Beamspace dual signal subspace projection (bDSSP): A method for separating deep brain activities from superficial brain activities:

Kensuke Sekihara[1,2], Yoshiaki Adachi[3],
Hiroshi K. Kubota[4], Srikantan S. Nagarajan[5]

1) Tokyo Medical and Dental University
2) Signal Analysis Inc.
3) Kanazawa Institute of Technology
4) Ricoh Ltd.
5) University of California, San Francisco

Outline

We have proposed a novel method for separating deep brain activities from superficial brain activities. The proposed method is based on the ideas of beamspace methodology [1,2] and of dual signal subspace projection[3].

The prerequisite of the method is prior knowledge on the approximate location of the deep source. The method first computes beamspace basis vectors using the information on the location of deep source. It then projects the data vector onto the inside and outside the span of the beamspace basis vectors, creating two sets of data matrices. The intersection of the row spans of these two matrices is estimated as the time-domain signal subspace of the superficial sources.

The original data matrix is projected onto the subspace orthogonal to this signal subspace to suppress the activities of the superficial sources. The proposed method is validated by the computer simulation and by experiments using a phantom that has two sources, corresponding to deep and superficial sources.

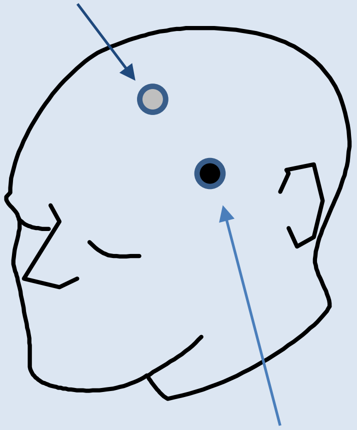
[References]

[1] Özkurt, T. E., Sun, M., & Sclabassi, R. J. (2008). Decomposition of magnetoencephalographic data into components corresponding to deep and superficial sources. *IEEE Transactions on Biomedical Engineering*, *55*(6), 1716-1727.

[2] Rodríguez-Rivera, A., Baryshnikov, B. V., Van Veen, B. D., & Wakai, R. T. (2006). MEG and EEG source localization in beamspace. *IEEE Transactions on Biomedical Engineering*, *53*(3), 430-441.

[3] Sekihara, K., Kawabata, Y., Ushio, S., Sumiya, S., Kawabata, S., Adachi, Y., & Nagarajan, S. S. (2016). Dual signal subspace projection (DSSP): a novel algorithm for removing large interference in biomagnetic measurements. *Journal of neural engineering*, *13*(3), 036007.

Beamspace processing



Beamspace processing is a method of projecting the data vector onto a low-dimensional subspace by using

$$\boldsymbol{y}(t) = \sum_{j=1}^{r} c_j(t)\boldsymbol{u}_j$$

where $r \ll M$, and $\boldsymbol{u}_1, \ldots, \boldsymbol{u}_r$ are the beamspace basis vectors.

The gram matrix, which represents the second moment of the lead field matrix, is computed from a small, localized region that contains the deep source.

The basis vectors, $\boldsymbol{u}_1, \ldots, \boldsymbol{u}_r$, can be obtained from the eigenvectors corresponding to distinctively large singular values.

Beamspace projector is obtained such that:

$$\boldsymbol{P}_b = \left[\boldsymbol{u}_1, \ldots, \boldsymbol{u}_r\right]\left[\boldsymbol{u}_1, \ldots, \boldsymbol{u}_r\right]^T$$

bDSSP Algorithm

Data Model:

$$\boldsymbol{B} = \boldsymbol{B}_D + \boldsymbol{B}_{SP} + \boldsymbol{B}_\varepsilon$$

$\boldsymbol{B}_D$: Signal from deep source,

$\boldsymbol{B}_{SP}$: Signal from superficial source,

$\boldsymbol{B}_\varepsilon$: Sensor noise.

Using the beamspace projector, DSSP computes two kinds of spatiotemporal matrices:

$$\boldsymbol{P}_b\boldsymbol{B} = \boldsymbol{B}_D + \boldsymbol{P}_b\boldsymbol{B}_{SP} + \boldsymbol{P}_b\boldsymbol{B}_\varepsilon$$
$$(\boldsymbol{I} - \boldsymbol{P}_b)\boldsymbol{B} = (\boldsymbol{I} - \boldsymbol{P}_b)\boldsymbol{B}_{SP} + (\boldsymbol{I} - \boldsymbol{P}_b)\boldsymbol{B}_\varepsilon$$

DSSP estimates the signal subspace of the superficial source, using:

