



The Forward Problem of EEG Source Localization Using Current Density Imaging

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INTRODUCTION:

The inverse problem of electroencephalography (EEG) is to use electric potentials measured on the skin to determine the position, orientation, and strength of the bioelectric sources within the brain. A practical and accurate solution to this problem would provide the spatial position of EEG sources and would lead to fundamental advances in neurophysiology and neuropsychology.

To solve the EEG inverse problem, one must be able to solve the related forward problem. The forward problem is to compute the skin potentials given the position, orientation, and strength of the bioelectric sources. This computation critically depends on the shape and electrical conductivity of the fluids and tissues of the head, i.e. the head model. All present methods use an assumed head model to solve the forward problem. Most methods use a three or four shell sphere to approximate the head. Recently, the shell model has been geometrically refined from MRI and CT data; however, assumptions and rough approximations about tissue conductivity are still required. We propose to use a new MRI method called Current Density Imaging (CDI)[1][2] to replace the assumed head model with measurements. By using CDI, we aim to measure the lead fields of the skin electrodes. Knowledge of the lead fields will allow the skin potential to be easily computed without any assumptions about the head model. Our hypothesis is that solutions of the inverse problem of the EEG based on lead fields will be more accurate than those based on assumed head model. The ability to actually measure the lead fields of the skin electrodes is the novel aspect of our proposal.

OBJECTIVE:

The objective of this experiment was to show that current density imaged lead fields can solve the forward problem in a simple phantom.

MATERIALS AND METHODS:

A. The Phantom

A cylindrical phantom was built using Acrylic Plexiglass. A dipole was placed at the centre of the phantom. This dipole was constructed from a semi-rigid coaxial cable consisting of a 0.84 mm outside diameter shield made from pure copper, a Teflon PTFE insulator and an inner silver plated copper conductor. The phantom was then filled with Tissue-Mimicking gelatin-agar gel containing 40% animal hide gel and 60% agar [3].

For the lead field measurement, two EEG surface electrodes (E5SH, Astro-Med) were placed horizontally on the surface of the phantom, 126 mm apart. The two electrodes and the centre of the phantom were on the same line.

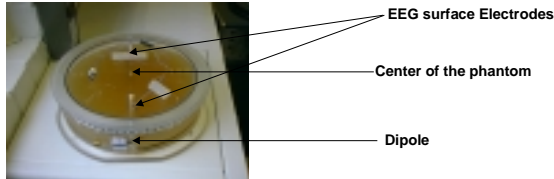


Figure 1. The phantom used for the experiment. For the injection of current and surface potential measurement, two EEG surface electrodes were placed on the surface of the phantom.

B. Computation of surface potential from dipole position and the measured lead fields

The surface electrode potential, V , was computed from the measured lead fields using following formula [from 4]:

$$V = \frac{J}{\sigma I} \cdot (iD) \quad (1)$$

Where, I is the current applied when J was measured (~200 mA).
 i is the current source used to create EEG measurements (~100 μ A).
 D is the length of the dipole source (~3mm).
 And σ is the electrical conductivity of the gel at the position of the dipole source.

C. Lead Field Measurement

The magnetic resonance imaging was performed with a General Electric 1.5 Tesla MR scanner. A modified spin echo MRI pulse sequence was used. The applied current pulse had a bipolar rectangular wave shape. Two orthogonal orientations of the phantom were required to measure the two components of B perpendicular to the dipole. For both orientations, 21 identical slices orthogonal to the dipole were obtained. Slices were five mm thick with a separation of zero mm.

$$\text{The current density } J \text{ was computed from: } J = \frac{1}{\mu_0} \nabla \times B \quad (2)$$

D. Conductivity measurement

Auto balancing bridge was used to measure the conductivity of the gel. A four-electrode technique was applied and the measurement was repeated for six different electrode positions.

E. Current Density calculation at the dipole position

The position of the dipole was determined from the MR images associated with current density images. The dipole appeared as a signal void in these images. It was assumed that dipole laid in the last consecutive slice in which this void appeared (Figure 2).

