Frequency Analysis Based on the Pruned Generalized Sliding FFT for the Real-Time EEG-BCI System

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Abstract

To enhancement the efficiency of BCI systems, the computational redundancy in the conventional time-frequency domain conversion should be minimized. To cope with this problem, we introduce the pruned generalized sliding FFT (PGSFFT) which is combined version of the generalized sliding FFT and the pruned FFT. Experimental results show that the proposed method has the same result as the conventional method based on the short-time Fourier transform (STFT) only with about 52% lower computational complexity.

Keywords: EEG, BCI, real time, PGSFFT

1. Introduction

BCI is a technology to connect human brain with a computer by acquiring and analyzing the brainwave. Recently BCI systems have been studied for a variety of purposes such as games for improving of concentration as well as medical applications. This produces great advances in the relevant research and technology. The key point of the EEG-based BCI system is how to generate the reliable control signals through the feature detection and analysis from the raw EEG signals in the frequency domain. However, the STFT calculates the full-band spectrum, whereas the required information is only included in the specific sub-band of the EEG signals. Therefore, a more efficient frequency analysis method is needed to minimize the computational complexity.

In this paper, we propose a new frequency analysis method applying the PGSFFT in EEG-based BCI systems. Since the PGSFFT is the combination of the generalized sliding FFT and the pruned FFT, the proposed method achieves their advantages simultaneously when the only specific sub-band spectrum of the continuous input EEG signals is required. The rest of this paper is organized as follows. The overall procedure of EEG signal processing in the BCI system is briefly described in Section 2. The proposed frequency analysis method is presented in Section 3. In Section 4, the experimental results are included to show the effectiveness of the proposed method. Finally, in Section 5, we conclude this paper.

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2. Frequency Analysis Procedure of EEG Signal

EEG is the recording methodology of faint electrical signals by placing microelectrodes on the scalp. Fig. 1 describes the overall signal processing procedure of the EEG-based BCI system. The recorded signal is the combined neural activities of a group of neurons and passes through the poor propagation path such as a thick skull. In addition, the other interference signals are added such as EoG (electrooculogram) and EMG (electromyogram) signals produced by the eye movements and skeletal muscles, respectively. Therefore, it is needed to enhance raw EEG signals through appropriate pre-processing procedures such as de-nosing and interference rejection [1]. After the pre-processing procedure, the EEG signals include the purer and more accurate components corresponding to the input stimulus which are the thought and motor imagery of the subject. Since the response of specific input stimulus is represented in the narrow sub-bands, the pre-processing and the feature extraction are performed in frequency domain [2].

There are two phases according to the purpose of recording of EEG signals for a BCI system. The first one is a training phase for setting up the feature parameters as a criterion in the BCI system. To acquire the signals in this phase, the subjects perform repetitively a pre-appointed thought or movement. The BCI system is adjusted for the particular subject. In the second phase, a continuous EEG signal enters the BCI system as an input signal in real-time. The input signal is transformed to the frequency domain to operate the BCI system according to the criterion determined in the first phase.

Table 1: Experimental parameters for the PGSFFT method

Sampling frequency	1 kHz
FFT size	1024
Update period	64
Desired frequency band	About 0~50Hz
Subset length of desired frequency band	50

3. Pruned Generalized Sliding FFT

Since the real-time BCI system extracts the desired information from the narrow sub-band, the particular sub-band of the spectrum should be updated in short time period. To solve this problem, we propose the frequency transform method of real-time EEG signals based on the PGSFFT. The PGSFFT is the combined method of the TD (transform decomposition) and the GSFFT (generalized sliding FFT). The GSFFT is one of the sliding FFT techniques and it enables the sliding FFT to have variable updated sample length. The TD is one of the pruning techniques and it is known to have high computation efficiency, because it is based on the divide-and-conquer approach of the general FFT algorithm. The main idea of the divide-and-conquer approach is that the DFT can be divided into small DFTs and obtained by combining their results [3]. The transformation to frequency domain using the PGSFFT is able to reduce the computational burden by calculating only the wanted sub-band but for the shaded bands with the updated signal components.

4. Experimental Results

In order to compare the computational complexity and the resultant spectrum of the conventional STFT method with those of the proposed PGSFFT, we recorded the EEG signals when the subject performed the eye closing and opening movements. Firstly the subject closed his eyes for 3 seconds, then he opened his eyes and kept opening for 5 seconds. Lastly, the subject closed his eyes. To effectively capture the EEG signals by the eye movements, the EEG signals are measured from O1 area on the scalp. Then, the resultant spectra by the two methods are compared each other. The used EEG signals are recorded using BIOPAC MP150 system. The experimental parameters are listed in Table 1.

To show that two frequency transform methods have the same resultant spectrum in the specific sub-band, we compared their spectra. In [2], the α-rhythm (8–12 Hz) is increased when the subject opens his eyes. Fig. 1 (a) and (b) show the resultant EEG spectra obtained by the conventional STFT and the proposed PGSFFT,

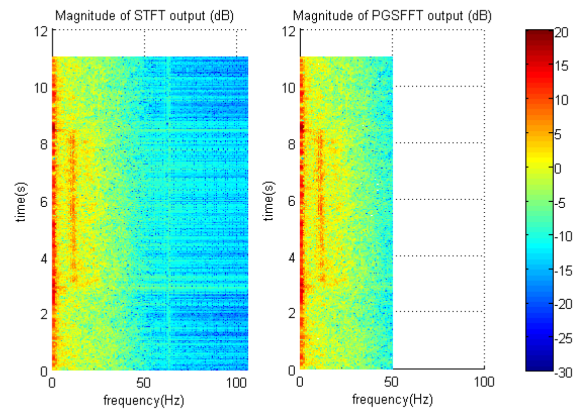

Figure 1. Resultant EEG spectra using the frequency transform methods: (a) STFT (b) PGSFFT

respectively. In both of them, we can find out the activation of the α-rhythm for 3-8 seconds.

However, the spectrum calculated by the PGSFFT is represented only the interested band given in Table 1. Because of this property, the PGSFFT is able to have the lower computational complexity. With the parameters in Table 1, the number of calculations is 51,200 in the case of STFT, and that of PGSFFT is 24,740[3]. Finally, the proposed PGSFFT reduces the number of operations about 52% compared to the conventional STFT.

5. Conclusion

In this paper, the frequency analysis method based on the PGSFFT was proposed to reduce the computational burden in real-time processing of EEG signals. The proposed method calculates only the specific sub-band of interest without the redundant computations of the overlapped part of input signal compared to the previous STFT-based analysis method. Therefore, it is expected that the proposed method can be helpful to implement the real-time BCI systems.

References

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