Signal subspace of the superficial source

= row space of $\boldsymbol{B}_{SP} \approx$ (row space of $\boldsymbol{P}_b\boldsymbol{B}$) $\cap$ (row space of $(\boldsymbol{I} - \boldsymbol{P}_b)\boldsymbol{B}$)

bDSSP Algorithm-continued

SVD of $\boldsymbol{P}_b\boldsymbol{B}$ and $(\boldsymbol{I}-\boldsymbol{P}_b)\boldsymbol{B}$:

$$\boldsymbol{P}_b\boldsymbol{B} = \boldsymbol{S}\Lambda\boldsymbol{D}^T = \boldsymbol{S}\Lambda\left[\boldsymbol{d}_1,\ldots,\boldsymbol{d}_\phi,\ldots,\boldsymbol{d}_M\right]^T$$

$$(\boldsymbol{I}-\boldsymbol{P}_b)\boldsymbol{B} = \boldsymbol{T}\Lambda'\boldsymbol{E}^T = \boldsymbol{T}\Lambda'\left[\boldsymbol{e}_1,\ldots,\boldsymbol{e}_\varphi,\ldots,\boldsymbol{e}_M\right]^T$$

Orthonormal basis vectors of the intersection between span$\{\boldsymbol{d}_1,\ldots,\boldsymbol{d}_\phi\}$ and span$\{\boldsymbol{e}_1,\ldots,\boldsymbol{e}_\varphi\}$ can be obtained using an algorithm described in [4]:

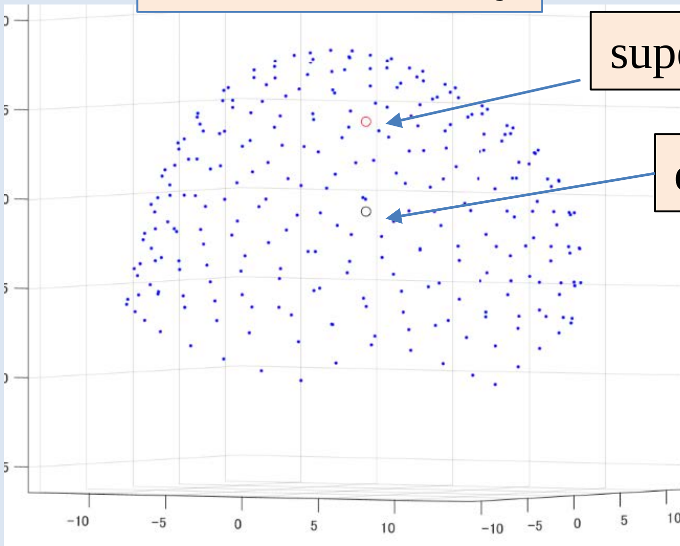
Denoting these basis vectors by $\boldsymbol{\psi}_1,\ldots,\boldsymbol{\psi}_r,$ signal from the deep source can be retreived using:

$$\hat{\boldsymbol{B}}_D = \boldsymbol{B}(\boldsymbol{I}-[\boldsymbol{\psi}_1,\ldots,\boldsymbol{\psi}_r][\boldsymbol{\psi}_1,\ldots,\boldsymbol{\psi}_r]^T)$$

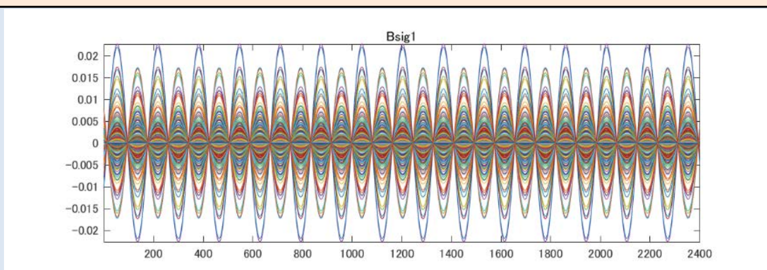
[4] Golub G. H. , Van Loan C. F. (1996) Matrix computations. The Johns Hopkins University Press, Baltimore and London

