Environmental noise cancellation for room-temperature magneto-resistive (MR) sensor arrays

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Outline

Development of a sensor system that can measure biomagnetic signals in a room-temperature environment has gained great interests.

Particularly, MR sensors are promising candidates for room-temperature biomagnetic systems because the MR sensor system can lead to developing novel low-initial-cost and maintenance-free biomagnetic instruments.

However, to attain such a goal, an efficient method of environmental noise cancellation method should be developed. This is because with such low-cost instruments, the cost for a magnetic shielded room should also be low.

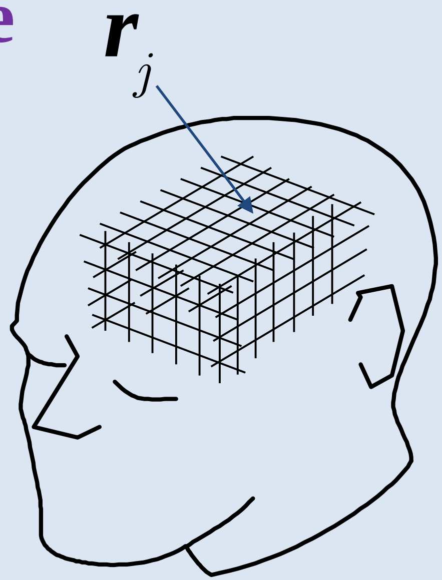
Outline-continued

In our study, we have applied DSSP algorithm previously-proposed for removing the stimulus-induced artifacts in magnetospinography to remove environmental noise.

We present results of our experiments in which the sixty four channel MCG data were measured at COEX hotel lobby as a part of commercial exhibition/demonstration in Biomag Soul 2016.

We show that, although the data contained a large amount of environmental noise, the DSSP algorithm was able to remove the most of these noise, demonstrating the effectiveness of the DSSP algorithm in environmental noise cancellation.

Projector onto pseudo-signal subspace



Voxel Lead field Matrix

$$\boldsymbol{L}_V = \begin{bmatrix} \boldsymbol{l}(\boldsymbol{r}_1), & \cdots, & \boldsymbol{l}(\boldsymbol{r}_N) \end{bmatrix}$$

SVD of $\boldsymbol{L}_V$

$$\boldsymbol{L}_V = \boldsymbol{U}\boldsymbol{\Gamma}\boldsymbol{V}^T = \begin{bmatrix} \boldsymbol{u}_1, \ldots, \boldsymbol{u}_M \end{bmatrix} \begin{bmatrix} \gamma_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & \gamma_M \end{bmatrix} \boldsymbol{V}^T$$

Denoting distinctively large singular values by $\gamma_1, \ldots, \gamma_\xi$, singular vectors, $\boldsymbol{u}_1, \ldots, \boldsymbol{u}_\xi$ form orthonormal basis vectors of the pseudo signal subspace.

Pseudo signal subspace projector: $\boldsymbol{P} = \begin{bmatrix} \boldsymbol{u}_1, \ldots, \boldsymbol{u}_\xi \end{bmatrix} \begin{bmatrix} \boldsymbol{u}_1, \ldots, \boldsymbol{u}_\xi \end{bmatrix}^T$

DSSP Algorithm

Data Model:

$$\boldsymbol{B} = \boldsymbol{B}_S + \boldsymbol{B}_I + \boldsymbol{B}_\varepsilon$$

Signal — Interference — Sensor noise

Using the pseudo signal subspace projector, DSSP computes two kinds of spatiotemporal matrices:

$$\boldsymbol{PB} = \boldsymbol{B}_S + \boldsymbol{PB}_I + \boldsymbol{PB}_\varepsilon$$

$$(\boldsymbol{I} - \boldsymbol{P})\boldsymbol{B} = (\boldsymbol{I} - \boldsymbol{P})\boldsymbol{B}_I + (\boldsymbol{I} - \boldsymbol{P})\boldsymbol{B}_\varepsilon$$

DSSP estimates the interference subspace using:

> Interference subspace = row space of $\boldsymbol{B}_I$
>
> $\approx$ (row space of $\boldsymbol{PB}$) $\bigcap$ (row space of $(\boldsymbol{I} - \boldsymbol{P})\boldsymbol{B}$)

