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Evaluation of Cortical Imaging Techniques Based on Somatosensory Evoked Potentials

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Abstract— **In the present study we evaluate the performance of several inverse algorithms for reconstructing the cortical current density distributions from scalp EEG recordings. The direct cortical SEP recordings in a patient were used as a gold standard to assess the performance of the numerical algorithms. The present results suggest that L_1-norm methods gave the most accurate results in terms of cortical current density imaging of brain responses invoked by somatosensory stimulation.**

I. Introduction

Electroencephalography (EEG) is an economic and easy-to-use method of detecting brain electrical activity. It offers high temporal resolution but has limited spatial resolution. A number of efforts have been made to improve the spatial resolution of EEG by solving the so-called inverse problem [1]. Among the EEG inverse solutions, the cortical imaging methods have received considerable attention [2]-[5].

Several effective current density reconstruction (CDR) techniques have been reported for modeling distributed and spatially distinct source activity independent of prior knowledge concerning the selection of the number of sources, including the minimum–norm least squares solution (MNLS) [6], low-resolution electromagnetic tomography (LORETA) [7], L_1-norm [8], and standardized low-resolution electromagnetic tomography (sLORETA) [9] methods. Studies have also been conducted to assess the performance of the above methods using experimental EEG recordings [10]-[15]. These previous studies assessed two or three methods with noninvasively measured scalp EEGs.

In the present study we evaluate these inverse algorithms for cortical CDR including the MNLS, LORETA, standardized low-resolution electromagnetic tomography (sLORETA) and the L_1-norm, by means of direct ECoG recordings [16].

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II. Materials and methods

A. Source Reconstruction

The CDR estimation can be obtained by solving the following minimization problem

$$\min_{\mathbf{J}} \{\|\mathbf{\Phi} - \mathbf{KJ}\|_p + \lambda \|\mathbf{WJ}\|_p\}, \tag{1}$$

where ||•|| symbolizes the norm of the p order, $\mathbf{\Phi}$ a $m\times 1$ vector of the measured EEG recording, the $3n\times 1$ $\mathbf{J}$ vector the cortical current density (CCD) at all the n discrete cortical sources simultaneously, $\mathbf{K}$ the $m\times 3n$ lead field matrix representing the system transfer coefficients from all n sources to m measuring points (the locations of m electrodes), λ the regularization parameter, and $\mathbf{W}$ a $3n\times 3n$ weighting matrix. The different strategies are to obtain the inverse solution of equation (1) depending on how the norm and what kind of the weighting matrix and regularization method are selected.

B. SEP studies of a Patient

A neurosurgical patient who underwent surgical evaluation for cortical resection due to medically refractory epilepsy was studied. Informed written consent was obtained according to a protocol approved by the Institutional Review Board. The recordings included the structural magnetic resonance (MR) images, computerized tomography (CT) images, SEP scalp recordings, direct cortical SEP recordings, and scalp electrode locations and subdural electrode locations (Radionics Medical Products Inc., Burlington, Massachusetts). The stimuli were 0.2-ms-duration electrical pulses delivered at 5.7 Hz at the motor threshold. Five replications of 500 stimuli were averaged. Using a commercial signal acquisition system (Neurosoft Inc., El Paso, TX), 32-channel scalp EEGs referenced to Cz were amplified with gain of 5000 and band-pass filtered from 1 Hz to 1 kHz. The cortical SEPs were recorded from a 4×8 rectangular electrode grid with an inter-electrode distance of 1 cm, placed directly on the surface of the brain as part of their diagnostic evaluation for the surgery. The electrocorticogram (ECoG) referenced to the contralateral mastoid was also band-pass filtered from 1 Hz to 1 kHz, but a gain of 1000 was used. A realistic geometry boundary element model was constructed from the MR images of the patient. The discrete cortical source models were set according to the cortex surface of the patient, obtained from the MR images.

III. Results

Results of four CCD algorithms for the patient were obtained. The central boundary of the positive/negative dipolar pattern can be determined in the scalp and subdural surface [4]. Comparing this boundary with the cortex's sulcus, the central sulcus, the motor and sensory areas can be accurately obtained. From the CCD results in which the L_1-norm, LORETA (p = 2), sLORETA and MNLS (p = 2) methods were used, it can be noted that the 'hot spot' (yellow area) of source activities given by all 4 algorithms for the patient were roughly located on the primary sensory area. However, the 'hot spots' of the L_1-norm solution was most closest to the primary sensory area as identified from the direct ECoG recording, suggesting that the L_1-norm method is more accurate than other methods for locating the focal cortical sources.

IV. Discussion

In the present study we evaluated the performance of several inverse algorithms including the minimum norm least square solution (MNLS), low-resolution electromagnetic tomography (LORETA), standardized low-resolution electromagnetic tomography (sLORETA), and the L_1-norm methods, using the experimental somatosensory evoked potentials (SEPs).

The main results of our analyses are as follows. First, the blurring CCD distributions given by the CDR methods were smoother when p value (the norm order) increases, which are in accordance with those reported in the previous literature [8], [10]. Second, the results further indicate that the L_1-norm method is more suitable to use in the discrete cortical sources model of the cortex surface than the L_2-norm (MNLS and LORETA) or sLORETA methods for focused source activities, which are consistent with results reported in the previous literature [11], [14], [15]. In summary, the present results suggest that the L_1-norm method provides the best performance in cortical current density imaging for localizing and imaging focal cortical sources invoked by somatosensory stimulation.

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