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

Adil Deniz Duru, *Student Member IEEE*, Ali Bayram, Tamer Demiralp and Ahmet Ademoglu

Abstract— **Localization of the cognitive activity in the brain is one of the major problems in neuroscience. Current techniques for neuro-imaging are based on Functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography (PET), and Event Related Potential (ERP) recordings. The highest temporal resolution is achieved by ERP, which is crucial for temporal localization of activities. However, the spatial resolution of scalp topography for ERP is low. There is a severe limitation for the parametric inverse solution algorithms that they can only perform well for the temporally uncorrelated sources. In this study, a spatial decomposition method is proposed to separate the temporally correlated sources using their topographies prior to their localization.**

Index Terms— **Spatial Wavelet Decomposition, ERP, Source Localization, Brain Topography**

I. INTRODUCTION

Several current-density estimation techniques were developed to overcome the spatial resolution limitation of scalp topography [1]. The goal is to find the location of intracerebral activities in the three-dimensional brain structure by solving an inverse problem [2]. ERP, generally, consists of several electrical sources some of which are temporally as well as spatially overlapping. For this reason, the scalp topography constituted by these multiple sources makes the inverse problem more complicated. The aim of the spatial wavelet decomposition of ERP scalp maps is to identify the subtopographic maps whose spatial frequency bands are determined by the depth and extension of individual sources.

Two dimensional (2D) spatial decomposition has been implemented by projecting the ERP data to a 2D regular grid [3]. In this study, a spatial decomposition is performed by interpolating a three dimensional (3D) scalp topography into a volumetric map and then applying a 3D wavelet transform on it. After decomposition, each individual map obtained is used for source localization to determine its source configuration. For the validation of the method, 30 channel simulated ERP data is generated by the Boundary Element Method (BEM) solved on a realistic head model. The centre of gravity (COG) approximation is used for solid angle computation [4]. Inverse problem is solved by Multiple Signal Classification (MUSIC) algorithm [2] and Low Resolution Tomography (LORETA) [1].

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A.D. Duru, A. Bayram and A. Ademoglu are with the Biomedical Engineering Institute, Bogazici University, Istanbul, Turkey.

T. Demiralp is with Department of Physiology, Istanbul Medical School, Istanbul University, Istanbul, Turkey. deniz.duru@boun.edu.tr

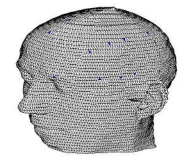

Fig. 1. Realistic head model developed from T1 weighted human brain MRI data containing 16188 triangles and 7800 vertices.

A. 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. BEM is used with the COG approximation on a realistic head model. 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 $\mathbf{v}(\vec{\mathbf{s}})$ at electrode location $\vec{\mathbf{s}}$ due to a dipole at $\vec{\mathbf{r}}$ with strength $\vec{\mathbf{m}}$ as in Eq. (1)

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

Here, $\mathbf{v}(\vec{\mathbf{s}})$ is $P \times 1$ electrical field vector, $\vec{\mathbf{m}}$ is a 3×1 strength vector for a single current dipole source located at $\vec{\mathbf{r}}$ and $\mathbf{H}(\vec{\mathbf{s}}, \vec{\mathbf{r}})$ is a $P \times 3$ dimensional transfer function which depends on the dipole location $\vec{\mathbf{r}}$, the measurement sites $\vec{\mathbf{s}}$, 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 80's . 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 (SPM99) 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 that we need to solve the forward problem. 30 channel

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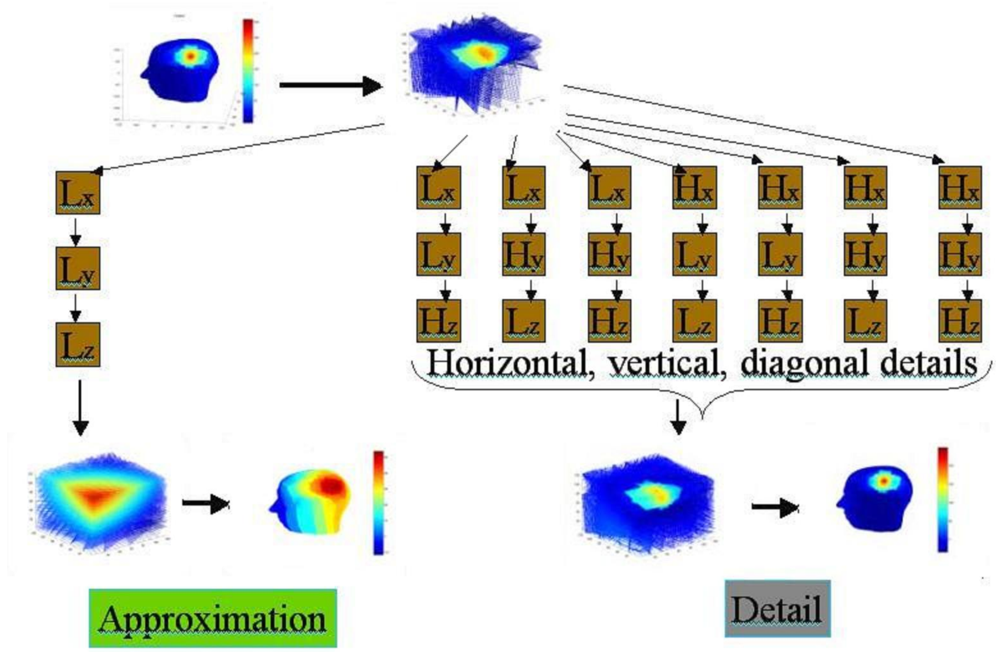

Fig. 2. 3D topography is converted to a 3D regular volumetric grid. By using 1D DWTs, at each stage volumetric grid with raw data is decomposed into two sets called approximation and detail. Finally, the original topograhies are regenerated from these volumetric maps.

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 Fig.1.

B. 3D Spatial Wavelet Decomposition

Given a signal $\mathbf{s}$ of length N, the first step of Discrete Wavelet Transform (DWT) produces two sets of coefficients: approximation, and detail coefficients. These vectors are obtained by convolving the signal with the low-pass filter for approximation, and with the high-pass filter for detail, followed by dyadic decimation (downsampling) [5].

This decomposition splits data at level j, into two components: the approximation at level $j+1$, and the detail at level $j+1$. For images, the algorithm is similar to the 1D case where the two-dimensional (2D) wavelets and scaling functions are obtained the by tensor product of respective 1D functions. 2D DWT leads to a decomposition at level j into four components: the approximation at level $j+1$, and the details in three orientations (horizontal, vertical, and diagonal). Similarly, to perform 3D wavelet decomposition, 1D DWT is applied on three directions on the 3D volume data. That leads to eight components from level j to $j+1$; one being the low pass filtered data and seven others as the various combinations of low and high pass filtered data, in all 3 directions.

C. Inverse Problem

The inverse problem estimates the source positions and their strength from multichannel ERP data. The MUSIC scanning algorithm and LORETA are used for the inverse problem. MUSIC method is based on subdividing the brain tissue into a 3D grid and computing the spatial power spectrum with an eigenbased approach for each voxel element. In order to do this, the transfer function $\mathbf{H}(\vec{\mathbf{s}}, \vec{\mathbf{r}})s$ in Eq. (1) has to be computed numerically [4]. In this study, cortex of the brain is seleced as a solution space for MUSIC algorithm.

II. VALIDATION OF THE METHOD

In order to validate the method proposed, a simulated multichannel ERP data is generated by using COG approximation of the BEM. Two stationary radial point sources are assumed; one being superficial while the other being deeper in the brain. Forward problem is solved for these point sources using BEM over the predefined head model given in Fig.3. The amplitude changes of the two point sources were sinusoidal with 128 data points and they were temporally correlated. The inverse problem is solved using the total topographic activity. Although, temporally uncorrelated sources can be easily discriminated by the MUSIC algorithm, the source positions, in this case, are not clearly separated because of the temporal correlation of individual sources. Both MUSIC and LORETA estimate the location of the superficial source from the total topography which is a missing solution. Deeper source could not be localized by these inverse solutions. By the spatial wavelet decomposition prior to source localization, subtopographic maps which originate from individual sources can be identified whose superimposition yields the original ERP topography. In our case, seven octave spatial wavelet decomposition is applied to the topography serie of total activity and the original topography serie is divided into two sets. One of the topographic map serie denotes the approximation outputs which is the low-pass filtered in all directions and the other serie shows the detail output which is the remaining part of the original topography serie. When these topographic map series are individually localized, it can be observed that the predefined sources can be easily discriminated as shown in Fig.4. Superficial source is localized from the approximation output while the deeper source is estimated from the detail output. Although it could be decomposed into any number of subtopographies, the original simulated MAP is divided into two, each of which corresponds to one individual distinct source.

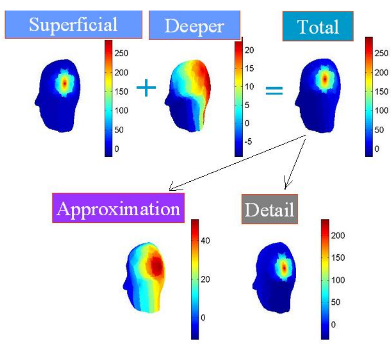

Fig. 3. Topography of superficial source, deeper source and total activity at the time instant of 32. Fourth topography is the approximation and the fifth topography is the detail output.

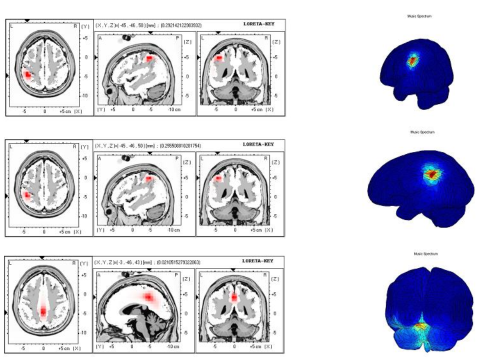

Fig. 4. Inverse solutions of the total, approximated and detail topographies with LORETA and MUSIC, respectively.

III. CONCLUSIONS AND FUTURE WORK

A. Conclusions

Spatial wavelet analysis of ERP at a given temporal location yields spatially stationary scalp maps at different spatial frequencies determined by the depth and extension of individual ERP sources. Therefore, a spatial preprocessing of the ERP simplifies the complexity of the scalp map into several maps produced by individual ERP sources prior to their source estimation which helps us to increase to sucess of the source localization procedures.

B. Future Work

Due to the large number of grid points, the spatial wavelet decomposition requires a high computational complexity and memory usage. New algorithms may significantly decrease the computational cost and memory allocation, dramatically. Future studies will show us whether these individual ERP sources when localized in space will eventually correlate with the distinct and/or interacting cognitive functions of the brain.

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