management Science

localized.

Fourier analysis is an established technique for signal analysis, and it is used in all areas of science and technology. In Fourier analysis, the signal spectrum is decomposed into sinusoidal waves, i.e. it aims to discover periodic features in the spectrum. But in most of the biomedical applications, interests are in the localized complex phenomena superposed on the periodic signals as well as on the background noise. Since early nineties, a technique called "wavelet analysis" has drawn much attention, and its applications are vastly expanding in various fields. While Fourier analysis is not well suited for analysis of localized phenomena, wavelet analysis has shown its strong ability in the analysis of non-periodic phenomena.

The present author has applied wavelet analysis technique for normal and epileptic EEG [1,2] as well as electrocardiogram (ECG) [3]. In the previous papers, we analyzed human data provided either by a database (MIT-BIH) [4] or other workers. In the present paper, EEG signals have been measured with a four-channel EEG measuring system, and the signals have been analyzed with wavelet analysis as well as Fourier analysis.

2. Measuring EEG signals

2.1 Measuring system

Measuring system consists of four sets of electrodes, a signal input box, four amplifiers (NIHON KODEN, AB-621G), an analog-to-digital converter (ADC) (TEAC, PS-2032GP), and a notebook computer (DELL, Inspiron 3200, 266MHz). The computer was equipped with 144MB RAM and 6GB HDD, and ran on Windows 98. Measurements were done in a room surrounded by iron panels from ceiling to floor, and the amplifiers were grounded to a metal doorknob of an iron-panel door. Each set of electrodes consists of three Ag-plate electrodes, i.e. positive, negative, and a common-base.

2.2 EEG measurements

Two young (age 22 and 25) healthy male subjects who had been well informed about the experiment participated in the measurements. Scalp EEG signals were recorded from Fp1, F3, P3 and O1 through negative electrodes according to the international 10-20 system, while positive electrodes were attached to the right earlobe and the common-base to the center of the forehead (frontal). Measurements were repeated under several circumstances; Case-1: while listening to subject's favorite CD (compact disc) music through a headphone with relaxed and eyes closed; Case-2: while listening to subject's favorite music with eyes open; Case-3: while listening with eyes closed to a sound CD which was catch phrased that it would effectively produce α -waves; Case-4: while listening to the same CD with eyes open; Case-5: while reading a computer textbook; Case-6: while looking at a photograph of a beautiful young female TV talent in bathing outfit.

In each case measurement was carried out for sixty seconds with a sampling frequency of 200Hz. When a start signal was sent to the ADC, it started recording EEG signals for a preset time. The time constant of the amplifiers was set to 0.3 μ s. High cut filter for each channel was set at 100Hz, and hum eliminator was on. The recorded data were taken into the computer in a special format (TEAC TAFFmat). The data were then off-line converted into ASCII code for further analysis with Mathematica v.4 (Wolfram Research) and MATLAB 6.1 (MathWorks Inc).

