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A Comparison of LORETA and the Borgiotti-Kaplan Beamformer in Simulated EEG Source Localization with a Realistic Head Model

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Abstract

An accurate and robust EEG source localization algorithm is an asset in the understanding, diagnosis, and treatment of some neurological disorders. Two inverse algorithms, LORETA and the Borgiotti-Kaplan beamformer (BK Beam) are used to localize a single dipole source from a simulated EEG within a realistic head model. Compared over a range of SNR values and source locations, the BK Beam exhibited superior localizing capabilities with less dispersion than LORETA.

1. Introduction

The cortex of the brain is composed of a vast number of pyramidal cell assemblies that transmit electrical signals to various regions of the brain. Groups of cortical cells can be modeled as dipoles during cell depolarization. Distributed dipole source localization algorithms such as LORETA and the BK Beam are used to estimate the magnitudes of the model sources in the cortex.

In this work, an EEG is simulated using a single dipole source at a known location in the cortex. The two inverse algorithms are applied to the simulated EEG to estimate the location of the source. Localization accuracy is assessed in terms of the distance between the actual and estimated peak source magnitudes.

EEG source localization has two distinct aspects. The first is the formulation of the forward model and the second is the solution of the inverse problem. The forward model relates the magnitude and orientation of each dipole in the source space (cerebral cortex) to the potential produced on the scalp. Mathematically, this is written as:

$$\mathbf{v}(t) = \mathbf{K}\mathbf{j}(t) \tag{1}$$

where $\mathbf{v}(t)$ is a vector of potentials measured on the scalp at some time t, $\mathbf{j}(t)$ is the vector of underlying dipole magnitudes in the solution space and $\mathbf{K}$ is the lead-field matrix.

The inverse solution is an estimate of the underlying dipole magnitudes for a given set of measured scalp potentials:

$$\hat{\mathbf{j}}(t) = \mathbf{K}^{*}\mathbf{v}(t) \tag{1}$$

In (1), $\mathbf{K}^{*}$ is a pseudo inverse of $\mathbf{K}$. A full inverse of $\mathbf{K}$ cannot usually be obtained since the number of measured potentials is far less than the number of dipoles in the solution space.

Low Resolution Brain Electromagnetic Tomography (LORETA)

LORETA provides a solution to the inverse problem by minimizing the total energy of the dipole magnitudes in the source space while satisfying the constraints imposed by the forward model. The LORETA pseudo inverse for $\mathbf{K}$ is [1]:

$$\mathbf{K}^{*} = \mathbf{W}^{-1}\mathbf{K}^{T}\left[\mathbf{K}\mathbf{W}^{-1}\mathbf{K}^{T}\right]^{-1} \tag{3}$$

$\mathbf{W}$ consists of a depth weighting factor and a 3D high pass filter to achieve maximal smoothness accounting for the correlated activity of adjacent sources.

Borgiotti-Kaplan Beamformer (BK Beam)

The BK Beam provides a solution to the inverse problem by focusing the measurement electrodes on each location in the solution space [2]. The estimated magnitude of the dipole at location $\mathbf{r}$, with orientation η, at time t, is the dot product of the potentials measured at the electrodes and the weight vector at that location [3]:

$$\hat{j}(\mathbf{r},\eta,t) = \mathbf{w}^{T}(\mathbf{r},\eta)\,\mathbf{v}(t) \tag{2}$$

$\mathbf{w}(\mathbf{r},\eta)$ is usually described in terms of its x, y, and z components. The weight vector is determined such that the total energy of the dipole magnitudes in the solution space are minimized subject to [3]:

$$\mathbf{w}_x^T(\mathbf{r})\mathbf{w}_x(\mathbf{r}) = 1,\ \mathbf{w}_x^T(\mathbf{r})\mathbf{k}_y(\mathbf{r}) = 0,\ \mathbf{w}_x^T(\mathbf{r})\mathbf{k}_z(\mathbf{r}) = 0 \quad (5)$$

The solution to this problem is [3]:

$$\mathbf{w}_x(\mathbf{r}) = \mathbf{R}^{-1}\mathbf{k}_x(\mathbf{r})A_x(\mathbf{r}) \quad (6)$$

where $\mathbf{w}_x(\mathbf{r})$ is the x component of the weight vector, $\mathbf{k}_x(\mathbf{r})$ is the x component of the lead-field matrix, $\mathbf{R} = \langle \mathbf{v}(t) \cdot \mathbf{v}^T(t) \rangle$ is the covariance matrix of the measured scalp potentials and $A_x(\mathbf{r})$ is a scalar that ensures unity white noise gain [3]. Similar expressions can be obtained for $\mathbf{w}_y$ and $\mathbf{w}_z$.

2. Methods

A realistic head model is used for the simulated source localizations. The geometric properties of the model are obtained from 176 slices of T1 weighted NMR images of a human head. The model is digitized onto a regular grid with 1 mm resolution and segmented using a semi-automatic dynamic edge tracer segmentation algorithm into eight tissue types [4].

The lead-field matrix is obtained using the finite difference method [5]. The solution space is placed along the cortical gray matter/white matter boundary and contains 61 041 dipole sources.

The EEG is simulated using a single 17 Hz sinusoidal source, oriented normally to the cortical surface, located at randomly chosen locations in the solution space. The scalp potentials are calculated using (1) at 32 scalp locations. White noise simulating SNRs of 10, 5, and 2 is added at the scalp sites. One hundred trials are conducted with different source locations at each noise level.

3. Results

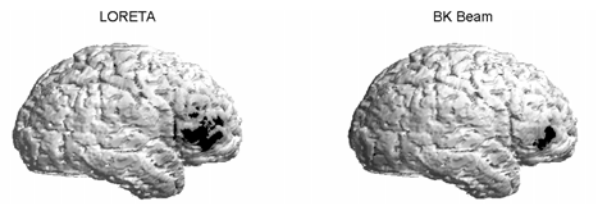

Fig. 1. Example inverse solutions for a single simulated source located in the right frontal lobe. SNR = 5.

The localization accuracy is the Euclidean distance between the actual dipole location and the global maximum of $\hat{\mathbf{j}}$.

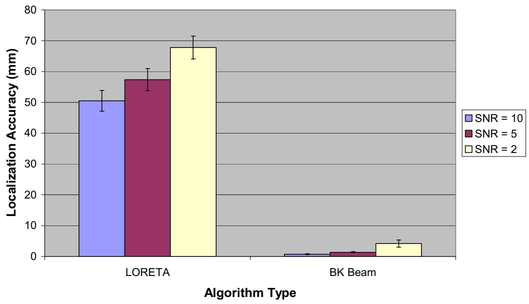

Fig. 2. Mean localization accuracy for 100 trials for varying SNR. Error bars represent standard errors of the mean.

4. Discussion

Of the two distributed source localization algorithms, BK Beam exhibited significantly better source localization than LORETA. The finding that LORETA does not provide accurate localization of dipole sources contradicts earlier findings [1] and we suggest that this might be due to the spherical head model used in the previous work. With a realistic head model, sources at different depths in the cortical solution space might well under lie the poorer performance provided by LORETA.

5. References

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