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Source Localization of Subtopographic Brain Maps for Event Related Potentials (ERP)

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INTRODUCTION: DECOMPOSITION OF ERP DATA AND THE INVERSE PROBLEM

Event-related potentials (ERP) are transient brain responses to cognitive stimuli, and they consist of several stationary events whose temporal frequency content can be characterized in terms of oscillations or rhythms. Precise localization of electrical events in the brain, based on the ERP data recorded from the scalp, has been one of the main challenges of functional brain imaging. Several currentDensity estimation techniques for identifying the electrical sources generating the brain potentials are developed for the so-called neuroelectromagnetic inverse problem in the last three decades (Baillet, Mosher, & Leahy, 2001; Koles, 1998; Michela, Murraya, Lantza, Gonzaleza, Spinellib, & Grave de Peraltaa, 2004; Scherg & von Cramon, 1986). Generally, there are two main assumptions for the source models:

1. The number of sources are less than the number of measurements, which leads to the parametric methods that estimate the strength and position of the dipole sources by optimization methods (Mosher, Lewis, & Leahy, 1992).
2. The number of sources are more than the number of measurements that calls for the imaging methods searching for an optimum source distribution in a 3D brain image (Pascual-Marqui, Michel, & Lehmann, 1994). Since the number of source locations are much higher than the number of sensor measurements, the latter case is a severely underdetermined problem.

The uniqueness of the inverse solution for both cases can only be acheived by imposing additional constraints. Introducing a mathematical criterion such as the minimum norm, the maximum smoothness, or the minimum variance, or constraining the solution space is a common way to circumvent the uniqueness problem. Also, a well defined anatomical region where the orientation or position of the dipole is, a priori known can be used as an additional constraint. Other physiological constraints obtained from functional magnetic resonance imaging (fMRI), and Positron Emission Tomography (PET) studies may also be incorporated in the inverse solution methods. The sources underlying the ERP, which are rather distributed in the brain and nonstationary in time, also motivate the researchers to invent additional simplifications and analyses on the multichannel data before they apply source localizaton. Several studies aimed for isolating stationary frequency components in temporal windows, using time frequency analysis, and then applying source localization techniques to the scalp maps generated by these time frequency components. Source localization of epileptic discharges is performed after wavelet prefiltering to isolate the spiky waveforms from the background EEG (Ademoglu, Demiralp, Istefanopulos, Comu, & Baykan, 2004). Gonzalez Andino, Grave de Peralta Menendez, Lantz, Blank, Michel, and Landis (2001) proposed an eigen-based method to identify the location of each underlying source in the time-frequency plane that generates a certain topographic distribution. Unlike the previous time-frequency studies that use single channel data, Koenig, Marti-Lopez, and Valdes-Sosa (2001) perform time-frequency optimization on mutichannel data with the wavelet coefficients having minimum energy and maximum spatial smoothness distributions. A more general and unique space/frequency/time decomposition in terms of so-called atoms are proposed by Miwakaichi, Martinez-Montes, Valdes-Sosa, Nishiyama, Mizuhara, and Yamaguchia (2004), which overcomes the limitation of introducing artificial assumptions as indepence in

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ICA or uncorrelatedness in PCA approaches (Zhukov, Weinstein, & Johnson, 2000).

BACKGROUND: SPATIAL DECOMPOSITION OF ERP MAPS

In all these studies, the problem of identifying the individul ERP components are treated by proposing a decomposition method that involves the time, frequency, channel, or their various combinations. Another common feature observed is that the concept of frequency is always associated with, and defined in, temporal domain. In Wang, Begleiter, and Porjesz (1998) the spatial ERP maps are enhanced by using first, a projection method that transforms the scalp poentials defined on a 3D surface to a 2D plane, and then applying a 2D multiresolution decomposition. This is the first approach that attempts to simplify the scalp topography by decomposing it into simpler maps using a spatial multiresolution.

A scalp topographic map for an ERP may be a superposition of several simpler subtopographic maps, each resulting from an individual electrical source located at a certain depth as a focal or extended activity. Furthermore, this source may have a temporal characteristics as an oscillation or a rhythm that extends in a certain time window, which has been a basis of assumption for the time-frequency analysis methods.

The subtopographic maps arising from sources located at certain depths with different extention of activities generally fall into different spatial frequency bands on the scalp. Therefore, a spatial frequency decomposition of a scalp potential distribution yields these subtopographic maps, whose source localizations will lead us to their electrical sources in the brain. It is essential to perform this spatial frequency decomposition on a realistic scalp surface without any distortion. To achieve this purpose, we propose a method that involves a realistic scalp model on which a 3D wavelet transform is performed, and the subtopographic maps obtained are source localized using inverse modeling.

FORWARD PROBLEM AND REALISTIC HEAD MODEL

Forward problem of EEG computes the electrical potentials on the scalp surface from the given source positions and strenghts in the brain. Boundary Element Method (BEM) is used with the Centre of Gravity (COG) approximation on a realistic head model (Hamalainen & Sarvas, 1989; Schlitt, Heller, Aaron, Best, & Ranken,1995). Realistic head model consists of brain, skull, and scalp surfaces. Surfaces of the brain, skull, and scalp are tesselated with 2000, 1200, and 1200 triangles respectively. If we have P different measurement sites in the conductor model, the forward problem can be formulated by the electrical potential $\mathbf{v}(\vec{s})$ at electrode location $\vec{s}$, due to a dipole at $\vec{r}$ with strength $\vec{m}$, as in Equation 1.

$$\mathbf{v}(\vec{s}) = \mathbf{H}(\vec{s}, \vec{r})\, \mathbf{m}(\vec{r}) \tag{1}$$

Here, $\mathbf{v}(\vec{s})$ is $P \times 1$ electrical field vector, $\vec{m}$ is a 3×1 strength vector for a single current dipole source located at $\vec{r}$, and $\mathbf{H}(\vec{s}, \vec{r})$ is a $P \times 3$ dimensional transfer function which depends on the dipole location $\vec{r}$, the measurement sites $\vec{s}$, and the geometrical and physical properties of the media.

BEM used for the forward problem is a numerical approximation technique which partitions the surface of a volume conductor into a triangular mesh. This technique has been used in dipole source localization of brain electromagnetic activity since the end of 80s. The human head is modeled as three homogeneous conductor layers: the outermost surface being the boundary for the scalp, the intermediate being for the skull, and the innermost being for the brain. The head model that we used in this study is developed using the average T1 weighted human brain MRI data provided by Montreal Neurology Institute (MNI). Statistical Parameter Mapping software 99 release (http://www.fil.ion.ucl.ac.uk/spm/), which is developed by Wellcome Institute is used for 3D segmentation of the brain, skull, and scalp. After segmentation, the surfaces are triangulated in order to generate the realistic head model. 30 channel electrode locations (Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T7, C3, Cz, C4, T8, TP7, CP3, CPz, CP4, TP8, P7, P3, Pz, P4, P8, O1, Oz, O2) are registered to the scalp surface by spline interpolation, using the T1 weighted MR data, the inion-nasion and pre-auricular coordinates, and the 10-20 Electrode Placement System. The surface of the scalp, which is represented with 16188 triangles, can be seen in Figure 1.

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