A Study on SSVEP-Based BCI

Zheng-Hua Wu and De-Zhong Yao

Abstract—Brain-computer interface (BCI) can help the deformity person finish some basic activities. In this paper, we concern some critical aspects of SSVEP based BCI, including stimulator selection, method of SSVEP extracting in a short time, stimulating frequency selection, and signal electrode selection. The conclusion is that the stimulator type should be based on the complexity of the BCI system, the method based on wavelet analysis is more valid than the power spectrum method in extracting the SSVEP in a short period, and the selections of stimulating frequency and electrode are important in designing a BCI system. These contents are meaningful for implementing a real SSVEP-based BCI.

***Index Terms*—Brain-computer interface, electro-encephalogram, steady-state visual evoked potential.**

1. Introduction

When stimulated by a repetitive flicker, some sinusoidal oscillatory waveforms with the frequency same as the stimulus or its harmonics would be observed from the scalp of a person, and these signals are called steady-state visual evoked potential (SSVEP). Although SSVEP has been observed many years before, its mechanism has not been understood yet. A reasonable explanation is that, when the repetitive flicker functions on the retina, there come out the dark-current and the bright-current in the cone cell, and this current would flow through the vision nerve, then it is delivered to the primary vision cortex, which locates at the back scalp. Someone thought that the signal in this area would deeply function with the other area in the scalp or the inner structure in the brain, which was called Cortico-Cortico loops or Thalamo-Cortico loops accordingly[1],[2].

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Although the mechanism of SSVEP is not definite, and there is some difference of its amplitude among subjects, it could be observed stably for anyone with a normal or adjusted-normal vision in a relatively wide frequency range (5 Hz to 60 Hz)[3]. This quality of SSVEP can be used in many researches about cognitive-science, such as brain-computer interface (BCI). From a BCI system, some attempts of a person would be detected from the electric signals measured from him/her, including the electro-encephalogram (EEG), magnetoencephalographic (MEG), etc. In a SSVEP-based BCI system[4],[5], some buttons including different frequency flickers are sited in front of the subject. If the subject wanted to select a button, he/she only needs to stare at the button for a few seconds, then the frequency same as the button flicker in the EEG would be enhanced. From detecting this frequency, we can know the button the subject wants to select.

In this paper, we considered some critical aspects involved in designing an SSVEP-based BCI. First, we used three different type stimulators to evoke SSVEP, and studied the spectrum of the flicker and SSVEP. Second, we designed a new method of extracting SSVEP in a short period, which was based the wavelet analysis, and was proved to be more valid than the traditional method. Last, we studied the stimulating frequency selection and signal electrode section.

2. Stimulator Selection

In a SSVEP-based BCI, the first problem faced is the stimulator type selection. Many types of stimulator can be used for evoking SSVEP, including a cathode ray tube (CRT) monitor, a liquid crystal display (LCD) monitor, or a light-emitting diode (LED) array, etc. Because of the different lighting mechanisms, these stimulators can be used in different complexity BCI system, and this had been reported in one of our researches in detail[6].

First, we had measured the spectrum of the three types of flicker with different frequencies. Fig. 1 shows the situation of 10.8 Hz. In all the situations, the results showed the spectrum of LED flicker was very simple, only including the fundamental frequency and the harmonics. While there were many high frequency components related to the fresh frequency in the CRT spectrum, and low frequency components in the LCD flickers except for the fundamental frequency and harmonics. The fundamental frequency in LED flicker was the biggest one in three of them, while there was not significant difference between the CRT and LCD fundamental frequency.

Second, we used these three types of flicker to evoke SSVEP. The comparison of SSVEPs showed the same difference as the flicker spectrum difference themselves. One situation is shown in Fig. 2.

At last, associating the frequency setting for different type stimulator with the SSVEP amplitude, we discussed the stimulator selection in SSVEP-based BCIs. In a word, the LED stimulator can be used in a complex BCI system, the LCD stimulator can be used in a simple BCI system, and the CRT stimulator can be used in a middle-complexity BCI system.

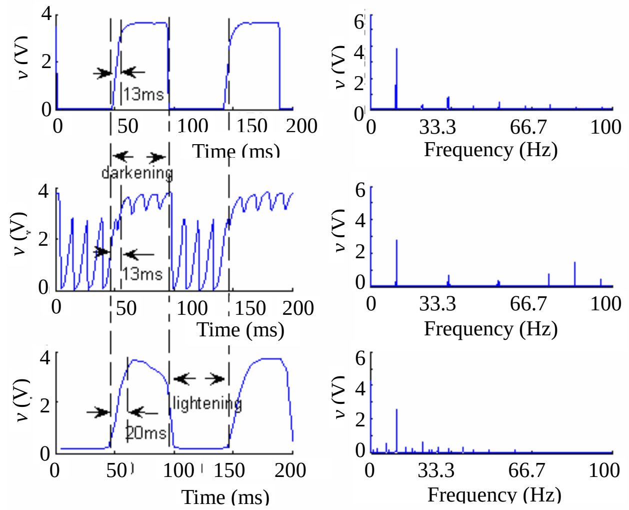

Fig. 1. Signal waveforms and frequency spectra of the flickers. The stimulus frequency was 10.8 Hz. The left column shows the waveform in two cycles of the three flickers, and the right column is the frequency spectrum. The flicker was LED,CRT and LCD for the first, second and third row, respectively.

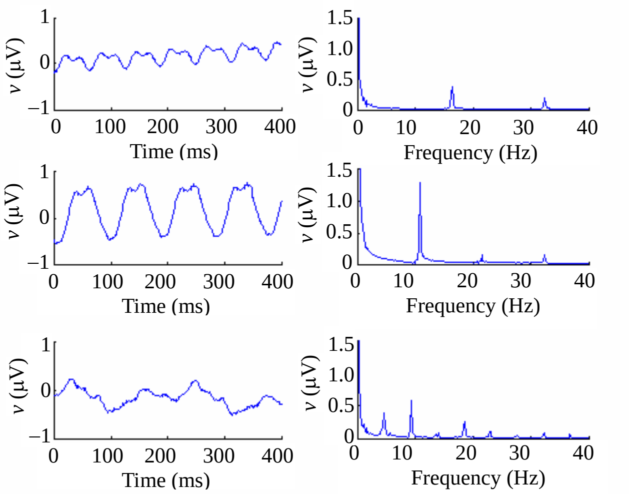

Fig. 2. LED evoked SSVEP in subject KB at electrode 85. The stimulus frequency was 16.1 Hz, 10.8 Hz and 4.6 Hz for the first, second and third row, respectively. The left column is the averaged SSVEP, and the right column is the frequency spectrum.

3. Method of Extracting SSVEP

The second problem in this type BCI is the method to extract the valid frequency in a relatively short time, which is the core problem in this system. The most widely used method is the power spectrum method (PS). In this method, the EEG measured from the scalp within a few seconds is analyzed with the fast Fourier transform (FFT), the power of each frequency used in the BCI system is computed, and then it is compared with the power of the corresponding frequency in EEG or the average power of EEG within a frequency range. If the ratio was bigger than the given value (threshold), then the button stood by this frequency is selected. This ratio may be different for different frequency. As the low frequency SSVEP is notable, the ratio may be big; conversely, as the high frequency SSVEP is weak, the ratio may be small. For example, in a SSVEP-based BCI system with 12 buttons[7], the SSVEP power within about 3 seconds was compared with the average power of EEG between 4 Hz and 35 Hz, the ratio was selected as 2.

For a relatively long time such as more than 3 or 4 seconds, the PS method can make a good detecting result, and the accuracy may be higher than 80%[8]. Although the spontaneous component in EEG with the same frequency as the stimulus may fluctuate in a wide range, if the sample time was long enough, this fluctuating component may be weakened significantly, and the average component is almost decided only by the evoked component. This can conduct a right detection. If the sample time was short, such as 1 second, the influence by the fluctuating component in the spontaneous EEG may be significant, and this could conduct a false detection.

In order to overcome the defect of PS method in a short data analysis, we had reported another method-based stability of SSVEP to discriminate the target, called as stability coefficient (SC) method[9]. In this method, wavelet was first used to discompose the EEG into a serial of frequencies, which included many spontaneous components and evoked component-SSVEP. For the spontaneous components, it is influenced by the potential mental or physical matters all the time, so the amplitude difference between two near sample point may be big, in another word, the stability of these frequencies may be low. While for the extracted compound component, it can be thought to be built by two elements, one is spontaneous and variable, and the other is evoked by the flicker, which is almost a constant. From this definition, the stability of the SSVEP is bigger than the other spontaneous frequencies. Using this property, we can conclude whether the SSVEP has been evoked sufficiently. The SC method had been used to discriminate the short analog BCI data, and a good result was obtained. Table 1 shows the decoding accuracy with the PS and SC method.

