Visual Evoked Potential Estimation by Eigendecomposition

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Abstract: In this paper an eigendecomposition method is presented to estimate evoked potentials (EP). Taking into account of the characteristic of evoked potentials, the method uses two observations both of which contain desired EP signal and undesired EEG signal. If the desired and undesired signal are uncorrelated (i.e. they are orthgonal) and the signal-to-noise-ratios (SNR) of each observations are different, we can use eigendecomposition method to separate EP signal from EEG. Visual evoked potentials (VEP) of human have been estimated and good results obtained by this method.

Keywords: Eigendecomposition, Signal to noise ratio, Evoked potentials

1. INTRODUCTION

Evoked Potentials (EPs), which are brain electrical activities resulting from sensory stimulation. EP plays an important role in the diagnosis of the abnormalities of human brain. However the amplitude of the EP signals are usually much smaller than that of the background EEG. Ensemble averaging (EA) is the most widely used method for obtaining the EPs [5]. However, this method ignores the fact that the EPs are also time-varying signals and the results of EA may introduce significant distortion and loss of information about the response variability from trial to trial. Digital filters are usually used to enhance the quality of EP signals [3,5]. Adaptive filtering technique is one of the powerful methods to design time-varying filter for estimation of EP signals [4]. In this paper, we present eigendecomposition method to estimate the visual evoked potential (VEP) signals.

II. METHODS

In some traditional methods (for example EA) of EP estimation, main background EEG is usually assumed to be a Gaussian distributed white noise. However, the EEG is found to be non-Gaussian in some studies [6]. In this paper, we consider a special case to separate VEP from EEG using two observations. To simplify the analysis we assume that the VEP and EEG are all from one source respectively. The model to generate two observations is shown as Fig.1. Therefore, we have

$$x_1(t) = s_{EP}(t) \otimes h_{11}(t) + s_{EEG}(t) \otimes h_{12}(t) + w_1(t) \quad (1)$$

and

$$x_2(t) = s_{EP}(t) \otimes h_{21}(t) + s_{EEG}(t) \otimes h_{22}(t) + w_2(t) \quad (2)$$

where '$\otimes$' means linear convolution, w_1 and w_2 indicate unknown noises which are introduced during measurement are assumed as white.

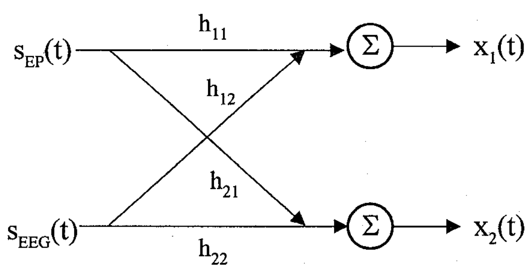

Fig.1 Model of two channel observations

We use the eigendecomposition method [1,2] to separate the VEP signal from the background EEG on the assumption that they are independent or orthogonal to each other. Considering the $p \times (p+N)$ data matrices

$$X_i = \begin{bmatrix} x_i(1) & x_i(2) & \cdots & x_i(N) & 0 & 0 & \cdots & 0 \\ 0 & x_i(1) & x_i(2) & \cdots & x_i(N) & 0 & \cdots & 0 \\ \vdots & \vdots & & & & & & \\ 0 & 0 & \cdots & 0 & x_i(1) & x_i(2) & \cdots & x_i(N) \end{bmatrix} \quad (3)$$

where i=1,2 for two observations. N is the point number in each trial and p should be equal to or greater than twice the number of components of the EEG [1]. We then get the correlation matrices of two observations,

$$R_{X_i} = E\{X_i X_i^T\} \qquad i = 1,2 \quad (4)$$

where '$E\{\}$' is expectation. We build a ratio matrix R_{ratio} as following

$$R_{\text{ratio}} = R_{X_1}^{-1} R_{X_2} \quad (5)$$

which is the ratio of the two observations. Since there exists residual noise in the recording system, the matrix R_{X_i} is positive definite, therefore, R_{X_i} is invertible. Cao et al. [1] indicated that the signal subspace spanned by the eigenvectors of R_{ratio} is coincident with that spanned by the eigenvectors of R_{X_i}. The eigenvalues of R_{ratio} are the ratio of the corresponding power densities for each signal component of the two observations. Thus, if the SNR in the two observations are different we can separate the EP signal and the background EEG. Here we define the SNR as the power ratio of desired EP signal and the undesired EEG.