To estimate the current density in this images. It was assumed that dipole laid in the last consecutive slice in which this void appeared (Figure 2). To estimate the current density at the dipole position, an identical 10 x 10 pixel area, centred on the dipole position, was chosen and the current density of the pixels in this area was averaged. The procedure was repeated for the two slices below and two slices above the dipole.

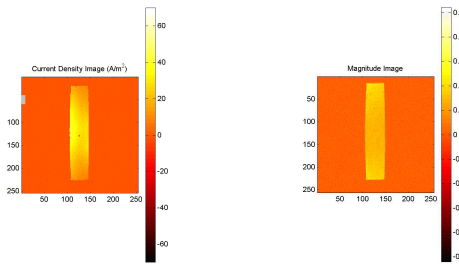


Figure 2. A coronal slice through the phantom. The dipole appeared as a signal void area at the centre of the current density image(left). The image on the right is the MR image associated with the current density image.

F. Potential measurement

The potential caused by the stimulation of the dipole source with sinusoidal current (~100 μ A) was measured using an EEG differential AC amplifier. The experiment was repeated on three consecutive days.

G. Forward solution accuracy

The accuracy of the forward problem was tested by comparing the calculated surface potential using measured lead fields with those measured using differential amplifier. The sources of error and their magnitude were determined through standard error analysis.

RESULTS AND DISCUSSION:

A. Conductivity measurement

The results (Figure 3) from four-electrode apparatus showed that conductivity of the gel is frequency independent (from 100Hz to 100kHz).

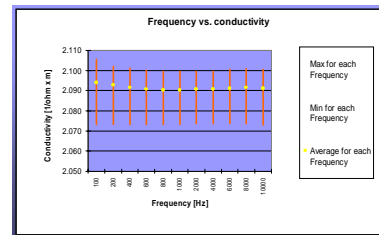


Figure 3. The min, the max and the averaged conductivity of all six electrode positions for each frequency. The results show that the averaged conductivities for all the frequencies are the same up to three decimal points.

B. Surface potential difference measurement

The results from surface potential difference measurement are shown in Figure 4.

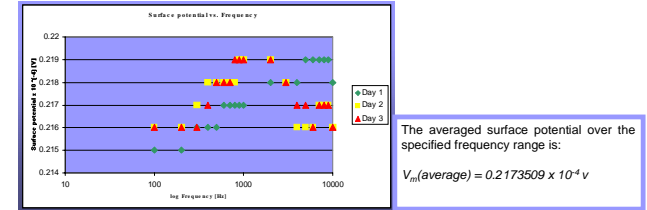


Figure 4. Surface potential measurement for different frequency. The measurement was repeated on three consecutive days. The results show that the measured surface potential was constant over the frequency range of 100Hz to 10kHz.

C. Calculating surface potential using measured lead fields

Using current density measured lead fields, the surface potential was calculated (using Equation (1)) to be:

$$V_c = 0.21735102 \times 10^{-4} \text{ v .}$$

D. Forward solution accuracy

Calculated Surface Potential using measured lead fields	Measured Surface Potential	%Difference
$V_c = 0.21735102 \times 10^{-4} \text{ v}$	$V_m = 0.2173509 \times 10^{-4} \text{ v}$	$(1.2 \times 10^{-3})\%$

The results show that the calculated surface potential using our current density imaging technique is similar to the measured one up to 5 decimal point . Our estimated measurement accuracy for V_c was 7.1% and for V_m was 5%. The small error that we found may have been random errors associated with the measurements or systematic errors associated with the instruments. Therefore, to prove the liability of our results and consequently our method, more measurements are required.

CONCLUSIONS:

We conclude that it is possible to use current density imaging to measure lead fields of the surface electrodes. This was the first time that the lead fields of the skin electrodes were actually measured.

The knowledge of current density imaged lead fields allowed the surface potential to be easily computed without any assumptions about conductivity and geometry of the medium. Therefore, we conclude that solution of the forward problem of EEG source localization using this method is more accurate than those using conventional methods.

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