DSSP Algorithm-continued

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

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

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

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 [1]:

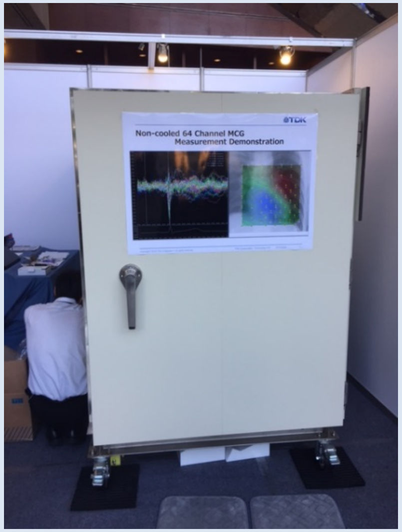
Denoting these basis vectors by $\boldsymbol{\psi}_1,\ldots,\boldsymbol{\psi}_r,$ DSSP algorithm removes interference by using:

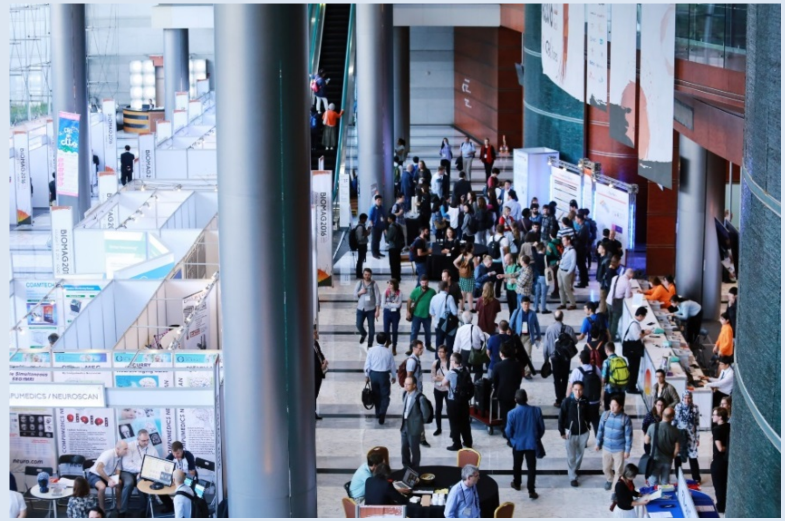
$$\hat{\boldsymbol{B}}_S = \boldsymbol{B}(\boldsymbol{I} - [\boldsymbol{\psi}_1,\ldots,\boldsymbol{\psi}_r][\boldsymbol{\psi}_1,\ldots,\boldsymbol{\psi}_r]^T)$$