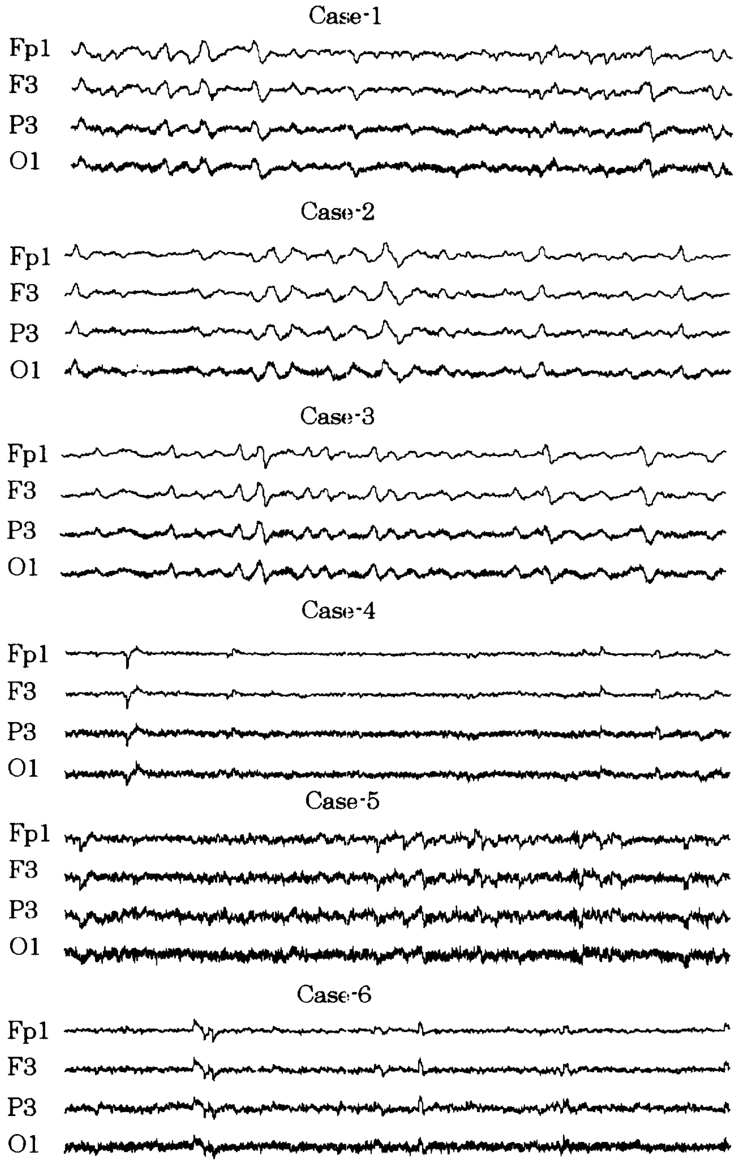

Fig. 1. EEG spectra from Fp1, F3, P3, and O1 leads measured under various circumstances (Case-1, -2, -3, -4).

3. Data analysis

3.1 Measured spectra

Fig. 1 shows measured spectra for one of the subjects. The case numbers correspond to the measuring circumstances above mentioned, and four sets of signals for each case correspond to channel-1, -2, -3, and channel-4, or Fp1, F3, P3 and O1 leads, respectively. Localized large-amplitude low-frequency irregular peaks superposed on basic EEG signals are conceivable to be caused by eye movement or blinking in the case where eyes were open. Four spectra in each case are similar, but the spectra from P3 and O1 leads appear somewhat thicker. The spectra for Case-5 (reading a book without music) are most pronounced compared to those for other cases.

3.2 Fourier analysis

Fourier analysis of the measured spectra was performed. Fig. 2 shows power spectrum densities from Fp1 and O1 leads for Case-1. Power spectrum density is expressed as the square of the absolute values of Fourier transform. Alpha rhythms are revealed clearly for O1 lead, but not for Fp1.

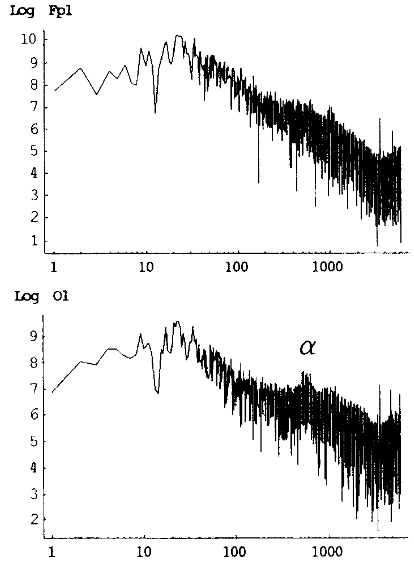

Fig.2. Power spectrum densities from Fp1 and O1 leads for Case 1.

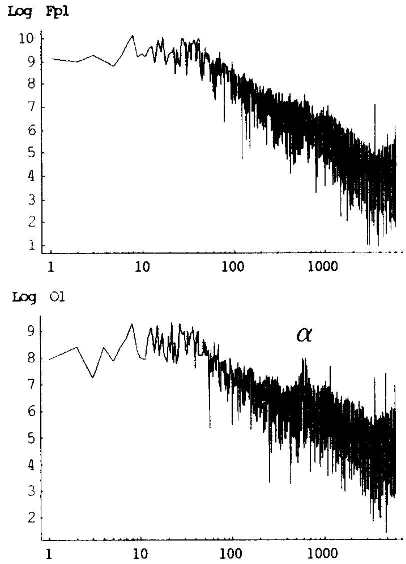

Fig. 3. Power spectrum densities from Fp1 and O1 leads for Case-2.

Fig. 3 shows similar spectra for Fp1 and O1 for Case-2. In this case, the subjects were asked to listen to their favorite music during EEG measurements. The alpha rhythms are revealed more clearly for O1 lead, but no alpha rhythms are discernible for Fp1. The result confirm the fact that alpha waves are pronouncedly produced in the occipital region.

Fig. 4 shows power spectrum densities from O1 lead for Case-3. In this case, EEG measurements were done while the subjects were listening to the so-called α-waves producing CD. No pronounced differences are seen between Case-2 and Case-3, or alpha rhythms are produced equally either by the subject's favorite music CD or by the α-waves producing CD. In Case-4, -5, and -6, no alpha rhythms were observed from any leads. No other waves than alpha waves were identifiable in any power spectrum densities.

3.3 Continuous wavelet analysis

Many textbooks as well as review papers on wavelet analysis have been published [5-10]. The continuous wavelet transform (CWT) of an analog signal $f(t)$ with analyzing wavelet $\psi(t)$ is given by

$$(W_\psi f)(b,a) = |a|^{-\frac{1}{2}} \int_{-\infty}^{\infty} f(t)\overline{\psi\left(\frac{t-b}{a}\right)}dt \qquad (1)$$

Function $\psi((t-b)/a)$ is obtained by scale factor a and translation b of the wavelet $\psi(t)$. The result of the CWT is many wavelet coefficients

$$C_{j,k} = (W_{\psi} f)\left(\frac{k}{2^j}, \frac{1}{2^j}\right), \qquad (2)$$

where $b = k/2^j$ and $a = 2^{-j}$.

Wavelet analysis was done using MATLAB 6. Fig. 5 shows a typical example of a plot of the continuous wavelet transform coefficients for O1 (Case-2). The measured EEG spectrum is also shown together at the top of the figure. Scale levels (ordinate axis) were incrementally changed from 2 (higher frequency) to 128 (lower frequency) in step 2. The abscissa shows sample numbers, or time. Daubechies wavelet with order 4 (db4) was used as mother wavelet, or analyzing wavelet.

3.4 Discrete wavelet analysis

In EEG signals, the low-frequency content is the most important part. Fig. 6 explains the multilevel wavelet decomposition process. The original signals (S) are first decompose into the approximation part (A1), or the high-scale, Slow-frequency component, and the detail part (D1), or the low-scale, high-frequency component, i.e. S = A1 + D1. In second step, the approximation A1 is decomposed into further approximation part (A2) and the detail part (D2), or S = A1 + D1 = A2 + D2 + D1. This process is iterated until the specified decomposition level is reached.

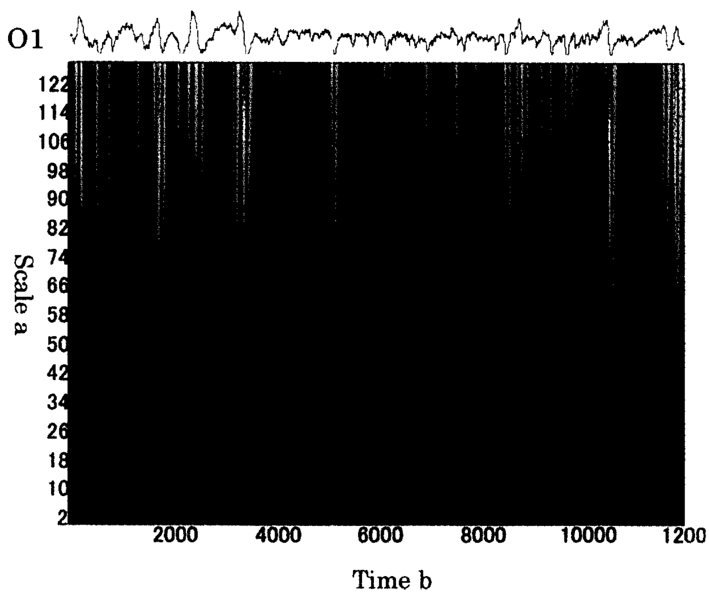

Fig. 5. Absolute values of Ca,b coefficents for scale a=2, 4, 6,..., 128 by continuous wavelet analysis with Daubechies wavelet with order 4 for O1 lead (Case-2).

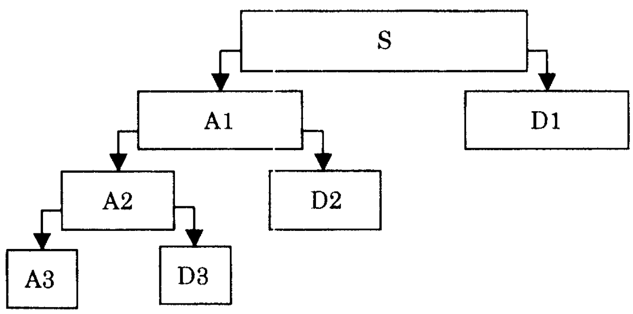

Fig. 6. Multilevel wavelet decomposition process.

