SINGLE TRIAL VEP SOURCE SEPARATION THROUGH SANDWICH SPECTRAL POWER RATIO METHOD

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***Abstract*-In single trial source separation problem of VEP signals, the selection of legitimate Principal Components (PCs) is an important phenomenon. The Spectral Power Ratio (SPR) method developed by us earlier for PCA has proven to be capable of selecting only the required PCs in a sophisticated manner. Our continuous enhancement has lead to the current development of the proposed method, Sandwich SPR (SSPR). The SSPR performs the reconstruction of source signal in an effective way better than the related SPR method. When this technique was applied on artificial Visual Evoked Potential (VEP) signals contaminated with background electroencephalogram (EEG), with a focus on extracting P3 parameters, it was found to be feasible shown by the resulting high values of the Signal to Noise ratio (SNR) as compared to the SPR and 2 tier SPR (SPR2) methods. Subsequently, we applied this method to study the P3 amplitude responses from a set of real EEG from Wadsworth BCI dataset obtained with target and non-target stimuli, and found that the P3 parameters extracted through our proposed SSPR method showed higher P3 responses for the target stimuli than the both SPR and SPR2 methods, which conform to the existing knowledge on P3 responses.**

Keywords: Electroencephalogram, Principal components, P3, Single trial analysis, Visual Evoked Potential.

1. INTRODUCTION

Single trial analysis of Visual Evoked Potential (VEP) signals is a vital research topic, considered as the first step to construct an effective Brain Machine Interface (BMI). Principal Component Analysis (PCA) has been used for this purpose [5], [7], [9], and [11]. It is common to avoid the delay and signal loss in the conventional method of ensemble averaging [3]. Averaging method of solving the electroencephalogram (EEG) contamination in VEP comprises many trials and it might distort the specific information from a single trial.

Undistorted VEP signals are essential in many clinical application and neuropsychological analysis. Particularly, the P3 component of VEP is an important resource to develop BMI. In designing and constructing BMI effectively, we are in a process of developing methods of PCA variants to perform single trial analysis of VEP signals. The proven popular method to select principal components (PCs) for PCA is Spectral Power Ratio (SPR) method [2]. As another recent development in this area, we propose to use SPR in a sandwich model (SSPR) to make this tool more elite.

The purpose of this paper is to propose and describe the efficiency of the SSPR in selecting PCs for the effective reconstruction of the VEP, with two different experiments.

In the first experiment, we set to prove the effectiveness of our proposed method through a simulation study using artificial VEP signals buried in real EEG. Signal to noise ratio (SNR) calculation is used to show the advantage of our proposed method over single SPR and two tier SPR methods in selecting PCs. In the next experiment, we use the SSPR method to analyse single trial P3 amplitude responses for a set of real VEP signals grouped into target and non-target stimuli.

2. METHODS

2.1 VEP simulation by artificial signals

Artificial VEP (AVEP) signals were created using different combinations of Gaussian waveforms, each with different mean, variance and amplitude. These basic waveforms were created using the equation

$$G(n) = (A/sqrt(2\pi\sigma^2))exp(-((n-\mu)^2)/2\sigma^2) \qquad (1)$$

where σ is the standard deviation, μ is the mean, and A is the amplitude. These AVEPs, X were limited to 8 Hz to simulate P3 responses, which are limited to 8 Hz [4, 11]. Sixty-four different artificial signals were created to represent 64 different channels on the scalp.

These signals were mixed with the real EEG signals, which were obtained when the subjects were at rest. These EEG signals were whitened to remove their correlation, before adding to the AVEP signals,

$$W(n)_{AVEP+EEG}=X(n)_{AVEP}+Y(n)_{EEG} \quad (2)$$

The contaminated signal, W was then normalized to zero mean and unit variance.

$$W = (W - mean\ (W))\ /\ Std\ (W) \quad (3)$$

2.2 Principal Component Analysis

We performed PCA method on signal W to extract the AVEP signal from EEG mixture. First, the covariance of the signal W was computed using

$$R = E\ (WW^T) \quad (4)$$

Let F be the orthogonal matrix of eigen vectors of R and D is the diagonal matrix of its eigenvalues $D= diag\ (d_1....d_n)$. Then the PCs could be computed using,

$$Y = F^T\ W^T \quad (5)$$

Some of the PCs will represent the AVEP and some will represent the remaining EEG. The selections of AVEP representing PCs from overall PCs were carried out by three different variants of SPR methods: single (original) SPR, two tier SPR (SPR2) and SSPR. These selected AVEP representing PCs were then used in reconstruction, where the reconstructed signal now contains only AVEP. The reconstruction was carried out by

$$X = FF^T\ YY^T \quad (6)$$

where the FF and YY corresponds to the selected eigenvectors and PCs.

