Directional Sensitivity of MEG Forward and Inverse Problems

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Abstract — An important properties of magnetoencephalography (MEG) is that MEG is insensitive to radially oriented sources even when the real shaped head model is adapted. Therefore we investigated the directional characteristics of MEG forward and inverse problems depending on the orientation and activated region of sources. Validation with simulated data shows that as the activated source region is extended beyond the 400mm^2 which is the threshold to produce a detectable MEG signal at the scalp, the directional characteristic of source is moderated and accuracies of forward and inverse problem are enhanced.

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I. Introduction

MEG have been widely used in clinical and cognitive neuroscience as powerful neuroimaging modalities that can estimate neuronal electrical activities with millisecond temporal resolutions [1]. Despite their excellent temporal resolution, however, the spatial resolutions provided by MEG are not comparable to that provided by functional magnetic resonance imaging (fMRI) or positron emission tomography (PET) due to limited spatial samplings and additive noise/artifacts. The spatial resolutions of MEG can be substantially improved by performing source imaging or by solving an inverse problem to estimate the source which is generated by the activities of large pyramidal cortical neurons.

It is well known that the radially oriented dipoles do not produce any external magnetic field outside a spherically symmetric head model, regardless of the sensor orientation [2]. Though the human head is not exactly spherically symmetric, MEG is still insensitive to radially oriented dipoles even when the real shaped head model is adapted [3]. In contrast to the equivalent current dipole (ECD) model, which assumes small numbers of current dipoles to approximate the flow of electrical current in a small brain area, the distributed source model assumes numerous current dipoles scattered in a limited source space to describe the distribution of activated neural source. Since the activated region of at least 400mm^2 was necessary to produce a detectable MEG signal at the scalp [4], the directional sensitivities of MEG can be an important element in the MEG forward and inverse problem using the distributed head model. Our goal is the quantitative analysis on the relation of directional properties of MEG and accuracy of MEG forward and inverse problem.

II. Method

While trivial in a spherical head model, the radial directions of cortical sources in a realistic geometric head model need to be defined differently. In the present study, the radial direction of a cortical source was defined as the orientation along which the total magnetic flux density generated by a unit dipole placed at a source location is minimized. To identify the radial direction, singular value decomposition was applied to the MEG leadfield matrix and the singular vector corresponding to the weakest singular value was assigned to the radial direction [5].

Neuroelectromagnetic inverse problems are hard to verify using in vivo experiments because exact source locations inside a human brain cannot be estimated a priori. Therefore, artificially-constructed forward data have been widely used. [6]. The MEG sensor layout used for the simulation was adopted from a commercial 148-channel whole-head magnetometer system (Magnets 2500 WH; Biomagnetic Technologies, San Diego, CA).

For accurate forward calculation, we applied a first-order node-based boundary element method (BEM) to calculate the forward magnetic field and electric potential distributions [7]. We obtained MEG leadfield matrices by applying BEM to three-layer tessellated boundary surfaces, consisting of the inner and outer skull boundaries and scalp surface. A total of 3,393 nodes were used for the node-based BEM computation. The relative conductivity values of the brain, skull, and scalp were assumed to be 1, 1/16 and 1 (S/m), respectively [8].

We assumed that current sources were constant cortical patches composed of a set of dipoles with constant dipole moments and orientations perpendicular to the cortical surface. To generate activation patches and construct a forward data set, we adopted the concept of a virtual area. The activation patch was generated using the following process: 1) a point was selected as a seed of an activation patch; 2) the patch was then extended to include neighboring vertices around the patch; 3) if the total virtual area of the cortical patch exceeded the target surface area, the extension of the activation patch was terminated [9]. To evaluate the accuracy of the reconstructed source, we adapted the correlation coefficient of the true and reconstructed source.

III. Result

To investigate the influence of the orientations of the cortical sources on MEG forward and inverse problem, the

4,568 source patches were classified on the basis of the proportion of the radial component γ, defined as

$$\gamma = \sum_{i \in \Pi} \frac{j_{r,i}^{\ 2}}{j_i^{\ 2}} \qquad (1)$$

where Π denotes the source patch area, i represents the i-th cortical vertex, j_i is the amplitude of a cortical source at the i-th vertex, $j_{r,i}$ is the amplitude of the radial component of a cortical source j_i and γ ranges from 0 to 1. A value of γ close to 0 indicates that a cortical source patch is oriented in the tangential direction, whereas a value of γ close to 1 indicates that a source patch is oriented in the radial direction.

The histogram depicted in Fig. 1 shows the distribution of the number of source patches with respect to γ. black and gray bars indicate the cases that the averaged area of the activation patches is 11.4mm^2 and 421.0mm^2 respectively. Compared that small activation patches (gray) are distributed in the radially oriented source region(γ>0.8), extended activation patches (black) are not placed on that region which implies that the radially oriented source are reduced as the source patch size increases.

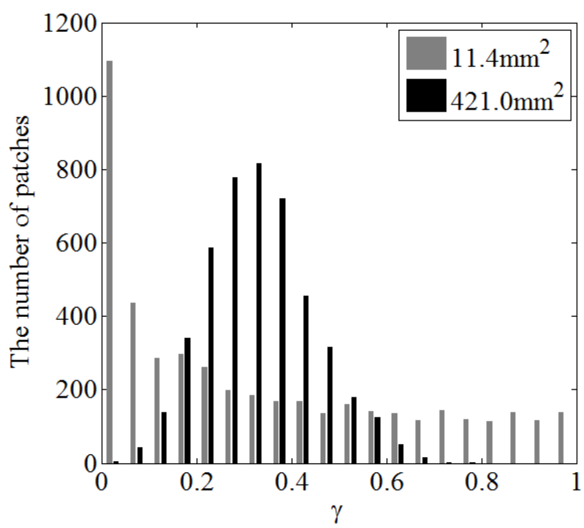

Fig. 1. distribution of source patches with respect to γ

Fig. 2 shows the results of MEG forward and inverse problem with sources whose center is placed on same location but different source area. We assumed that unit dipoles are located in every vertex within the patch and oriented to normal direction to the cortical surface. As the source area increases the power of detected MEG data increase linearly and the correlation coefficient of true and reconstructed source also increase. It means that when the source area is small, MEG forward and inverse problem is sensitive to the orientation of cortical source. However as the activated region is extended beyond the 400mm^2 which is the threshold to produce a detectable MEG signal at the scalp, the directional characteristic of source is moderated and accuracies of forward and inverse problem are enhanced.

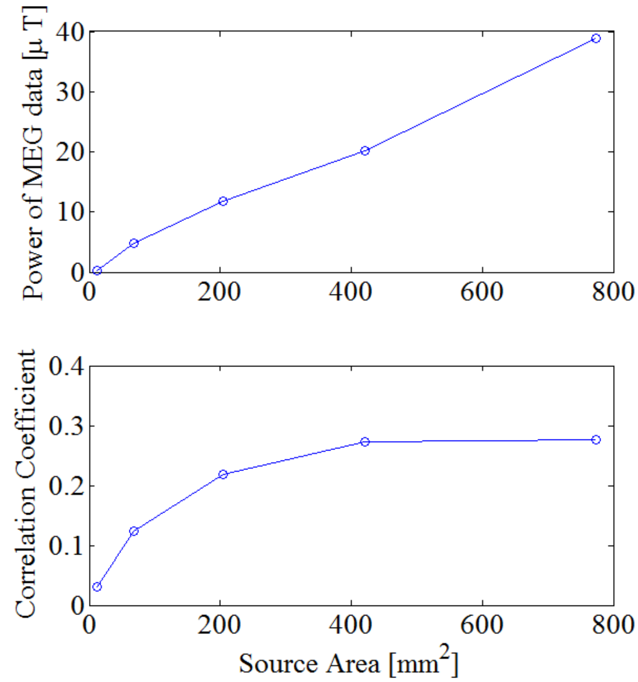

Fig. 2. Result of MEG forward and inverse problems

IV. References

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