Table 1: The decoding accuracy of the analogous BCI data in different length time window for all subjects

Sample length	Sub.	GQ	HYJ	LC	LCO	LY	SJS	WXL	ZP	ZSQ	ZXL	Mean/std.
	Electrode	72	77	60	72	73	85	76	76	67	73	
1s	SC	0.87	0.70	0.66	0.65	0.74	0.78	0.85	0.72	0.75	0.71	0.74/0.07
	PS	0.70	0.61	0.63	0.63	0.60	0.58	0.58	0.61	0.59	0.67	0.62/0.04
2s	SC	0.94	0.64	0.80	0.64	0.76	0.62	0.70	0.66	0.68	0.78	0.72/0.10
	PS	0.74	0.58	0.68	0.68	0.60	0.56	0.58	0.54	0.60	0.64	0.62/0.06
3s	SC	0.94	0.76	0.85	0.73	0.73	0.79	0.73	0.76	0.85	0.85	0.80/0.07
	PS	0.94	0.70	0.85	0.70	0.73	0.73	0.73	0.76	0.70	0.88	0.77/0.09
4s	SC	0.92	0.72	0.76	0.76	0.72	0.76	0.80	0.72	0.72	0.84	0.77/0.07
	PS	0.92	0.76	0.84	0.80	0.80	0.72	0.80	0.76	0.76	0.80	0.80/0.05

There are many other methods to be used to extract the SSVEP too. An adaptive line enhancement model was used to extract the SSVEP in alpha band by Carlos[10]. In Proceedings of the 26th Annual International Conference of the IEEE EMBS, Matching Pursuit with Chirplet Atoms was introduced into the SSVEP discrimination[11]. The coherent analysis has been used to extract the SSVEP in many researches, for example, Mr. Lin had studied the coherent coefficient between the evoked EEG in the occipital area with the stimulating frequency and harmonics, and found if the SSVEP was evoked sufficiently, this coherent coefficient would be bigger than the one in the spontaneous state[12].

In order to make the SSVEP-based BCI into application, it is vital important to extract the SSVEP in a short time. Although many methods about this problem have emerged, it is far away from the last goal. So, some new methods should be studied, such as the method-based the nonlinear system theory[13].

4. Selection of Stimulating Frequency

Another important aspect of SSVEP-based BCI is the selection of stimulating frequency. Normally, the SSVEP can be evoked in a wide frequency range (5 Hz to 60 Hz). In the low frequency band, the SSVEP amplitude is bigger compared with the background components and can be extracted out easily. On the other hand, we had used wavelet to analyze the stability of the SSVEP[9], and found the amplitude variability of low frequency SSVEP was smaller than that of the high frequency one. So, in many BCI experiments, the low frequency was often selected as the stimulating frequency. Fig. 3 shows the time-frequency property of the 8.3 Hz and 20 Hz SSVEP. However, the low frequency flicking is unhappy for the subject. If the staring time was long, the eyes can not stand it. If using the high frequency as the stimulus, the subject would feel well. When the SSVEP amplitude is small, it is difficult to extract it sufficiently. So we should select the stimulating frequency according to the actual state. For example, if there were not many selection buttons, the high frequency can be selected as the stimulus, and other auxiliary method can be used to improve the accuracy of discrimination[8].