2.3 Selecting the PCs

A. Spectral Power Ratio (SPR)

In this method, only the PCs that contained significant amount of 0-8 Hz spectral powers were selected [2]. This frequency limit could be varied according to the purpose. In this case, since we considered the P3 responses, the limit was chosen to be 8 Hz. After some experimental simulations, we found that the values of 0.25- 0.5 were sufficient as thresholds, i.e. for the PC under consideration, if the ratio of spectral power below 8 Hz over the total spectral power exceeded this threshold, then that PC would be selected. The other PCs with SPR below this threshold were set to zero. Next, these selected PCs were used to reconstruct the AVEP signals.

B. Two tier SPR

In two tier SPR (SPR2) method, the output signal from level one SPR is given as an input again to the same SPR process. It means that we perform SPR based PCA method on the source signal twice.

C. Sandwich SPR (SSPR)

The SSPR model is produced by inserting a low pass filter constructed using a combination of a ninth order forward and ninth order reverse Butterworth digital filter with a cutoff frequency at 8 Hz, in between the two tiers of the 2 tier SPR. The inserted Butterworth filter is capable of achieving a minimum attenuation of 30 dB in the stop band, with the transition band being between 8 and 12 Hz. The need for both forward and reverse filtering is to ensure that there would not be any phase distortion. This method is explained in Figure 1.

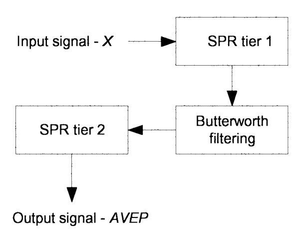

Fig. 1: Sandwich SPR method.

2.4 SNR calculation

In order to compute and compare the efficiency of the above three different PC selection methods, SNR computations were carried out for the reconstructed VEP signals. This was implemented by

$$SNR=10log_{10}(Variance(X)/Variance(W-X)) \quad (7)$$

The total SNR for all the 64 reconstructed AVEP signals were also calculated for the above three methods.

2.5 Different noise factors

The entire experiment was repeated for all the three methods with the signal, W but adding noisier EEG signals, i.e. EEG signals with amplitude multiples of 2, 5, and 10:

$$W(n)_{AVEP+noise}=X(n)_{AVEP}+NY(n)_{noise} \quad (8)$$
$$\text{where } N = 2, 5, \text{ and } 10.$$

The performances of all the three methods were investigated using their resultant SNR values.

3. SINGLE TRIAL P3 ANALYSIS FROM REAL VEP

Using all the above three PC selection methods, a simple experiment was carried out with the real VEP signal samples taken from Wadsworth BCI Dataset. The real VEP signals were recorded from different subjects while being exposed to two kinds of stimuli: target and non-target stimuli.

An explanation of the dataset is as follows: In a combination of six row and six columns of alphabets A-Z and numbers 0 – 9, the visual stimulus (Sn) shown to the subjects was a randomly highlighted row or column,

The target character will be given to the subjects and they need to gaze at that character only when the rows or columns are highlighted. If the target character is present in the row or column, then the recorded signals are considered as target stimuli signals (TSn) and if not, they are called as non-target stimuli signals (NTSn). One-second measurements after each stimulus presentation were recorded. We randomly selected both TSn and NTSn from a set of eight channels for few trials from different subjects.

Next, to set the pre-stimulus baseline to zero, the data were made zero mean [11]. Following the approach from by Begleiter *et al.* [4], where P3 responses were shown to be band-limited to 8 Hz, the extracted VEP signals from TSn and NTSn stimuli were low pass filtered using a combination of a 9^{th} order forward and 9^{th} order reverse Butter worth digital filter with a cutoff frequency at 8 Hz.

Single trials of VEPs from the Cz, Pz, Fz, Fcz, C1, Cp1, Cpz and C2 channels were analysed, because the P3 response reaches its maximum in the midline parietal area [11]. The amplitude of all the P3 responses from the above channels were detected as the largest positive peak in the period of 300-600 ms after the stimulus onset.

4. RESULTS AND DISCUSSION

The results of the artificial VEP analysis are given in Table 1. The results of SSPR method in comparison to performances using SPR method, taken from various trials are given in Tables 2 to 5. The SPR2 method did not show any significant difference from the SPR method for the real VEP experiment. The number of channels was restricted to four due to unavailability of space but the total and average for eight channels are provided. The evidence of the effectiveness of our proposed SSPR method could be seen from the increased SNR as compared to the SNR of SPR and SPR2 techniques from Table 1.

It is also clear that the proposed SSPR method gives improved performance in comparison with SPR, in conditioning the signals more effectively. It enhances the height of P3 peaks of target stimuli than the SPR technique, and suppresses the height of the P3 peaks of non-target stimuli. These results confirm the suitability of using this SSPR technique for extracting VEP signals for a BMI design.

Therefore, in conclusion, our proposed SPR-Sandwich method is proved its efficiency in extracting single trials of VEP signals not only by identifying the target stimuli but also in suppressing the noise that contaminate the VEP.

Acknowledgement

The authors wish to acknowledge the assistance of Prof. Henri Begleiter from the Neurodynamics Laboratory at the State University of New York, Health Center at Brooklyn, USA who recorded the raw VEP data and Mr. Paul Conlon, of Sasco Hill Research, USA for sharing the data.

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TABLE I
COMPARISON OF SNRS OF SPR, SPR-2 AND SSPR METHODS WITH DIFFERENT EEG FACTORS

Signal to Noise Ratio				
Noise Factors	Contaminated signal	SPR	SPR2	SSPR
1	-74.8582	-3.0780e-014	1.1227e+004	1.9270e+004
2	-255.3272	-1.593e-014	1.1551e+004	7.5868e+003
3	-424.0328	-3.4752e-014	1.1558e+004	7.4959e+003
5	-677.3005	-1.9651e-014	1.0112e+004	7.4599e+003
10	-1.0515e+003	-2.8588e-014	1.1785e+004	1.9239e+004

TABLE II
COMPARISON OF P3 PEAK HEIGHTS IN TARGET AND NON TARGET STIMULI USING SPR AND SPR-SANDWICH METHODS IN TRIAL 1

P300 Amplitude Peak heights				
Randomly selected channels	SPR		SPR - sandwich	
	Target	Non-Target	Target	Non-Target
Pz	2.3830	0.4104	2.3733	0.3533
Cz	2.3727	0.4299	2.3662	0.3732
Fz	0	0.6506	2.3315	0.6053
Cpz	0	0.7259	0	0.6844
Total (8 signals)	4.7557	4.6172	7.0711	4.2136
Average (8 signals)	0.5944	0.5771	0.8838	0.5267

TABLE III
COMPARISON OF P3 PEAK HEIGHTS IN TARGET AND NON TARGET STIMULI USING SPR AND SPR-SANDWICH METHODS IN TRIAL 3

P300 Amplitude Peak heights				
Randomly selecte channels	SPR		SPR - sandwich	
	Target	Non-Target	Target	Non-Target
Pz	1.9017	0.6569	1.9312	-0.8598
Cz	1.6629	1.0571	1.6939	1.0538
Fz	1.7144	0.8443	1.7400	0.8255
Cpz	1.7132	0.8985	1.7433	0.9503
Total(8 signals)	13.8549	6.9710	14.0917	5.3834
Average (8 signals	1.7318	0.8713	1.7614	0.6729

TABLE IV
COMPARISON OF P3 PEAK HEIGHTS IN TARGET AND NON TARGET STIMULI USING SPR AND SPR-SANDWICH METHODS IN TRIAL 7

P300 Amplitude Peak heights				
Randomly selected channels	SPR		SPR – sandwich	
	Target	Non-Target	Target	Non-Target
Pz	1.9665	0.2030	1.9980	0.0402
Cz	1.9786	0.3421	2.0220	0.1963
Fz	1.9763	0.1672	2.0134	0.0381
Cpz	1.9908	0.2336	2.0488	0.0989
Total (8 signals)	15.8316	1.8943	16.1403	0.7743
Average (8 signals)	1.9789	0.2367	2.0175	0.0967

TABLE V
COMPARISON OF P3 PEAK HEIGHTS IN TARGET AND NON TARGET STIMULI USING SPR AND SPR-SANDWICH METHODS IN TRIAL 9

P300 Amplitude Peak heights				
Randomly selected channels	SPR		SPR – sandwich	
	Target	Non-Target	Target	Non-Target
Pz	2.0353	0.3324	2.0558	0.3076
Cz	2.0304	0.0766	2.0584	0.0761
Fz	2.0180	0.1909	2.0481	0.1868
Cpz	2.0242	0.0923	2.0511	0.1004
Total (8 signals)	16.1766	1.4736	16.3993	1.4438
Average (8 signals)	2.0220	0.1842	2.0499	0.1804