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Functional source imaging of human spinal cord electrical activity from its evoked magnetic field

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1. Introduction

Background

In human spinal cord evoked magnetic fields (SCEFs) measurement, the three-dimensional source reconstruction is generally erroneous because the distance between the sensor array and the spinal cord is far.
The distance is typically 6 cm. Also, the false intensity change of the reconstructed source is caused by the depth non-uniformity of the spinal cord with respect to the sensor array.

Objectives

We propose a novel approach for imaging of the human spinal cord electrical activity.
Our proposed imaging method has two characteristics. One is the extraction of a plane including the subject's spinal cord from its X-ray image for the two-dimensional source reconstruction. The other is the application of the unit gain constrained minimum-norm (UGMN) [1] spatial filter, which is insensitive to the depth non-uniformity.

In this poster, we perform numerical experiments comparing the reconstruction results from the sLORETA used in our animal experiments [2] and the UGMN spatial filter.
We also apply the proposed imaging method to the patient's SCEF measurement data to demonstrate that the imaging of the spinal cord electric activity provides useful clinical information for diagnosing human spinal cord disorders.

2. Method & Numerical Experiments

Method

The weights and gains for unit-magnitude source of the sLORETA and the UGMN spatial filter

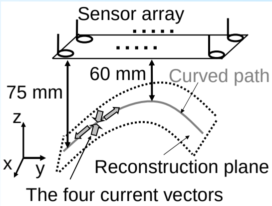
- $\boldsymbol{L}(\boldsymbol{r})$: lead field matrix, $\boldsymbol{G}$: gram matrix

	sLORETA	UGMN
$\boldsymbol{W}^T(\boldsymbol{r})$	$[\boldsymbol{L}^T(\boldsymbol{r})\boldsymbol{G}^{-1}\boldsymbol{L}(\boldsymbol{r})]^{-\frac{1}{2}}\boldsymbol{L}^T(\boldsymbol{r})\boldsymbol{G}^{-1}$	$[\boldsymbol{L}^T(\boldsymbol{r})\boldsymbol{G}^{-1}\boldsymbol{L}(\boldsymbol{r})]^{-1}\boldsymbol{L}^T(\boldsymbol{r})\boldsymbol{G}^{-1}$
Gain	$[\boldsymbol{L}^T(\boldsymbol{r})\boldsymbol{G}^{-1}\boldsymbol{L}(\boldsymbol{r})]^{\frac{1}{2}}$	1

The gain depends on $\|\boldsymbol{L}(\boldsymbol{r})\|$.

Since there are several sources in the SCEF measurement [1], it is difficult to compensate for each source by those of gains.

The UGMN spatial filter has a unit gain.

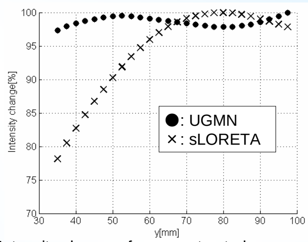


Source detector configuration

Numerical experiments

- We use a model consisting of four equi-intensity current vectors for expressing the SCEF sources [2].
- These four sources travel along a curved path.
- The magnetic field induced by these sources is calculated by using the Biot-Savart law.
- We apply the sLORETA and the UGMN spatial filter to the magnetic field data on a plane that contains the curved path.

Results



Intensity change of a reconstructed source

- The results from sLORETA have the false intensity change.
- The UGMN spatial filter can reconstruct the accurate source intensity.

3. Human SCEF Measurement & Source Reconstruction

SCEF measurement

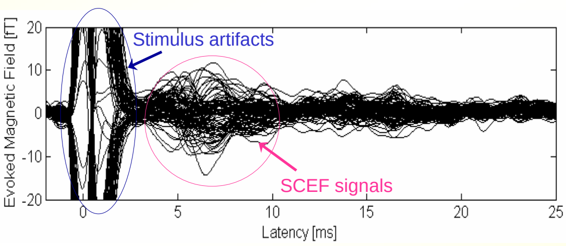
Measurement hardware

- The SCEF is measured using a 105-channel SQUID biomagnetometer system.