Computer simulation

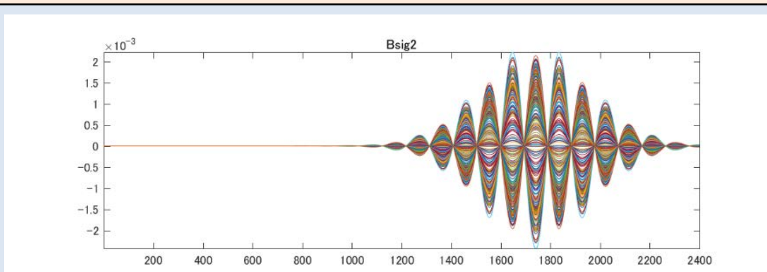
CTF sensor array



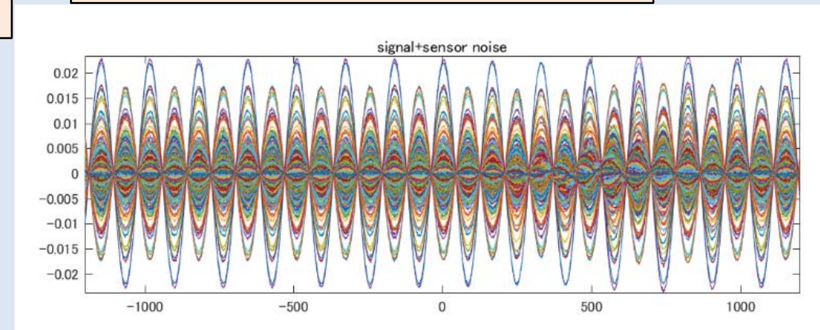
Sensor time courses corresponding to the superficial source activity



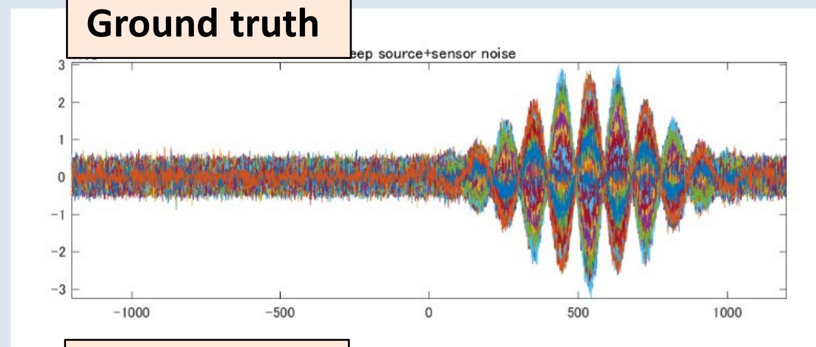
Sensor time courses corresponding to the deep source activity