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

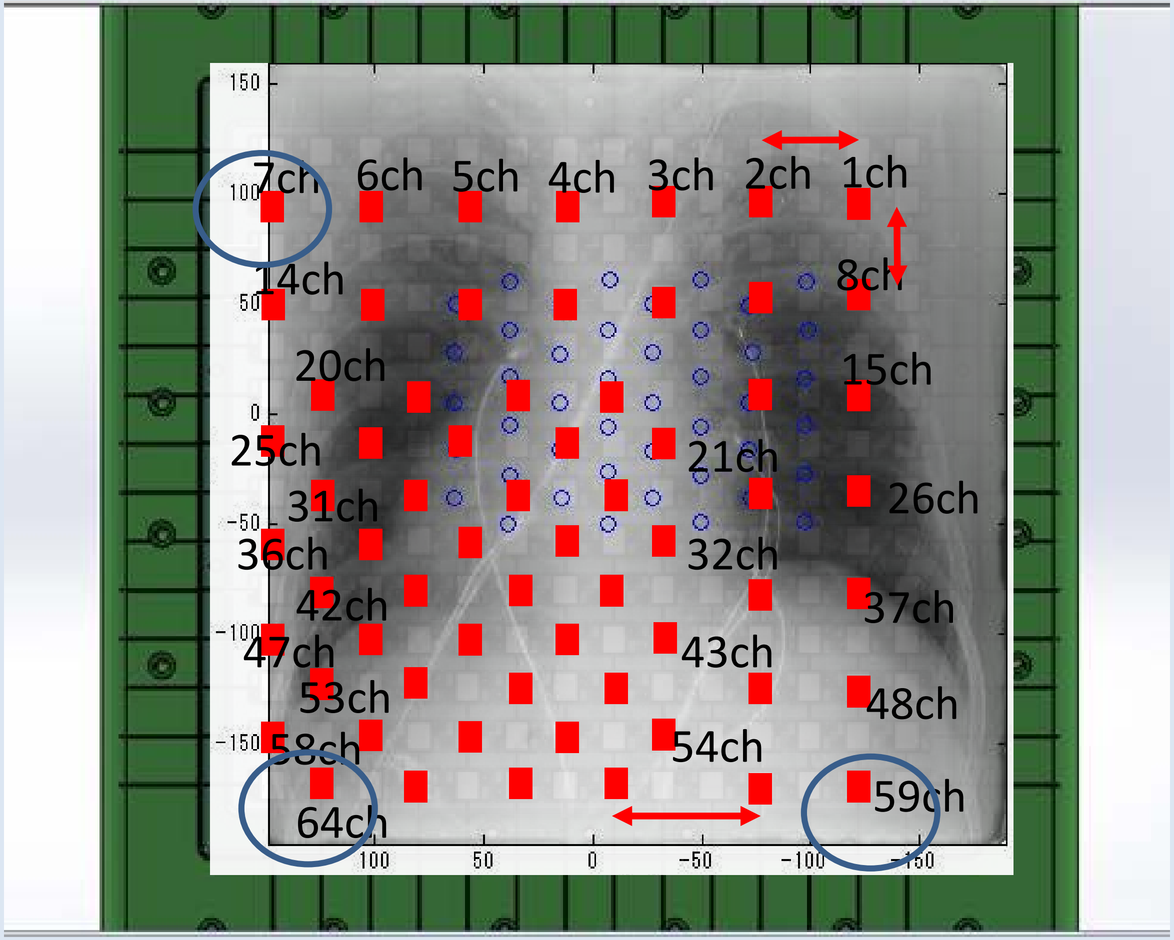
Commercial exhibition/demonstration in Biomag Soul 2016

MCG was measured from a number of volunteers





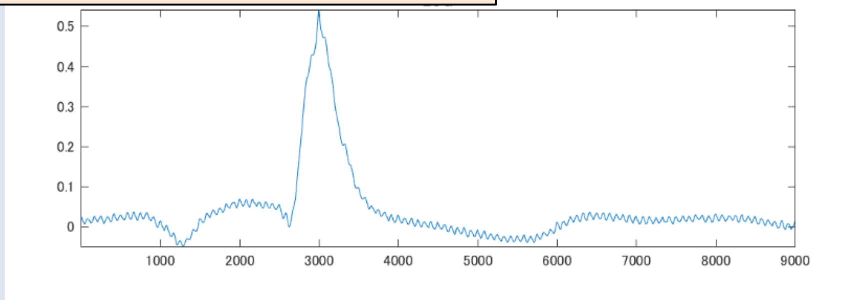
Sensor layout overlaid onto an X-ray projection image (a representative example)



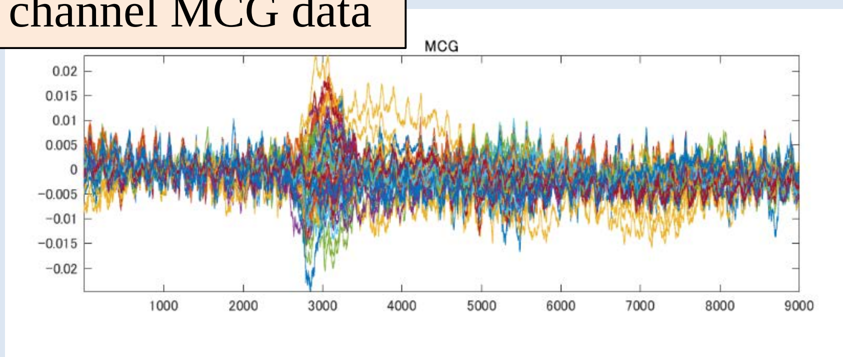
The 7th, 59th, and 64th channels were used as reference sensors in experiments using the adaptive noise cancelling