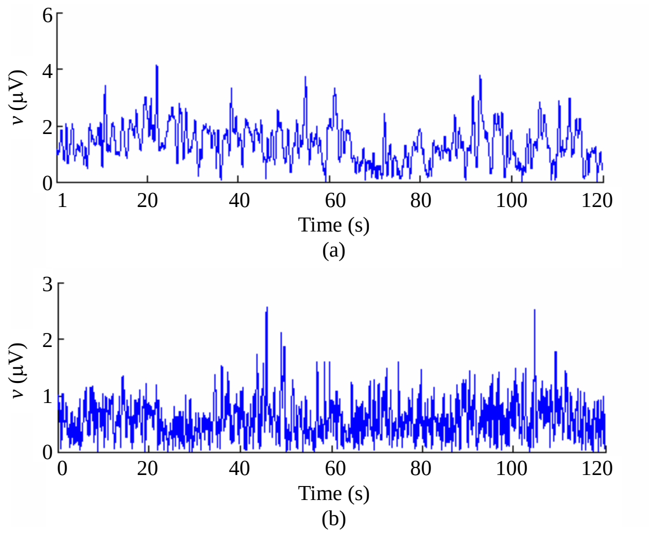

Fig. 3. SSVEP time-frequency property at electrode 60 for subject GQ: (a) the fundamental frequency is 8.3 Hz, and (b) the fundamental frequency is 20 Hz.

5. Selection of Signal Electrode

The signal electrode selection is a notable thing in the SSVEP-based BCI. SSVEP is a response of the vision to a light stimulus, the electric activity focuses at the vision cortex, mainly at the primary vision cortex, which locates at the occipital area. The electrodes in this area were selected as the signal electrode in many cases[14]. In one of our works[9], we compared the amplitude and stability of SSVEP in different cortical areas, and found that the SSVEP amplitude or stability in the occipital area was bigger or higher than that in other areas, as shown in Fig. 4 and Fig. 5.

The unsuccessful aspect of selecting these electrodes is that the contact between the electrode and the scalp is not good enough because of the hair. Along with the time elapsing, the impedance is variable, which would lower the accuracy of the distinction. Some studies had proved that the SSVEP in the forehead area was clear[15], although it may be contaminated by the eyes activity, the method to extract the SSVEP has the immunity to this distraction, the electrode in this area can be selected as the signal electrode too. Another advantage of this selection is that the contact between the electrode and the skin is always good, and does not lower the accuracy of discrimination.

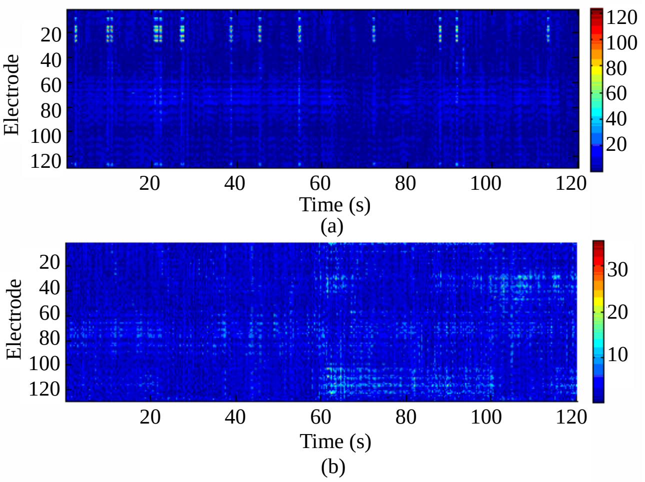

Fig. 4. SSVEP time-frequency property of subject GQ at all electrodes: (a) the fundamental frequency is 8.3 Hz, and (b) the fundamental frequency is 20 Hz.

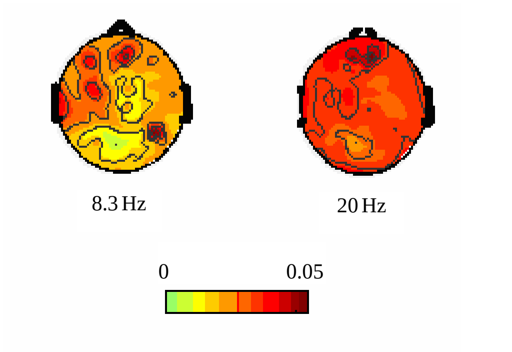

Fig. 5. The distribution of the average SC of the fundamental frequency signal for subject GQ within 2 min.

6. Conclusion

Compared with other type BCI systems[16], the SSVEP-based BCI possesses the property of many choices and relatively high accuracy and transfer rate. In designing this type of BCI, the aspects involved should be taken into consideration systematically. For example, a very complex method may conduct a very good accuracy, but it is time-consuming, which makes the system un-timely. In this situation, we should select a suitable accuracy and speed to make a better system[17].

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