Measurement conditions

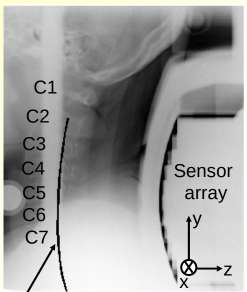
A patient's MRI

- Patient: 43 years old, female. A conduction block C5/6 vertebral level.
- Stimulus location: The patient's spinal cord at the level of lower thoracic spine.
- Stimulus current: Duration of 0.3 ms, intensity of 3 mA, repetition rate of 17 Hz.
- Data acquisition: 40 kHz sampling frequency, 500-5000 Hz bandpass filtering, 4000 epochs averaged.
- After the acquisition, a digital low-pass filter of 1290 Hz is applied to the averaged data.



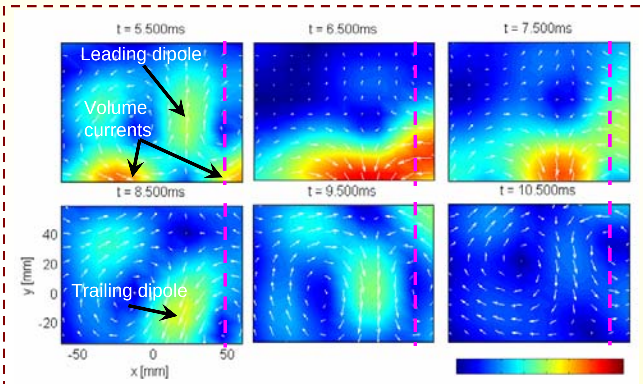
The measured waveforms of the SCEF

Reconstruction results



The subject's cervix and the sensor array

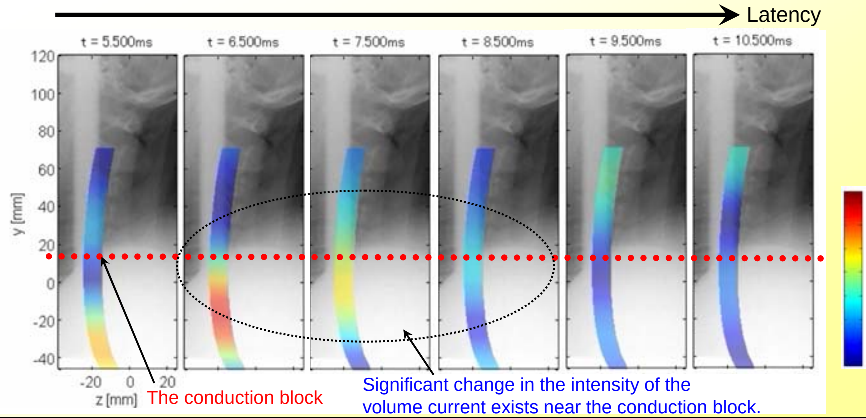
- A plane that contains the patient's spinal cord is extracted from X-ray image.
- We perform the two-dimensional UGMN spatial filter reconstruction on the curved plane.



The reconstructed source distributions from 5.5 ms to 10.5 ms

- The arrows indicate the source direction.
- The color represents the source intensity.

The distributions of reconstructed volume current on x = 50 mm



4. Conclusion

- Our proposed imaging method can reconstruct the human spinal cord electrical activity.
- Significant change in the intensity of the volume current near the conduction block can be visualized.

References

[1] Sato. T, Adachi. Y, Tomori. M, Ishii. S, Kawabata. S, and Sekihara. K, Spatial filter imaging of spinal cord evoked activity:Computer simulation and animal experiments, in Proceedings of the 16th International Conference on Biomagnetism , pp. 21–23, 2008.

[2] Sato. T, Adachi. Y, Tomori. M, Ishii. S, Kawabata. S, Sekihara. K, Functional imaging of spinal cord electrical activity from its evoked magnetic field, accepted for publication in IEEE Trans. Biomed. Eng.