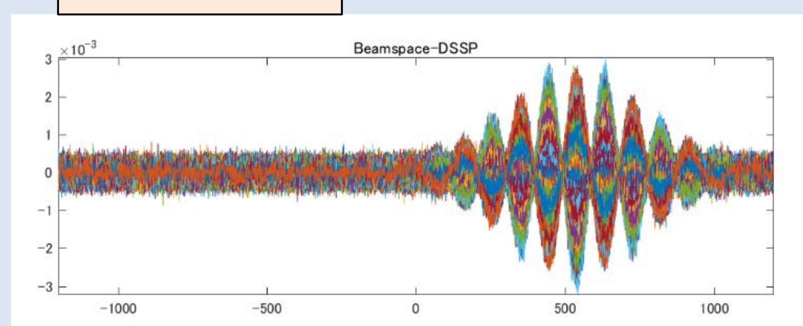
Simulated sensor time courses



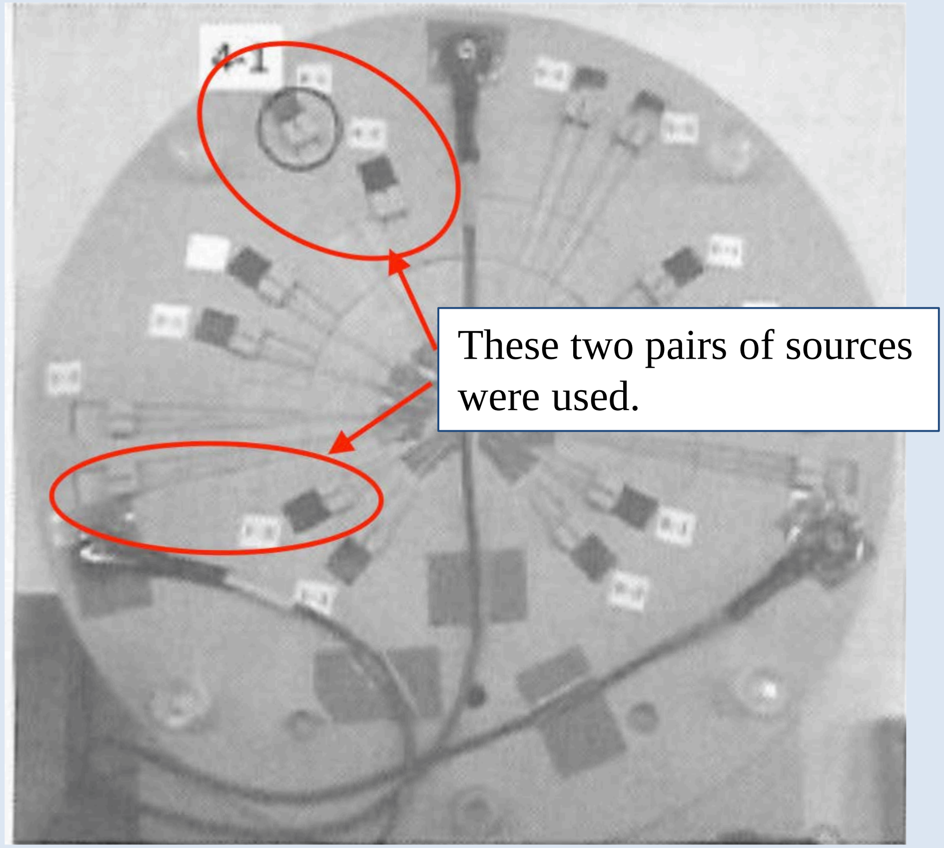
Ground truth



bDSSP results



Disc-shaped dry phantom used in our experiments

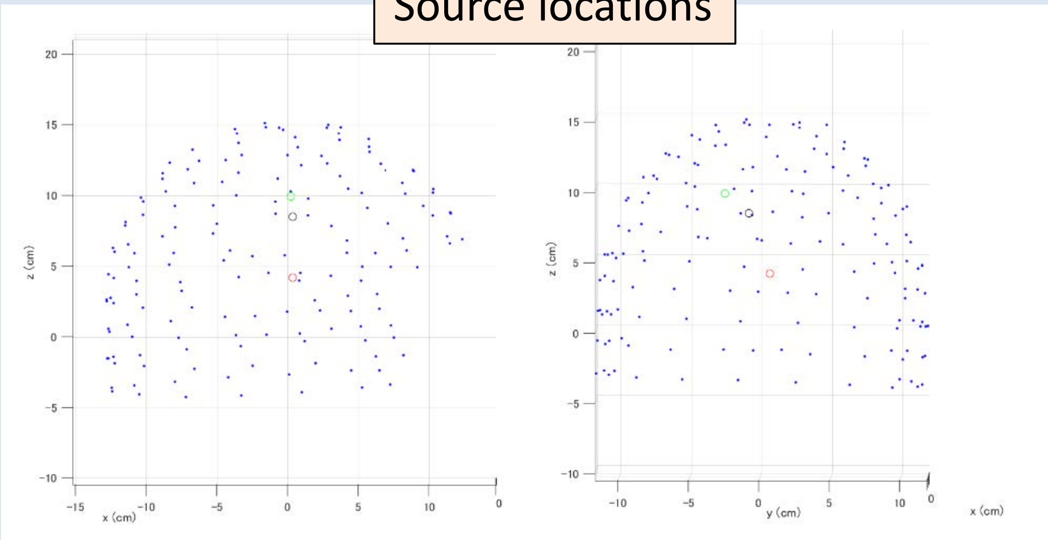


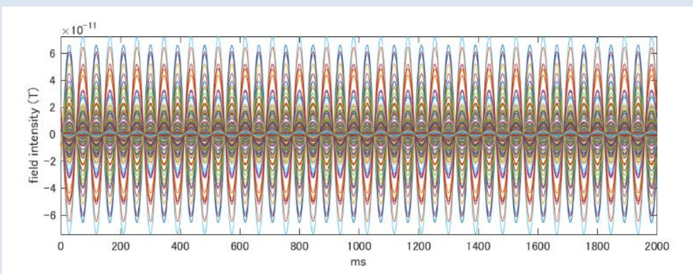
M. Kubota et al. “Disc-shaped dry phantom with a rotating mechanism”, Proceedings of 28th annual conference of Japanese Biomagnetism Society, Vol.26, 268-269, 2013.

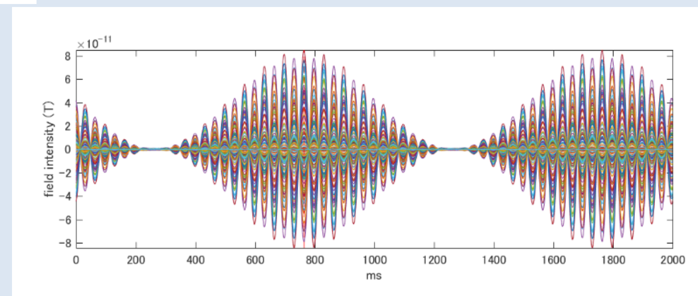
Phantom experiment I

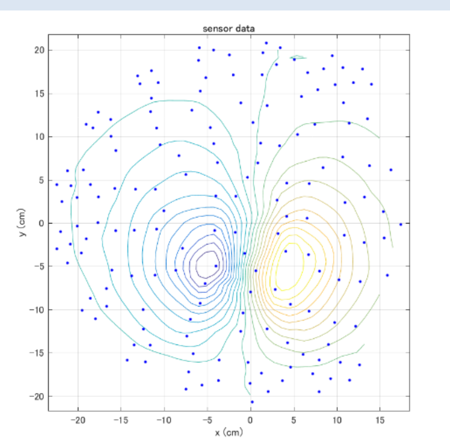
- Two sources near Parietal lobe.
- Source are 2cm apart.
- Ricoh 160-channel sensors used.

