BME511L: EEG Model Details

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The brain consists of about 10^{10} neurons, with varying shape, size, and orientations. Invidivudal neurons can generate a small amount of electrical activity, which cannot be picked up by surface electrodes on the scalp. However, when a large group of neurons is simultaneously activated, the resulting electrical activity is large enough to be picked up by the electrodes at the surface, generating the Electroencephalography (EEG).

1 Introduction

For my project, I plan to use four dipoles inside a three concentric-shell spherical head model to model the sources of EEG signals. The locations of the dipoles will be fixed within the spherical model but their dipole moments will be time-dependent. These dipole moments will be calculated using the Reciprocity Principle to generate EEG waveforms at five electrode locations to match those obtained in a real experiment.

Then I will conduct sensitivity analysis on how these calculated dipole moments will change given more noisy EEG measurements at the electrodes.

2 Model Details

2.1 Head Model

The head model used will be the three concentric spherical shell model, whose cross section is shown in Figure 1. [1] has shown that this model of the head is a useful representation for many purposes. [2] compared the data from the model to "electrolytic tank measurements employing a human skull, to in vivo data from within a monkey brain, and to in nivo data taken from the surface of the head [and found] with some minor exceptions... the correlations are such as to indicate clearly that the model has adequate accuracy for most purposes presently forseen".

The parameters for the head models are:

- Brain: radius=$8.0cm$, resisitivity=$222\Omega \cdot cm$.
- Skull: radius=$8.5cm$, resisitivity=$80 * 222\Omega \cdot cm = 17.76k\Omega \cdot cm$.
- Scalp: radius=$9.2cm$, resisitivity=$222\Omega \cdot cm$.

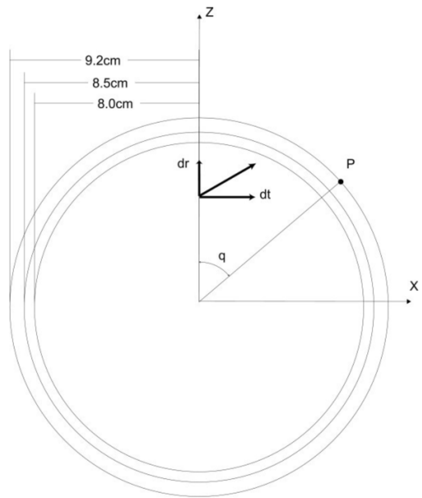

Figure 1: Cross section of the concentric shells head model. The shells from inside to outside represent the brain, skull, and scalp, respectively.

2.2 Dipole Sources

The generators of the EEG potential in my model will be 4 dipoles. I chose 4 because [4] has shown that 3 dipoles were able to explain 90% of the observed potentials measured at the EEG electrodes in its experiment. As shown in Figure 2, I have fixed the dipole sources within the brain-tissue (sphere of radius=8cm). The sources are evenly distribued in the y-z plane. In other words, the azimuth angle of the sources are 0. The Cartesian coordinates of the dipole sources are: $(0, 4, 4)$, $(0, 4, -4)$, $(0, -4, 4)$, and $(0, -4, -4)$.

2.3 Electrodes and Expected EEG Waveforms

The goal of the project is to determine the time-evolution of the four dipole sources needed to generate the EEG signals observed at the surface electrodes on the scalp. Since there are four dipole sources, there are 8 unknowns, therefore measurements at at least 5 electrodes are needed to solve this problem (4 electrodes provide only at most 6 equations).

I have chosen 5 electrode locations from the 10-20 system for EEG recording: *Cz*, *Fz*, *Pz*, *C3*, and *C4*. Figure 3 shows the electrode locations looking down at the top of the head. The Figure is generated from the EEGLab[5]. The Cartesian coordinates of the electrode locations are:

- Fz: $R_{scalp} * (0.715, 0, 0.700)$.
- Cz: $R_{scalp} * (0, 0, 1)$.
- Pz: $R_{scalp} * (-0.715, 0, 0.700)$.
- C3: $R_{scalp} * (0, 0.743, 0.699)$.
- C4: $R_{scalp} * (0, -0.743, 0.699)$.

, where R_{scalp} is the radius of the outermost shell.

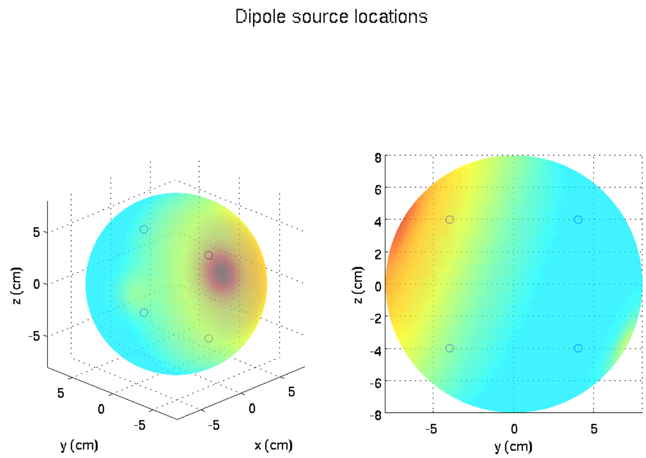

Figure 2: Left: 3D illustration of the dipole locations; Right: The dipole sources are evenly distributed in the y-z plane

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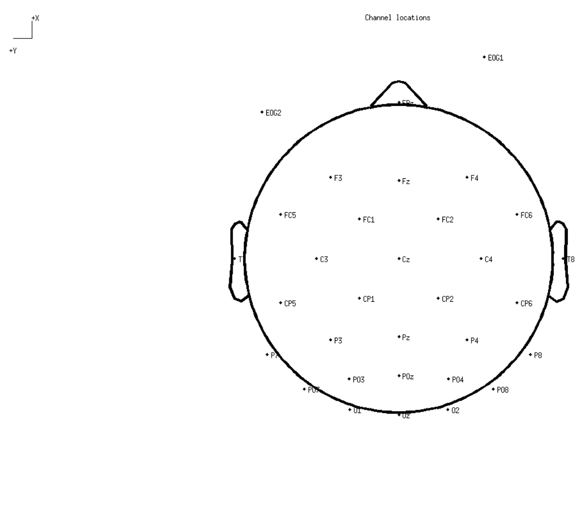

Figure 3: The 10-20 system for EEG electrode placements. The electrodes used in this model are *Cz*, *Fz*, *Pz*, *C3*, and *C4*

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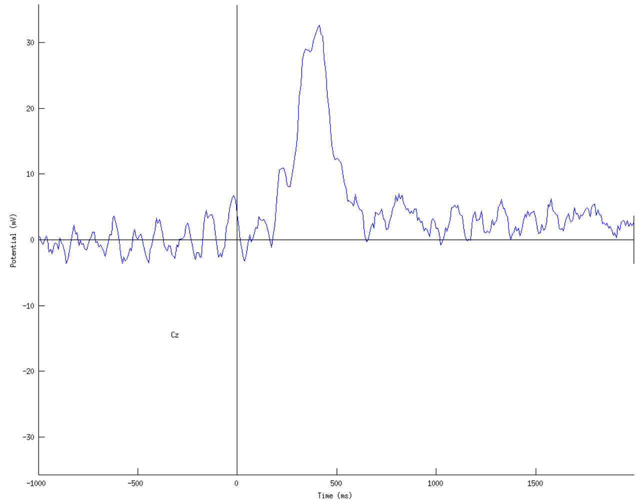

Figure 4: Expected waveform for Cz

The expected EEG waveform is obtained from the sample dataset that came with the EEGLab software[5]. The dataset was from the experiments conducted in [6]. In the experiment, subjects were to focus at one of five target locations along a horizontal line. Whenever a square appeared in that target location, the subject responds by pressing a button. Any other stimulus such as a circle appearing in the target location, or a square appearing in other locations should be ignored. During each trial, the event-related potentials (ERPs) were recorded.

The sample dataset includes 80 such trials for one subjects, 40 trials for target location 1, and 40 for target location 2. For my model, I will average the ERPs at my specified electrodes over all 80 trials, and calculate the time evolution of the source dipoles to obtain those waveforms. Figure 4-8 shows the expected waveforms.

2.4 Equations

The equations for my model is fairly straight-forward:

$$\nabla \cdot (-\sigma \nabla V) = 0$$

To calculate each of the lead-fields due to 8 pairs of electrodes (out of five total), we use this equation, and the boundary conditions:

- No flux conditions everywhere except for at the electrodes.
- The magnitude injected and sunk for each pair of electrodes is 1mA.
- Set the potential at the surface at the mid-point between the two electrodes for that given calculation to 0.

With the lead-fields calculated, we can then use the reciprocity theorem to calculate the source dipole

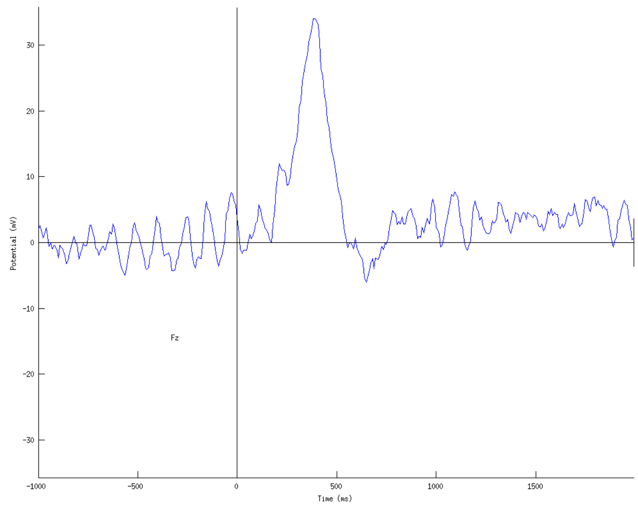

Figure 5: Expected waveform for Fz

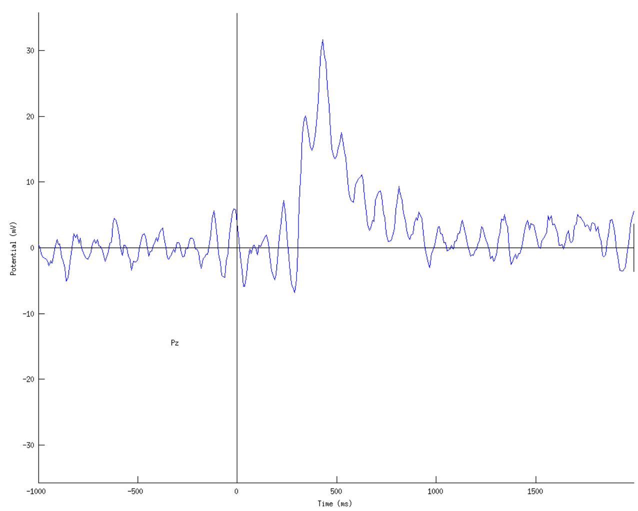

Figure 6: Expected waveform for Pz

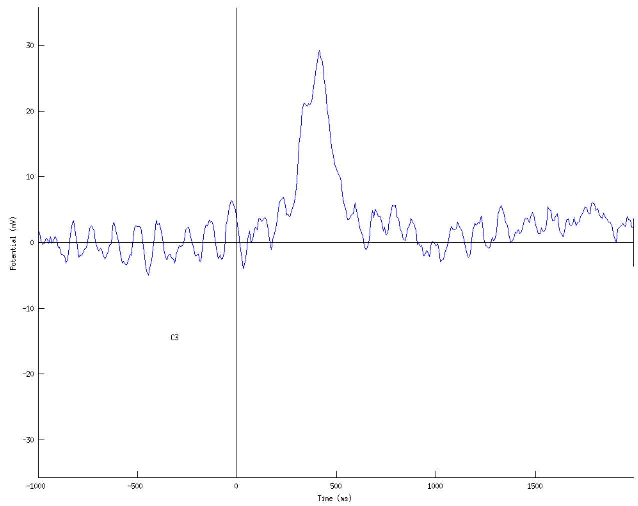

Figure 7: Expected waveform for *C3*

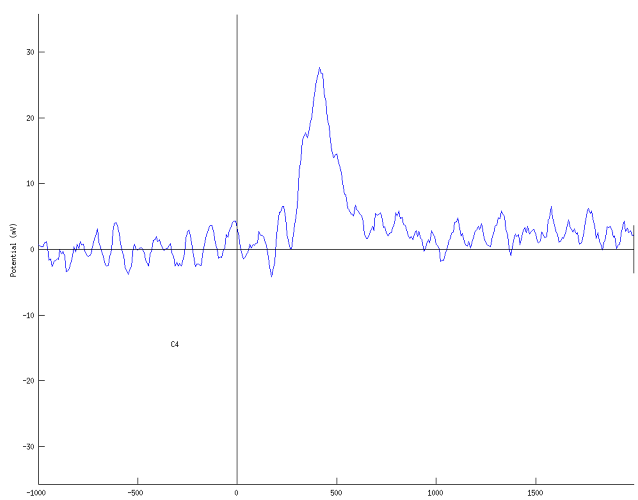

Figure 8: Expected waveform for *C4*

moments:

$$V_{ab} = \int_V \mathbf{J_i} \cdot \nabla \phi_2 dv$$

,where V_{ab} is the difference between the ERPs measured at electrodes a and b, ϕ_2 is the lead-potential due to that pair of electrodes inside the brain. We are then solving the inverse problem for the components of $\mathbf{J_i}$, which are the source dipole moments.

References

[1] Rush, S.; Driscoll, D. A.; "Current distribution in the brain from surface electrodes", *Anesthesia and Analgesia*, vol. 47, pp. 717-723, Nov-Dec 1968.

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