Case #1

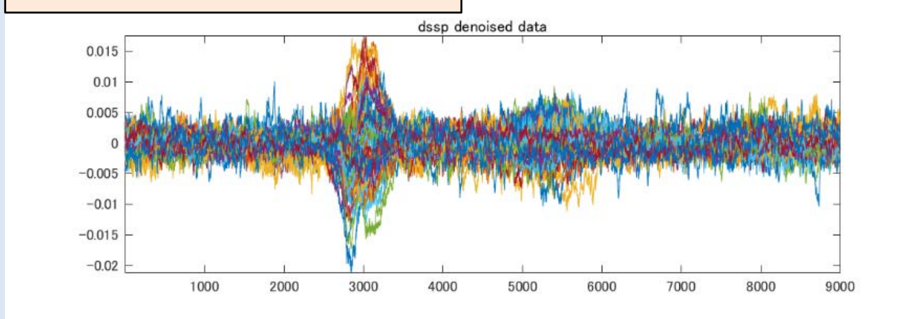
A single channel ECG data



64 channel MCG data

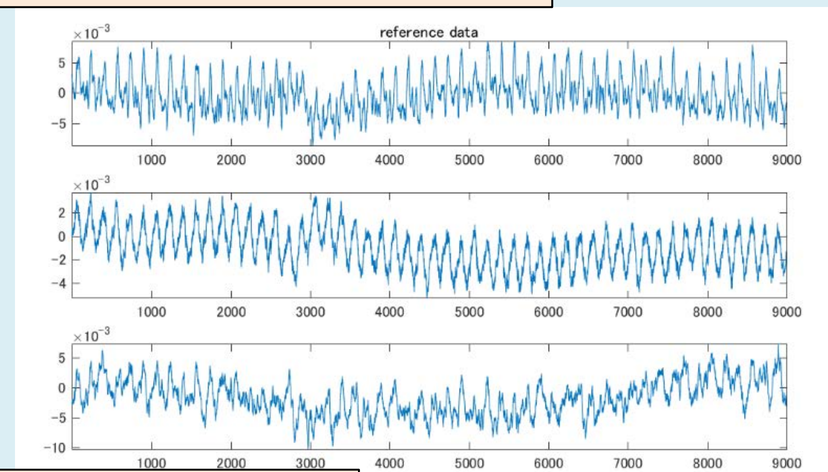


DSSP cleaned results

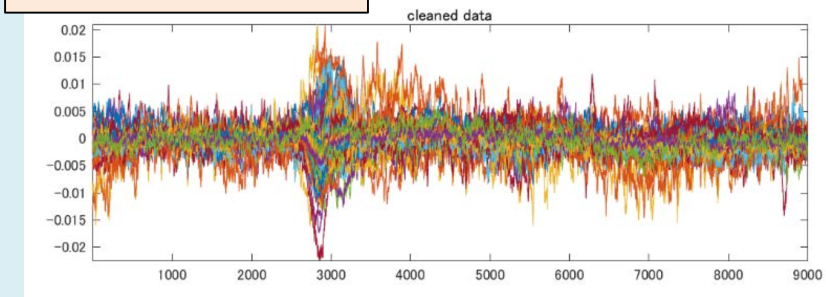


Adaptive noise cancelling experiments

Reference sensor data

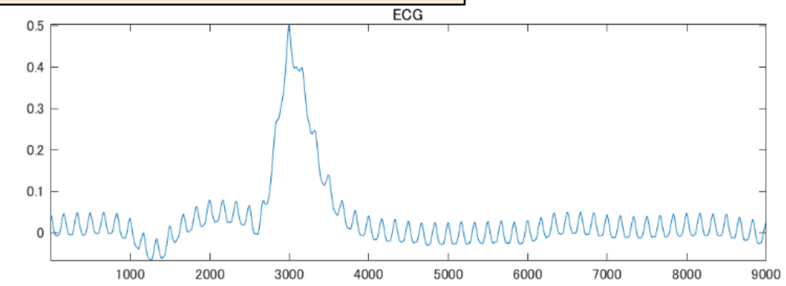


Cleaned results

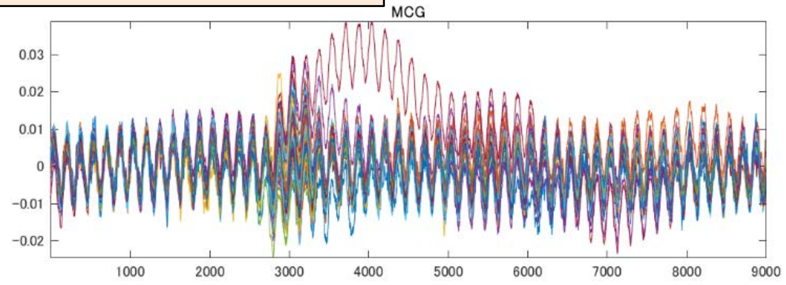


Case#2

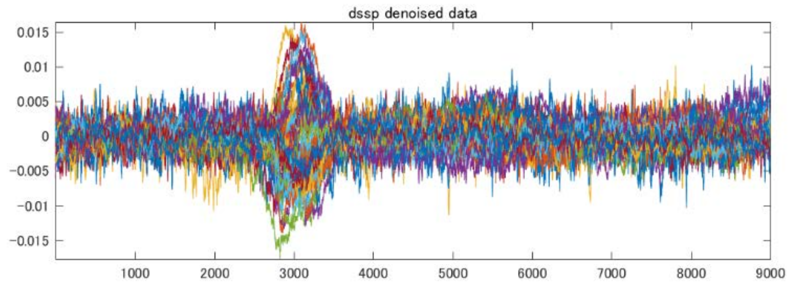
A single channel ECG data



64 channel MCG data

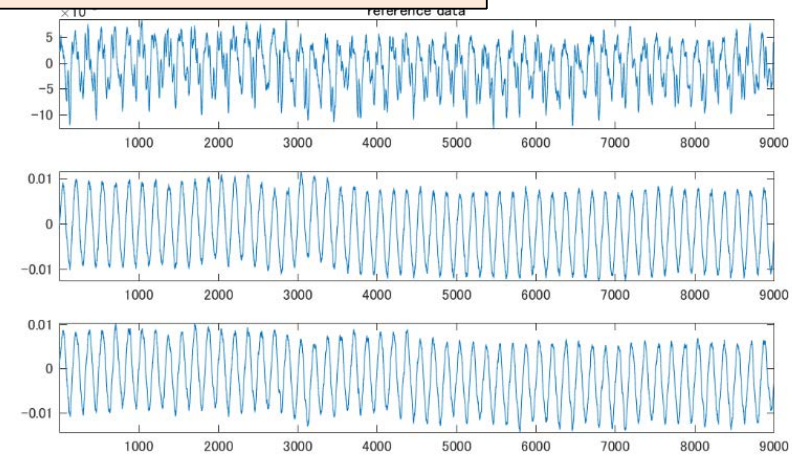


DSSP cleaned results