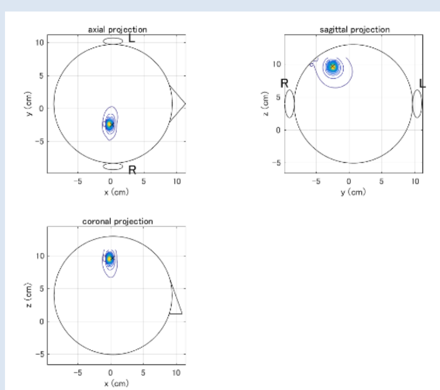
Source locations



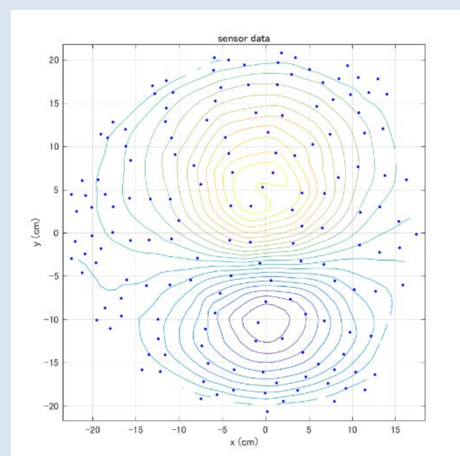


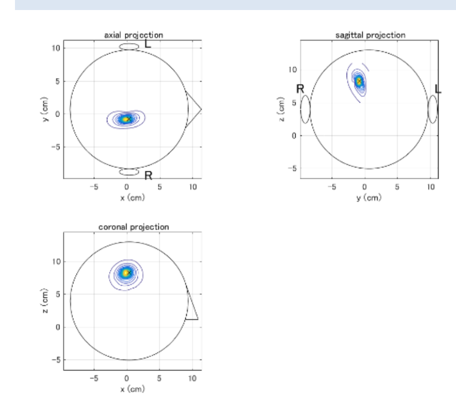






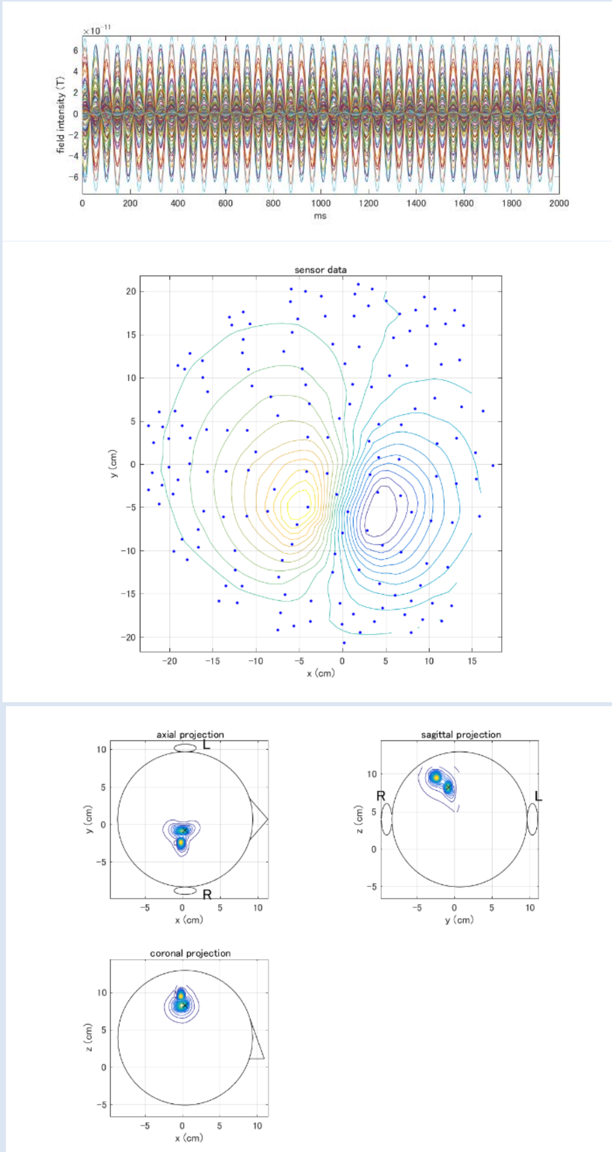
Superficial source



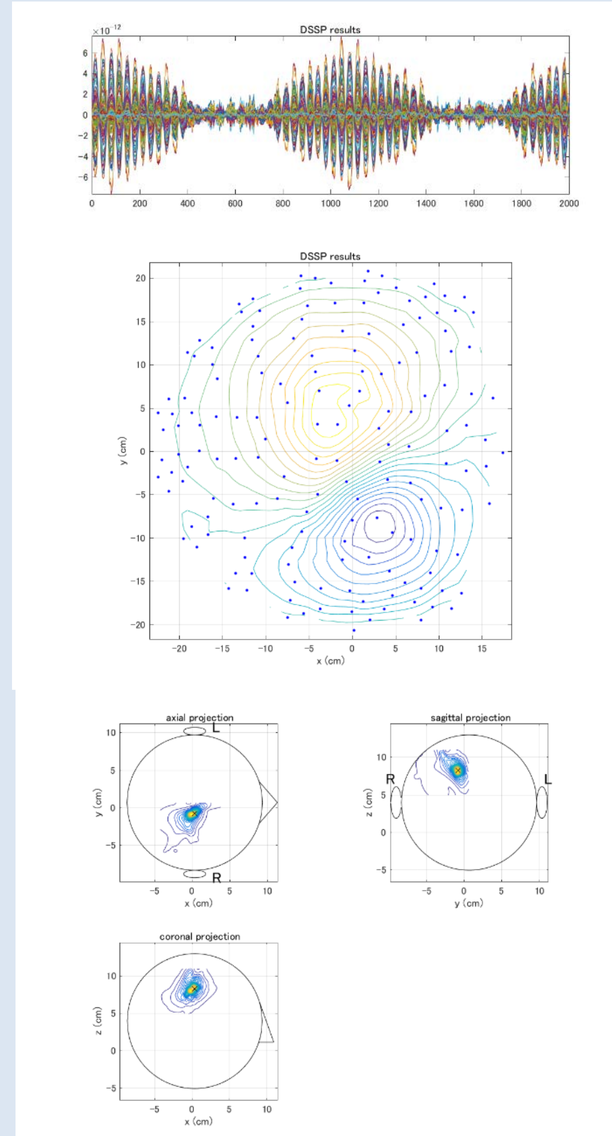


Deep source

Simulated sensor data when two sources are active

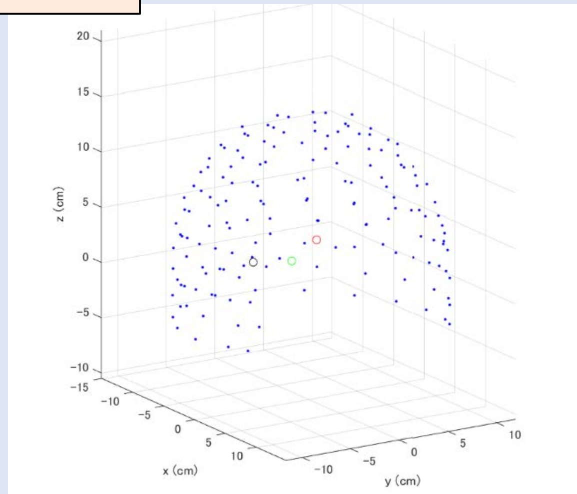


bDSSP results of estimating deep source activity



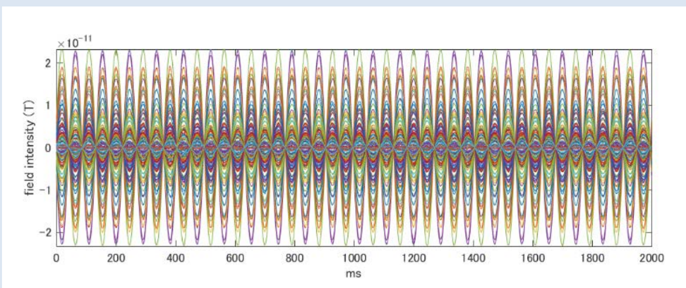
superficial source:1.42mA, deep source:0.225mA

