

# Cortical Dipole Layer Imaging of Brain Electrical Activity in Horizontal and Sagittal Planes

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## Abstract

*Horizontal and sagittal dipole layer distributions were estimated from scalp electroencephalogram for three dimensional dipole imaging of brain electrical activity. Horizontal dipole layer being parallel to the brain surface has been used in previous head models. In the present study, the dipole layer distribution in the sagittal plane was also introduced to identify the position of dipole sources in three dimensions. The parametric projection filter was applied to an inverse problem in a homogeneous plane head model under various signal conditions. The present simulation results suggest that the depth information of dipole sources could be observed by the present method.*

## 1. Introduction

Cortical dipole layer imaging technique, which attempts to estimate the cortical dipole source distribution from the scalp potentials, is one of the spatial enhancement techniques of brain electrical activity [1]-[12]. The cortical dipole layer imaging has represented the two dimensional location of dipole sources on the dipole layer surface. However, it was difficult to recognize the depth of the dipole sources from this dipole layer distribution. In the present study, we expanded our two dimensional dipole layer imaging to three dimensional dipole layer imaging. To accomplish this aim, an additional dipole layer was assumed at the sagittal plane that was perpendicular to the horizontal dipole layer. The depth of sources would be observed in the sagittal dipole layer distribution. The performance of the proposed three dimensional dipole imaging has been evaluated by computer simulations in a homogeneous plane head model.

## 2. Cortical dipole imaging in sagittal plane

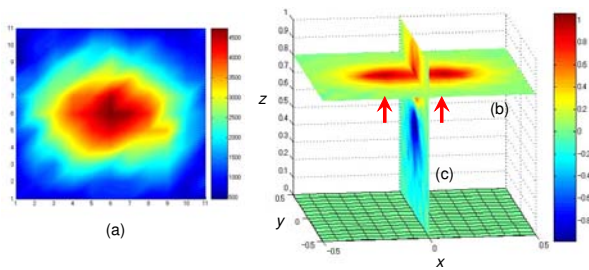
The electrical sources are equivalently represented by the dipole layer surrounding the sources. That is, the

dipole layer model used in the present study is an equivalent source model, which shall account for arbitrary source configurations within the dipole layer. The observation system of brain electrical activity on the scalp shall be defined using the transfer matrix from the equivalent dipole layer to the scalp potentials and additive noise. The transfer function is obtained by considering the geometry of the model and physical relationship between the quantities involved. The source distribution of the dipole layer shall be estimated from the scalp potential by applying the inverse filter of the transfer function [9], [10].

The proposed dipole layer imaging can represent arbitrary signal sources without *ad hoc* assumption on the number of source dipoles. However, it is difficult to obtain the information on the depth of the sources from the dipole layer distribution. We proposed new cortical dipole layer distribution on the sagittal plane in addition to the horizontal dipole layer. Radial equivalent dipole sources are uniformly distributed over the layers. The transfer function from the sagittal dipole layer to the scalp potentials are obtained as the same manner as horizontal dipole layer.

## 3. Simulation results

We have examined the inverse problem of the cortical dipole layer imaging in a homogeneous plane head model. The horizontal and sagittal dipole layers were set at  $z = 0.8$  and  $x = 0$ , respectively.  $15 \times 15$  radial dipoles were uniformly distributed on each dipole layer. Two dipoles were used as the sources to examine the spatial resolution of the estimated solutions. The scalp potentials measured with  $11 \times 11$  electrodes were contaminated with 10% Gaussian white noise. We have applied parametric projection filter to the inverse problem of the cortical dipole layer imaging [9], [10]. Figure 1 shows an example of the inverse solution of dipole layer imaging. Color maps show the normalized data by maximum and minimum values. The scalp



**Fig. 1. Simulation results of dipole imaging. (a) Scalp potential map at  $z = 1$ . (b) and (c) correspond to estimated dipole layer distributions in horizontal and sagittal planes, respectively. The vertical dipole sources are located at  $(\pm 0.15, 0, 0.6)$ .**

potential was blurred and contaminated with noise and hard to distinguish two poles (a). On the other hand, two well-localized areas were easily observed from estimated dipole layer distributions in horizontal plane (b). Moreover, the sagittal dipole layer distribution demonstrated that the brain electrical activity in vertical section (c). The position of dipole sources were easy to recognize at the center between plus and minus poles. It was confirmed that the directions of dipole sources were parallel to sagittal dipole layer.

#### 4. Discussion

The horizontal equivalent dipole layer can be set at arbitrary depth inside of the brain. However, it is difficult to estimate the depth of dipole sources. Thus, in the present study, we considered to estimate the 3D location of the equivalent dipole sources from the dipole layer imaging. Since vertical dipole layer has information on the depth of sources, we used sagittal dipole layer distributions for brain imaging.

Our trial simulations were performed with a homogeneous plane head model. In this model, we also applied this method to the radial, tangential, and leaning dipole sources and obtained the appropriate dipole source distributions in the sagittal plane. For cortical dipole source imaging, inhomogeneous sphere head model and realistic-shaped head model which represented the electrical activities on the brain surface have been proposed. Even if these models were constructed by considering the geometry of human brain, the depth information could not be represented. By combining these models with proposed model, we will obtain more precise brain electrical activity.

#### 5. Summary

We proposed a new cortical imaging model constructed horizontal and sagittal dipole layers for

three dimensional imaging of brain electrical activity. Dipole layer distributions in the sagittal plane which represent the vertical electrical activity was estimated from scalp electroencephalogram. The present simulation results suggest that the depth information of dipole sources could be equivalently observed by the present method. Further investigation using more realistic head conductor model and experimental data is necessary to fully validate the performance of the proposed model in cortical dipole imaging.

#### References

- [1] M. Hamalainen and R. Ilmoniemi, "Interpreting measured magnetic fields of the brain: estimates of current distributions," Univ. Helsinki, Finland Tech. Rep. TKK-F-A559, 1984.
- [2] R. Sidman, M. Ford, G. Ramsey, and C. Schlichting, "Age-related features of the resting and P300 auditory evoked responses using the dipole localization method and cortical imaging technique," *J. Neurosci. Meth.*, vol.33, pp.23-32, 1990.
- [3] J.Z. Wang, S.J. Williamson, and L. Kaufman, "Magnetic source images determined by a lead-field analysis: The unique minimum-norm least-squares estimation," *IEEE Trans. Biomed. Eng.*, vol.39, pp.665-675, 1992.
- [4] R. Srebro, R.M. Oguz, K. Hughlett, and P.D. Purdy, "Estimating regional brain activity from evoked potential field on the scalp," *IEEE Trans. Biomed. Eng.*, vol.40, pp.509-516, 1993.
- [5] F. Babiloni, C. Babiloni, F. Carducci, L. Fattorini, C. Anello, P. Onorati, and A. Urbano, "High resolution EEG: a new model-dependent spatial deblurring method using a realistically-shaped MR-constructed subject's head model," *Electroenceph. Clin. Neurophysiol.*, vol.102, pp.69-80, 1997.
- [6] Y. Wang and B. He, "A computer simulation study of cortical imaging from scalp potentials," *IEEE Trans. Biomed. Eng.*, vol.45, pp.724-735, 1998.
- [7] G. Edlinger, P. Wach, and G. Pfurtscheller, "On the realization of an analytic high-resolution EEG," *IEEE Trans. Biomed. Eng.*, vol.45, pp.736-745, 1998.
- [8] B. He, "High resolution imaging of brain electrical sources," *IEEE Eng. Med. Biol.*, Sept., pp.123-129, 1998.
- [9] J. Hori and B. He, "Equivalent dipole source imaging of brain electric activity by means of parametric projection filter," *Annals Biomed. Eng.*, vol.29, pp.434-445, 2001.
- [10] J. Hori, M. Aiba, and B. He, "Spatio-temporal dipole source imaging of brain electrical activity by means of time-varying parametric projection filter," *IEEE Trans. Biomed. Eng.*, vol.51, no.5, pp.768-777, May 2004.
- [11] B. He, D. Yao, and J. Lian, "High resolution EEG: on the cortical equivalent dipole layer imaging," *Clinical Neurophysiology*, vol.113, pp.227-235, 2002.
- [12] B. He, Neural Engineering, Kluwer Academic Publishers, 2005.