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COMPARISON BETWEEN PARAMETRIC WEINER FILTER AND PARAMETRIC PROJECTION FILTER IN CORTICAL EQUIVALENT DIPOLE LAYER IMAGING

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Abstract: **The objective of this study is to explore suitable spatial filters for inverse estimation of cortical equivalent dipole layer imaging from the scalp electroencephalogram. The effects of incorporating signal and noise covariance into inverse procedures were examined by computer simulations. The parametric projection filter (PPF) and parametric Weiner filter (PWF) were applied to an ideal 3D head model under various noise conditions. The present simulation results suggest that the PPF has better performance than the PWF, when the correlation between the signal and noise is low, and the PWF performs better than the PPF when the correlation is high.**
Keywords: **High resolution EEG, equivalent dipole layer imaging, inverse problem, parametric projection filter, parametric Weiner filter, signal and noise covariance**

I. INTRODUCTION

Electroencephalography (EEG) has historically been a useful modality to provide high temporal resolution regarding the underlying brain electrical activity. However, the spatial resolution of EEG is limited due to the smearing effect of the head volume conductor. In the past decades, much effort has been made in the development of high-resolution EEG techniques, which attempt to image and map spatially distributed brain electrical activity with substantially improved spatial resolution without *ad hoc* assumption on the number of source dipoles [1]-[11]. The equivalent dipole layer imaging (EDLI), which attempts to estimate the dipole layer distribution from scalp potentials, is one of the spatial enhancement techniques [11].

In parallel to the development of physical models for brain inverse problem, the inverse regularization algorithm plays an important role in the EDLI. Regularization strategies, such as general inverse with truncated singular value decomposition and Tikhonov regularization method (TIK), have been used to solve the ill-conditioned brain inverse problem (for review, see [1]). Several investigators have further explored the use of advanced regularization methods to improve the inverse results. Particularly, Weiner reconstruction frameworks based on both signal and noise covariance matrices have been investigated [12]-[15].

We investigated the EDLI by means of parametric projection filter (PPF), in which the noise covariance was taken into consideration [16]. In the present study, we examine the applicability of PWF and PPF to the EDLI through computer simulations.

II. METHOD

A. Principles of Equivalent Dipole Layer Imaging

In the present EDLI study, the head volume conductor was approximated by a 3-sphere inhomogeneous model and a closed dipole layer of radial dipoles are used [8]. The observation system of brain electrical activity on the scalp could be defined by $g = A f + n$, where f is the vector of the equivalent source distribution of a dipole layer, n is the vector of the additive noise and g is the vector of scalp-recorded potentials. A represents the transfer matrix from the equivalent source to the scalp potentials. The inverse process could be defined by $f_0 = B g$ where B is the restoration filter and f_0 is the estimated source distribution of the dipole layer.

B. Inverse Techniques

The parametric Weiner filter (PWF), which allows estimating solutions in the presence of information on signal and noise covariance matrices, has been introduced to solve the inverse problem [13]-[16]. The PWF is given by

$$B = R A^* (A R A^* + \gamma Q)^{-1} \qquad (1)$$

with A^* the transpose matrix of A and γ the regularization parameter. R and Q are the signal and noise covariance matrices derived from the expectation over the signal ensemble $E[ff^*]$ and noise ensemble $E[nn^*]$, respectively. If $R = I$ (identity matrix) then (1) is reduced to the parametric projection filter (PPF), in which the noise covariance matrix alone is taken into consideration. If $R = Q = I$ then (1) is reduced to the zero-order Tikhonov regularization (TIK).

In a clinical and experimental setting, the noise covariance matrix may be estimated from data that is known to be source free, such as the pre-stimulus data in evoked potentials [15]. Moreover, the signal covariance matrix can be estimated from the covariance of observed post-stimulus data [12]. The determination of the value of parameter γ is left to the subjective judgment of the user. To determine the optimal parameter without knowing the original source distribution, we use the recursive procedure [16]. We have applied PWF, PPF, and TIK to the inverse problem of the EDLI.

III. RESULTS

Fig. 1 shows the relative error between actual and estimated dipole layer distributions against the noise level in three inverse techniques. Two dipoles, located at the center position were used as the sources. The simulations were performed with various noise configurations such as uniform Gaussian white noise and edge-, center-, and one side-concentrated non-uniform noise. In the case of center-concentrated noise distribution (high correlation between signal and noise), the results of PWF were better than the TIK and PPF (Fig. 1(c), Fig. 2). On the other hand, the PPF has better performance for the edge-concentrated non-uniform noise (low correlation between signal and noise) (Fig. 1 (b)). The results of three inverse techniques were similar in the cases of the Gaussian white noise and one side-concentrated non-uniform noise (moderate level of correlation between signal and noise).

IV DISCUSSION

Noise plays an important role in the EDLI, as in any other ill-posed inverse problem. In the present study, we have investigated the performance of the EDLI by considering signal and noise covariance matrices through the use of PWF and PPF. The present results suggest that, the PWF incorporating signal information provides better EDLI results than the PWF and TIK under the condition of high correlation between signal and noise distributions. On the other hand, the PPF has better performance than other inverse filters under the condition of low correlation between signal and noise distributions.

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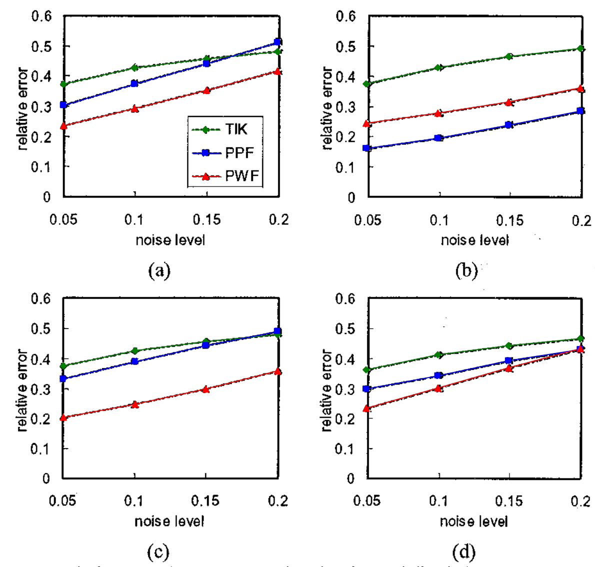

Fig. 1. Relative error between actual and estimated dipole layer distributions in various noise configurations. The scalp potentials were contaminated with (a) GWN and (b) edge-, (c) center-, and (d) one side-concentrated non-uniform noise.

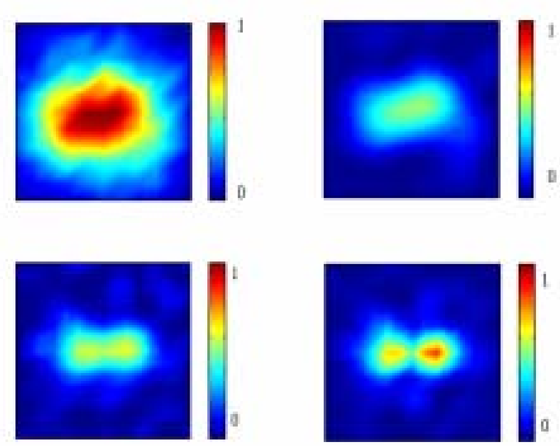

Fig. 2. One example of the estimated inverse solution in the case of two radial dipoles. (a) shows scalp potential contaminated with 10% center-concentrated non-uniform noise. (b)-(d) show the estimated dipole layer distribution by means of (b) TIK, (c) PPF, and (d) PWF.