To use eigendocompositon method to extract the EP signals from the background EEG, some simple pre-process procedure is needed. Since the SNRs in both channels are quite close, we use averaging method to make them different in both channels. The data from channel 1 remain the original form as the primary input, while data from channel 2 is averaged by a moving window with the window length of 4 trials. On the assumption that EP signal will not vary largely during a short 4 trials duration, the amplitude of EP signal after averaging will remain the same as that of individual trial. However, the amplitude of EEG will be suppressed by averaging, such that the maximum eigenvalue of the ratio metrix R_{ratio} , denoted as $\lambda_{\max}$, corresponds to the EP signal subspace, while the minimum eigenvalue of the of the ratio matrix R_{ratio} , denoted as $\lambda_{\min}$, corresponds to the EEG subspace. The eigenvalues between the maximum and minimum are related to other noise. From the eigendecomposation features we know that the eigenvector corresponding to $\lambda_{\max}$ is orthogonal to EEG. If we design a filter according to this eigenvector, it is possible to filter out the EEG noise. We proceed as follows to design an eigen-filter for EP signal and EEG separation

1. An eigendecomposition of the ratio matrix R_{ratio} is performed;
2. Only the largest egienvalue $\lambda_{\max}$ and the associated eigenvector $q_{\max}$ are retained;
3. The eigenvector $q_{\max}$ defines the impulse response of the optimum filter, it has the transfer function

$$H(z) = q_0 + q_1 z^{-1} + \cdots + q_{p-1} z^{-(p-1)} \tag{6}$$

where

$$q_{\max} = [q_0 \quad q_1 \quad \cdots \quad q_{p-1}] \tag{7}$$

is the eigenvector corresponding to $\lambda_{\max}$.

III. Results

We use the above method to estimate visual evoked potential (VEP) of human beings. VEP recorded with an active electrode placed at the occipital region of the scalp (Oz), and the reference electrode was placed at the frontal position (Fz). The signal was bandpassed from 1 to 800 Hz and sampled at 2000 Hz. The subject were asked to fixate their vision at the stimulus screen (21×28 cm) placed at 1 meter viewing distance. The stimulus pattern was a conventional black-and-white checkerboard and the pattern was reversed every second. The recording time for each trial is 400 ms following each pattern reversal. Two channel data are recorded at the same time. The SNRs of the raw data in two channel are about -5 dB. To make the SNRs in the two channel different, the data of channel 2 are summed for every 4 trials while the corresponding trials of data in channel 1 is processed from trial to trial.

Fig.2 (a) and (b) are the two observations from channel 1 and channel 2 respectively. Fig.2 (c) shows the frequency response of the eigen filter based on eigenvector corresponding to $\lambda_{\max}$. From Fig.2(c) we can see that the filter looks like a comb filter which can filtere out all components being orthogonal to the EP signals. Once the coefficients of the eigen-filter are obtained, we take current channel data as the input to the filter. The output of the filter will give the enhanced EP signal. Fig. 2(d) and (e) show the result of enhanced VEP signals of channel 1and channel 2, respectively. It is clear that the output of the filter produces a good SNR improvement. It is possible to investigate VEP from trial to trial by using eigen filer.

IV. Conclusion

We presented an eigenvalue analysis based method to separate VEP signal from EEG if they are uncorrelated each other. In the case of EP signal enhancement, we take EP as the desired signal with EEG signal as undesired signal. Two-channel of data are recorded at same time. To get different SNR of two observations, we averaged channel 2 data using a moving window with length of 4 trials. Two correlation matrices are formed for every couple of observations. We then divide desired signal (EP) subspace and undesired signal (EEG) subspace according to the eigenvector derived from ratio matrix R_{ratio}. On the assumption of the two signals being independent, an eigen-filter can be designed by choosing the proper eigenvector. Thus the desired signal can be separated from undesired signal subspace. VEP signals are estimated and good results are obtained by this method.

However, this method cannot remove other background noises recorded during measurement. These noises are usually much smaller than EEG. As shown in Fig.2 (d) and (e), there exist some high frequency noise components at the output of eigenfilter. Since the dominant undesired EEG is largely filtered out, it is much easier to remove the residual noises by some simple methods, eg. using a lowpass filter to filter the high frequency noise out.

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Reference

[1] Y.C.Cao, S.Sridharan and M.Moody, "Multichannel speech separation by eigendecomposition and its application to co-talker interference removal",*IEEE Trans. Speech and Audio Processing,* Vol.5, No.3,pp.2009-219,1997.

[2] E.Wernstein, M.Feder, and A.V.Oppenheim, "Multi-channel signal separation by decorrelation", *IEEE Trans. Speech and Audio Processing,* Vol.1,pp.4005-413,1993.

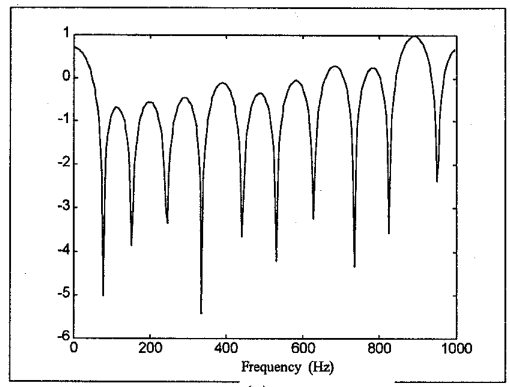
[3] J.I. Aunon, , C.D. Mcgillem, "Measurements of signal components on single visually evoked brain potentials", *IEEE Trans. Biomed. Eng.*, BME-24, pp.232-241, 1977.

[4] F.H.Y. Chan, F.K. Lam, P.W.F. Poon, W. Qiu, "Detection of brainstem auditory evoked potential by

adaptive filtering", *Med. & Bio. Eng. & Comput.* Vol. 33, pp.69-75, 1995.

[5] D. Regan, *Human brain electrophysiology: evoked potentials and evoked magnetic fields in science and medicine*, Elsevier, New York, 1989.

[6] N.Hazarika, A.C.Tsoi and A.A.Sergejew, "Nonlinear considerations in EEG signal classfication", *Proc. of 17th Conf., of IEEE EMBS*,pp.921-922,1995.



(c)

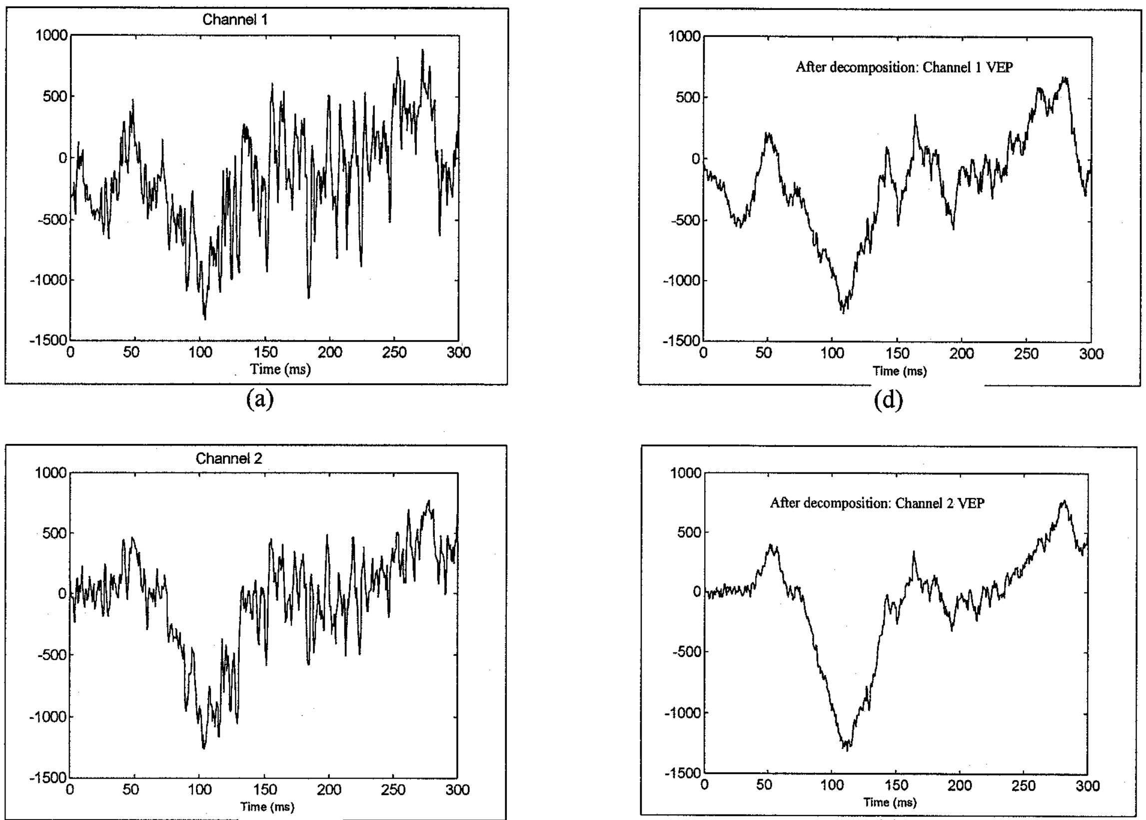


Fig.2 Illustrations for VEP signal enhancement using eigendecomposition method. (a) original data of channel 1; (b) moving window averaged data of channel 2; (c) eigenfilter frequency response; (d) enhanced VEP signal from channel 1 and (e) enhanced VEP signal from channel 2.