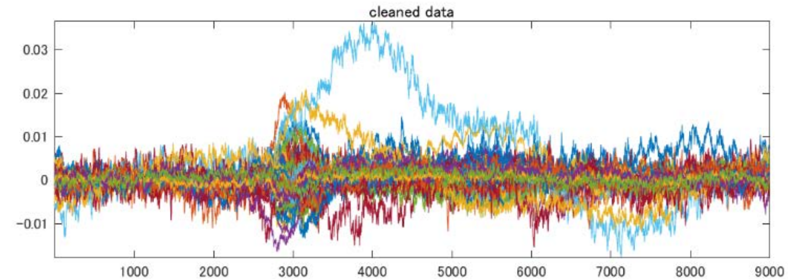


Adaptive noise cancelling experiments

Reference sensor data

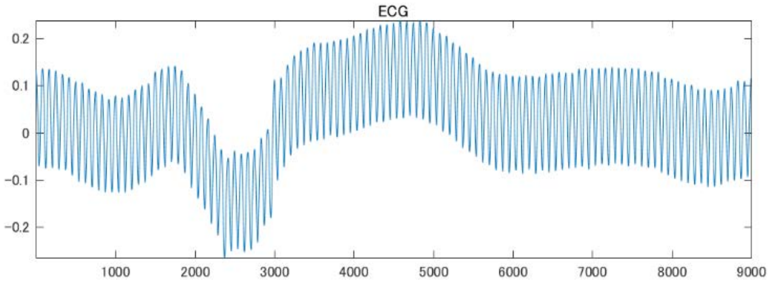


Cleaned results

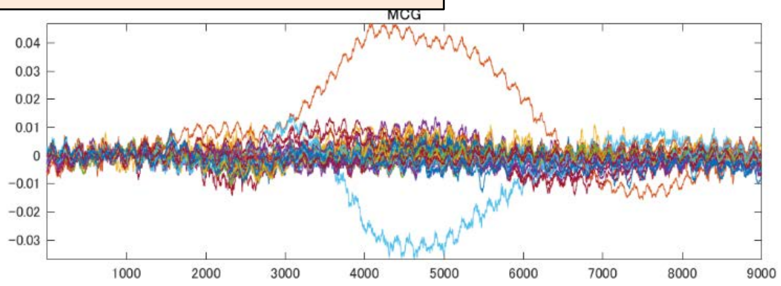


Case #3

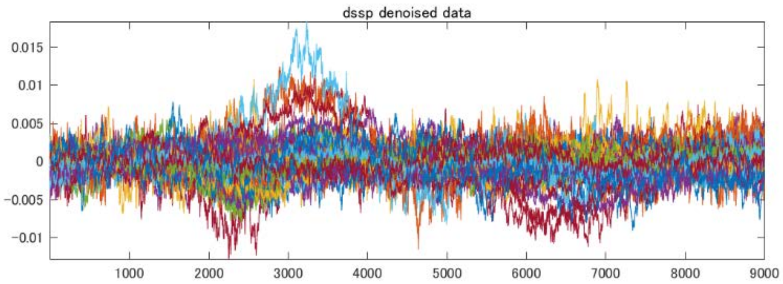
A single channel ECG data



64 channel MCG data

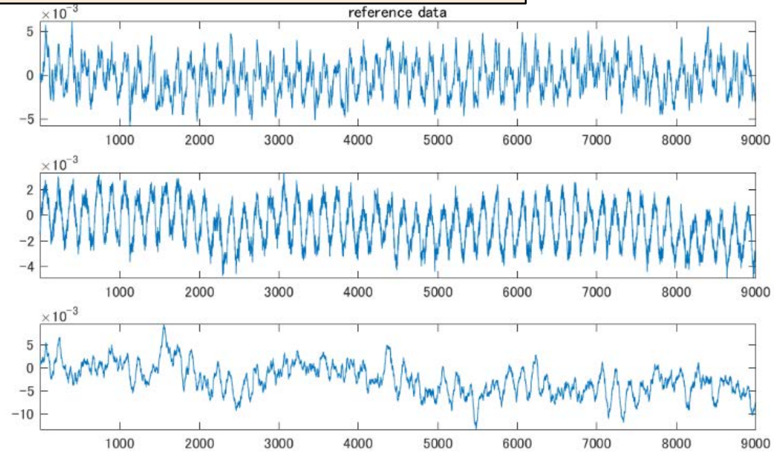


DSSP cleaned results

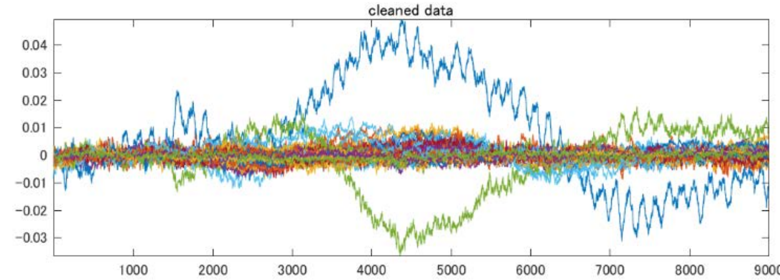


Adaptive noise cancelling experiments

Reference sensor data



Cleaned results



Summary

- The DSSP algorithm was applied to remove environmental noise from MCG data measured at COEX hotel lobby as a part of commercial exhibition/demonstration in Biomag Soul 2016.

- Although the data contained a large amount of environmental noise, the DSSP algorithm was able to remove the most of these noise, demonstrating the effectiveness of the DSSP algorithm in environmental noise cancellation.

The DSSP algorithm was published in Journal of Neural Engineering. The PDF can be downloaded from

http://www.signalanalysis.jp/images/dssp.pdf

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: