EEG Real-Time Feedback Based on STFT and Coherence Analysis

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Abstract: A method and system of real-time feedback and analyzing Electroencephalogram (EEG) using short-time Fourier transform (STFT) and coherence analysis is presented in this paper. The system composition of hardware and software are described. By the utilization of this method and system, the EEG's real-time time-frequency distribution (TFD) is obtained, and the EEG temporal spectral 3-dimention array is displayed on computer's screen for EEG real-time feedback. The time-frequency analysis (TFA) such as Wigner-Ville distribution (WVT) and wavelet transform (WT), has been successfully applied in some biomedical signals to detect both temporal and spectral features of biomedical signals. But real-time realization of TFA is difficult since the computation complication of WVT and WT. By using the STFT algorithm, we develop a system for the EEG feedback and TFA in real-time. This system may be used for EEG biofeedback, and possesses the value of clinical practice.

Key words: Electroencephalograph (EEG), EEG Biofeedback, Time-frequency analysis (TFA), Short Time Fourier Transform (STFT)

1. INTRODUCTION

Biofeedback is a training technique in which people are taught to alter brain activity, blood pressure, muscle tension, heart rate and other bodily functions that are not normally controlled voluntarily, and to improve their health and performance by using signals from their own bodies.

EEG biofeedback involves helping a person learn how to modify his or her brainwave activity to improve attention, reduce impulsivity, and to control hyperactive behaviors. It is a painless, non-invasive treatment approach that allows the individual to gain information about his or her brainwave activity through the use of computerized biofeedback equipment and use that information to produce changes in brainwave activity. EEG Biofeedback is an effective treatment for headaches, attention deficit hyperactive disorder (ADD/ADHD), epilepsy, sleep onset disorders and insomnia. More than 700 groups worldwide are using EEG biofeedback (neurofeedback) for treatment of ADD/ADHD.

Biomedical signals, such as electrocardiogram (ECG), electroencephalogram (EEG), event-related potentials (ERP), electromyogram (EMG), etc., are fundamental observations for analyzing body functions and for diagnosing diseases, and are useful for both physiological research and medical applications. Information provided by those signals are generally time-varying, nonstationary, sometimes transient, and usually corrupted by noise.

Time-frequency analysis (TFA) has been successfully applied in some biomedical signals. The main transforms of Cohen's class allow signal representation simultaneously in time and frequency domain. There are various methods to transform signals into Time-frequency distributions (TFD). Recent research in Time-frequency analysis have concentrated on Short-time Fourier transform (STFT), Wigner-Ville distribution (WVD), Exponential distribution (ED), Discrete Gabor spectrogram (DGS), Wavelet transform (WT), and Wavelet networks (WN). Cross-term interference occurred when using the WVD algorithm. This interference seriously disrupted the measurement of such biosignals, despite the fact that the WVD algorithm showed better time resolution. Choi and Williams introduced a distribution called the exponential distribution, in which cross terms can be controlled by a single parameter.

Wavelet transform has better resolution comparing

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Abstract

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to short-time Fourier transform and has not the cross-term interference comparing to the Wigner-Ville distribution. It has better features in time -frequency domain. Wavelet networks, a combination of wavelet transform and artificial neural networks, represent signals as linear wavelet nodes which characterized by time-frequency features related to the wavelet transform.

But real-time realization of TFA is difficult since the computation complication of WVT and WT. By using the STFT algorithm, we develop a system for the EEG TFA and feedback in real-time. This system may be used for EEG biofeedback, and possesses the value of clinical practice.

2. MATHEMATICAL METHODS

Short-time Fourier transform (STFT) is one of the Time-frequency analyses. The STFT transform of one channel EEG signals h(n),(n=0,1,...,N-1), is given by

$$H(k) = \sum_{n=0}^{N-1} w(n)h(n)e^{-2\pi nk/N}$$

Where w(n) is Kaiser Window.

The alpha index (the EEG alpha rhythm relative density) is defined by

$$I_\theta = P_\theta / P_{EEG}$$
$$I_\alpha = P_\alpha / P_{EEG}$$
$$I_\beta = P_\beta / P_{EEG}$$

here P_α and P_{EEG} are the EEG alpha rhythm power and total power respectively.

For the computation of coherence spectra, consider two channels of EEG data, x(n) and y(n), (n=0,1,...N-1). By STFT analysis, one obtains:

$$X(k)=A_x(k)+jB_x(k)$$
$$Y(k)=A_y(k)+jB_y(k)$$

From these amplitudes A(k) and B(k), the cross-spectra C and Q are determined from the relations

$$C_{xy}(k)=A_x(k)A_y(k)+B_x(k)B_y(k)$$
$$Q_{xy}(k)=B_x(k)A_y(k)-B_y(k)A_x(k)$$

To improve the statistical properties of these cross-spectral estimates, it is in general necessary to smooth them in some appropriate fashion. Denoting this smoothing process by boldface type, the coherence function at frequency kf/N, is defined by

$$\gamma_{xy}^2(k) = \frac{C_{xy}^2(k)+Q_{xy}^2(k)}{C_{xx}(k)C_{yy}(k)}$$

We may also define a total coherence function for the band [k1,k2] by

$$\Gamma_{xy}^2(k1,k2) = \frac{\sum_{k=k1}^{k2}[C_{xy}^2(k)+Q_{xy}^2(k)]}{\sum_{k=k1}^{k2}[C_{xx}(k)C_{yy}(k)]}$$

In order to draw COSPAR on a printer, the coherence function should be dealt with as following

$$\bar{\gamma}_{xy}(k) = \begin{cases} \gamma_{xy}(k)-h, & \gamma_{xy}(k) > h \\ 0, & \gamma_{xy}(k) < h \end{cases}$$

Here h is the threshold volume.

We define the EEG dominant frequency f_{max} and alpha index I_α as two EEG feedback object functions and they are

$$I_\alpha = I_\alpha(F3)+I_\alpha(F4)+ \Upsilon_{F3\,F4}(k1,k2)$$

Where $I_\alpha(F3)$ and $I_\alpha(F4)$ are alpha index of EEG's lead from F3 and F4 areas, is the alpha band coherence between F3 and F4.

$$f_{max}=f_{max}(F3)+f_{max}(F4)$$

Where $f_{max}(F3)$ is the dominant frequency of F3 and $f_{max}(F4)$ the dominant frequency of F4. In the feedback strategy, two criteria are used. The first is to increase the index I_α, and the second is to decrease the index f_{max}.

The automatic artifact rejection is the key aspect for the EEG closed-loop feedback control and it determines the robust and stability of the feedback system. By comparing the f_{max} with the baseline volume, the system decides whether the artifacts are serious and automatic rejection should be carried out.

3. SYSTEM CONFIGURATION

The EEG real-time feedback system consists of EEG amplifier , EEG pre-processor, A-D converter, IBM PC/AT microcomputer, earphone, Printer, CRT. Printer and CRT are used to output EEG feedback control results. EEG preprocessor is a notch filter inserted at 50Hz.
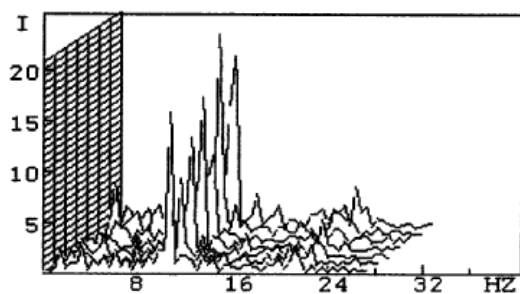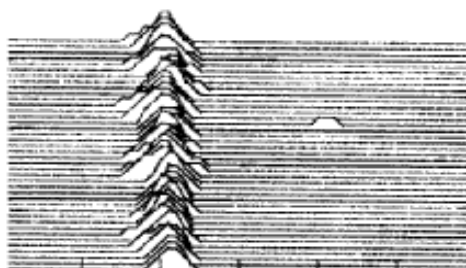
Fig1. The real-time EEG spectral array

Fig2. The EEG COSPAR (h=0.8)

System software consists of 3 parts that are initiation, EEG signal acquisition and analysis, result output. Firstly, and the Kaiser window w(n) is calculated. Then, the EEG signals are digitized on-line to 12 bits at 64 samples per channel in a A-D converter (PC-1232) connected to a IBM PC/AT microcomputer. Simultaneously with the data acquisition, eight channels of EEG are processed by adding Kaiser window, and short-time Fourier transform. By use of EEG power spectrum, EEG alpha rhythm relative power (alpha index), EEG main frequency, and total coherence in alpha band are calculated, the EEG temporal spectral 3-dimention array is displayed on computer's screen for EEG real-time feedback (Fig1). On the other hand, according to those EEG indexes, the computer will determined the strategy of feedback, and control the earphone to send out the auditory signals for EEG feedback.

. Finally, the system outputs the EEG index dynamic curve and the EEG coherence spectral array (COSPAR) (Fig2) on the printer and CRT.

4. RESULTS

Subjects were trained with the EEG feedback system. They were seated in a comfortable chair within a sound-controlled room. With eye slight closing, subjects concentrated on the warning sound from the earphone, and tried to decrease the appearance of the sound by subjective effort. Records, with linked ears for reference electrode, were taken from electrodes F3/F4 of the 10-20 system. The ground was to Fz.

In the early days of training, subjects were not able to effectively regulate themselves EEG's activity due to lack of experience. After several sessions of training, they gradually mastered the ability to control EEG's activity.

The experimental results of EEG feedback training suggested that EEG's activity was able to be effectively regulated after several sessions of training, and the effect of TM practice was received by the utilization of the EEG feedback system.

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