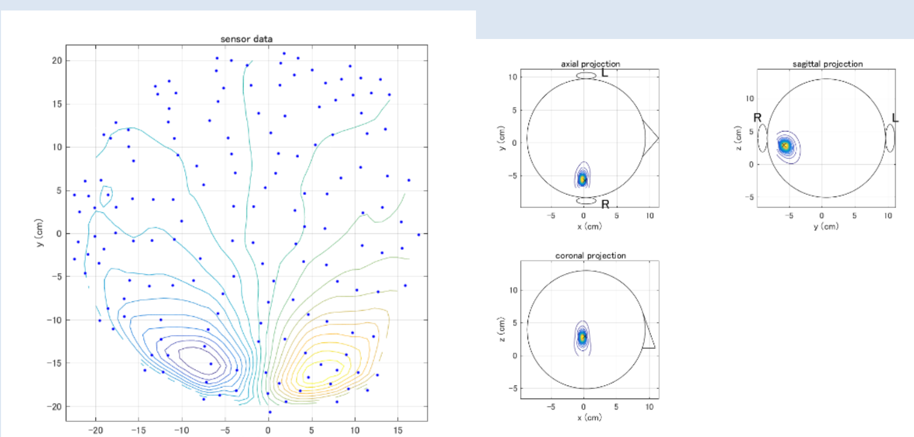
ソース位置



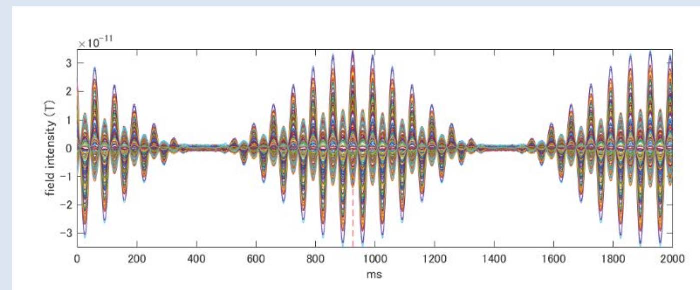
Phantom experiment II

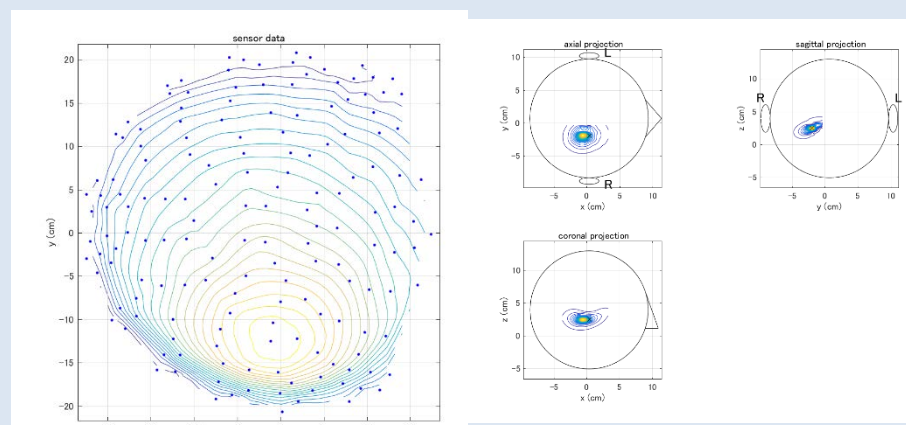
- Two sources near Temporal lobe.
- Source are 4cm apart.
- Ricoh 160-channel sensors used.





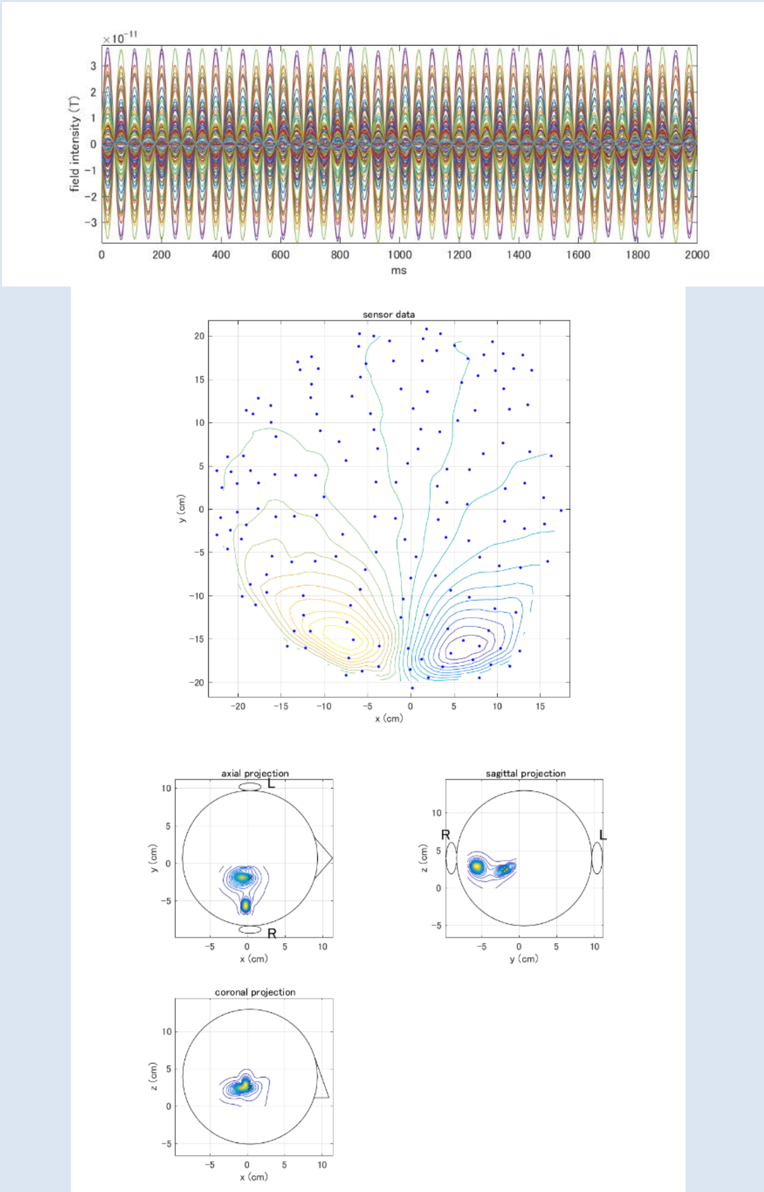
Superficial source activity



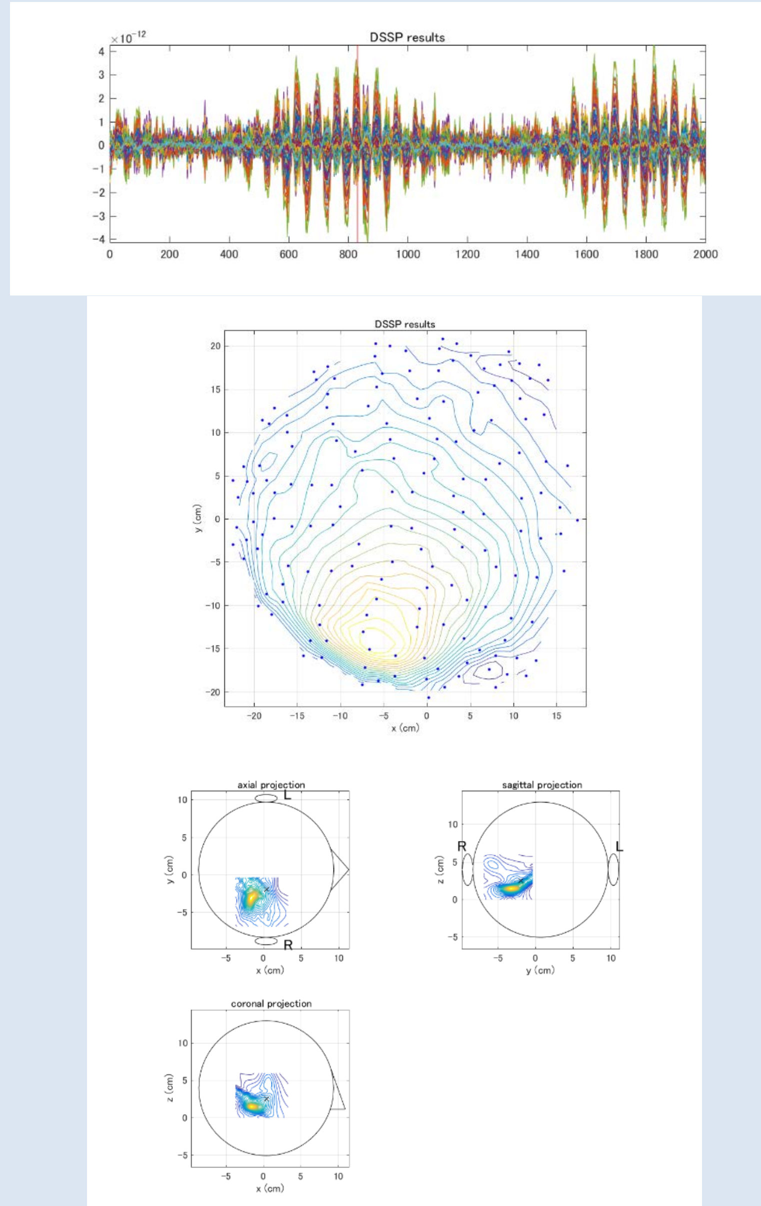


Deep source activity

Simulated sensor data when two sources are active



bDSSP results of estimating deep source activity



superficial source:1.14mA, deep source:0.25mA

Summary

- **A novel algorithm, called bDSSP, is proposed to separate deep brain activities from superficial brain activities.**
- **Results of computer simulation and experiments using phantom data show the effectiveness of the proposed algorithm.**

The paper "Subspace-based interference removal methods for multichannel biomagnetic sensor arrays" has been accepted for publication in Journal of Neural Engineering.
The PDF can be downloaded from: