Regularization approach to the single trial estimation of multi channel evoked potentials

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Abstract— **A method for the single trial estimation of the evoked potentials is proposed. The method is based on regularized least squares scheme in which the second order statistics of the set of multi channel measurements is used to form a spatial information model for the evoked potentials.**

Keywords— **Evoked potentials, single trial estimation, regularization**

I. Introduction

Currently the goal in the analysis of the evoked potentials is to obtain estimates for the single potentials. We call this task the single trial estimation. The most common approach to the single trial estimation is to form an estimator with which the unwanted contribution of the on-going background activity of the brain can be filtered out from the observations as well as possible. A major difficulty in this task is the often very low signal-to-noise ratio.

One possibility to improve the estimates is to apply additional information about the potentials to the estimation. The information can be concerned with the assumed smoothness of the evoked potentials or be in the form of limits for the possible locations of the peaks in the potentials. In the case multi channel measurements the spatial correlation between the channels can be interpreted in the form of additional information. A way to employ additional information is to use the so-called regularized least squares method. The method has been used in the case of single channel measurements in [1].

II. Single trial estimation of evoked potentials

We assume that the measurements can be described with the linear additive model

$$z = \begin{pmatrix} z_1 \\ \vdots \\ z_n \end{pmatrix} = \begin{pmatrix} s_1 \\ \vdots \\ s_n \end{pmatrix} + \begin{pmatrix} v_1 \\ \vdots \\ v_n \end{pmatrix} = H\theta + v \qquad (1)$$

Vector z_i is the length M measurement of one channel. A new vector z is obtained after each stimulation. The vector v describes the background EEG and can not be accessed directly. The evoked potentials are thus modeled as linear combinations of some basis vectors ψ_j that are the columns of the matrix $H = (\psi_1, \ldots, \psi_p)$. The task is then to form an estimate $\hat{\theta}$ for the parameters $\theta \in \mathbb{R}^{np}$ corresponding to each measurement z and by using some suitable estimation criterion. The single trial estimate of the evoked potential is then of the form $\hat{s} = H\hat{\theta}$.

A key point in this approach is the selection of the observation matrix H. The formulation of the matrix H also describes the relations of the measurements between the different channels. The true, physical model would necessitate the modeling of electrical properties of the head. This is not a trivial task. We propose a simplier solution here.

First we assume that the potentials consist of positive and negative humps. Sampled Gaussian or sigmoid functions can then be a good choice for the basis. The channels are modeled separately, that is, the matrix H is a block diagonal matrix. It would also be possible to use the p first eigenvectors of the covariance matrix of the measurements as a basis. The least squares solution with this basis is then equivalent to the so-called principal component regression approach. If the covariance is calculated using the stacked measurements z, the eigenvectors model also the covariance between the separate channels.

These two approaches can be combined together. We do not restrict the evoked potentials to be strictly a linear combination of either set of the basis vectors. We rather use one set of vectors as a model for the evoked potentials. These are the columns of the matrix H. Set of eigenvectors of the covariance matrix of the measuremens is used to represent spatial information about the problem. These are the columns of the matrix $H_{\mathcal{S}}$. It can be shown that the solution that takes account both of the sets can be written in the form of the regularized least squares solution

$$\hat{\theta}_{\mathcal{S}} = (H^T C_v^{-1} H + \alpha^2 H^T (I - H_{\mathcal{S}} H_{\mathcal{S}}^T) H)^{-1} H^T z \qquad (2)$$

where α is the parameter that controls the weight between the different sets and C_v^{-1} is the covariance of the background EEG. The estimate for the evoked potential is then $\hat{s}_{\mathcal{S}} = H\hat{\theta}_{\mathcal{S}}$.

References

[1] P.A. Karjalainen, J.P. Kaipio, A.S. Koistinen, and M. Vauhkonen. Subspace regularization method for the single trial estimation of evoked potentials. *IEEE Trans Biomed Eng*, 1999. In press.