As an example of the discrete wavelet analysis, Fig. 7 shows the decomposition at level 6 for EEG spectrum from O1 (Case-2). The signal frequencies are decomposed into 200~100 (D1), 100~50 (D2), 50~25 (D3), 25~13 (D4), 13~6 (D5), 6~3 Hz (D6), and less than 6 Hz (A6) components. Approximation A6 depicts the low-frequency component (due to the eye movement) clearly with high-frequency components

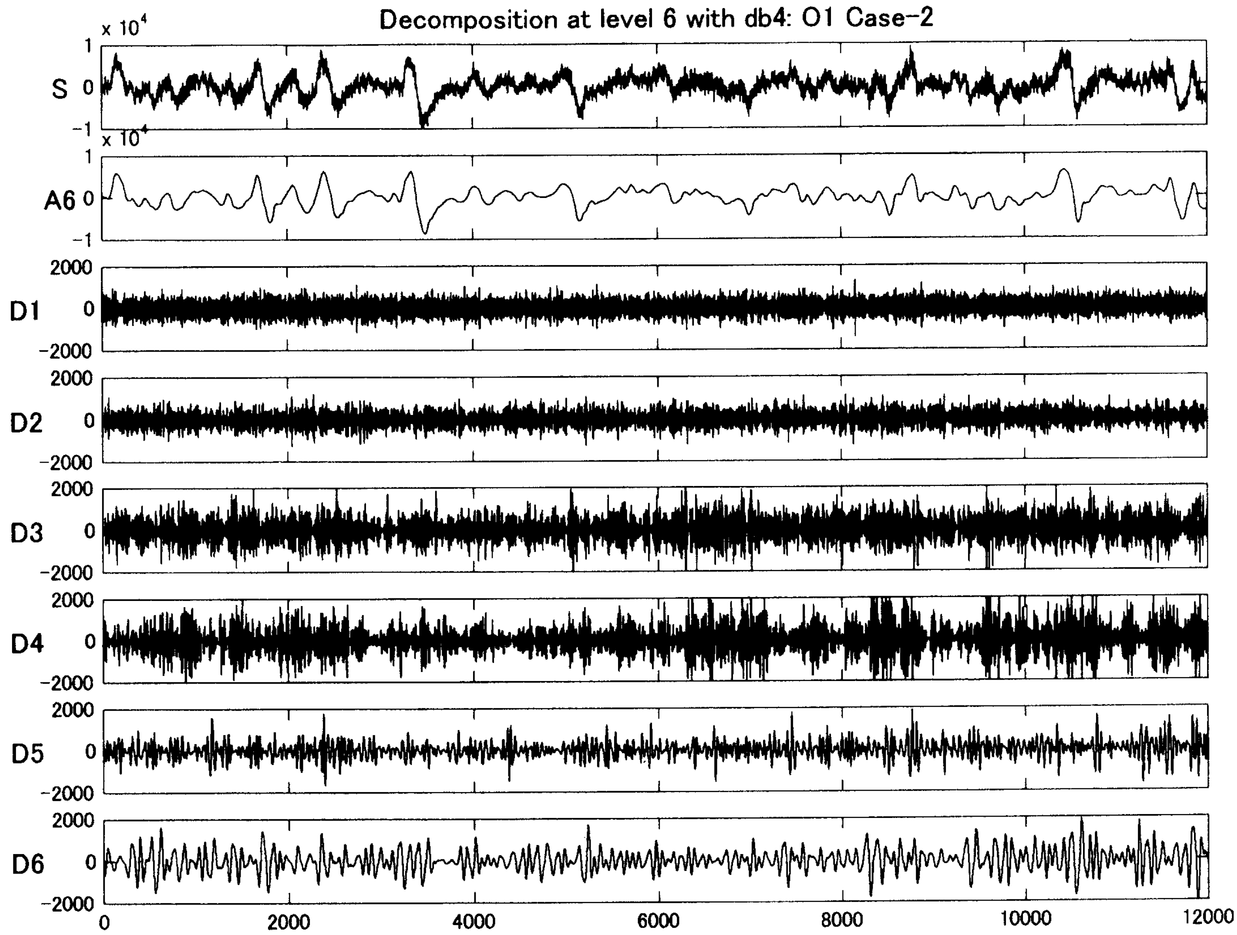

Fig.7. Discrete wavelet decomposition at level 6 for O1 (Case-2).

well "denoised. Alpha waves whose frequencies are 8～13 Hz by definition are represented by D5. Fig.8 shows the same decomposition for the spectrum from Fp1 (Case-4) lead. Fig. 8 shows the similar spectrum from Fp1 (Case-4). High-frequency component (D1) from Fp1 (Case-4) is smaller than that from O1 (Case-2), while the low-frequency component (D5) from Fp1 is larger than that from O1.

Conclusion

EEG spectra from human scalp were measured with 4-channel measuring system, and they were analyzed by Fourier analysis and wavelet analysis. It was confirmed that alpha waves are pronouncedly produced in the occipital region. Alpha rhythm appearance was slightly pronounced when the subjects were relaxed with their eyes closed and they were listening to their favorite music. No waves except alpha rhythms were identifiable in the power spectrum densities obtained by Fourier analysis. On the contrary, the low-frequency as well as

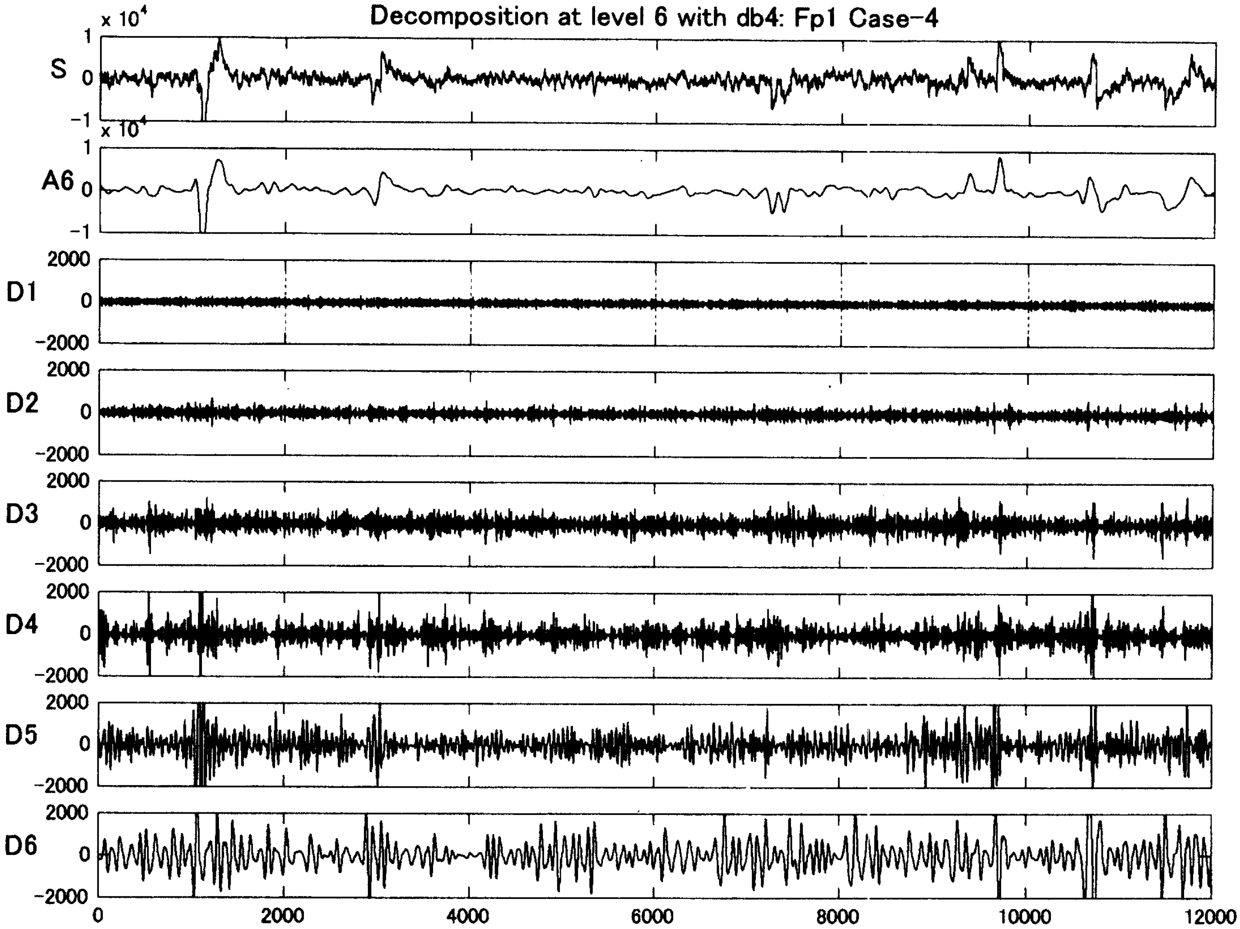

Fig.8. Discrete wavelet decomposition at level 6 for Fp1 (Case-4).

high-frequency components in the EEG spectra were clearly decomposed with wavelet analysis, either by continuous and discrete analysis. The results demonstrated that wavelet analysis is well applicable for the time-frequency analysis of EEG spectra. The so-called α-waves producing CD actually produced alpha rhythms, but not more than subjects' favorite music did.

References:

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(Received December 6, 2001)