In this lab we go deeper into EEG source localization. First we will solve the forward problem and gain insight in how a dipole affects the potential distribution at the scalp. Next, we will solve the inverse problem and investigate what the effect is of the dipole estimation if an electrode is broken.

Forward problem

In this section an EEG fragment will be simulated. From the course we know that the EEG caused by a dipolar source can be written as

$$\mathbf{V} = \mathbf{L}(\mathbf{r})\mathbf{d} \quad (1)$$

where $\boldsymbol{V} \in \mathbb{R}^{m\times 1}$ is a set of electrode potentials (m is the number of channels), $\boldsymbol{r} \in \mathbb{R}^{3\times 1}$ and $\boldsymbol{d} \in \mathbb{R}^{3\times 1}$ are the dipole location and orientation, respectively. $\boldsymbol{L} \in \mathbb{R}^{m\times 3}$ is a matrix which is dependent on the headmodel properties (geometry, electrode locations, conductivities) and on the dipole location.
In this session we will use a 3 shell spherical head model with a standard electrode (see figure 1). The forward problem is then computed through an analytical formula. The implementation of this formula is beyond the scope of this exercise session.

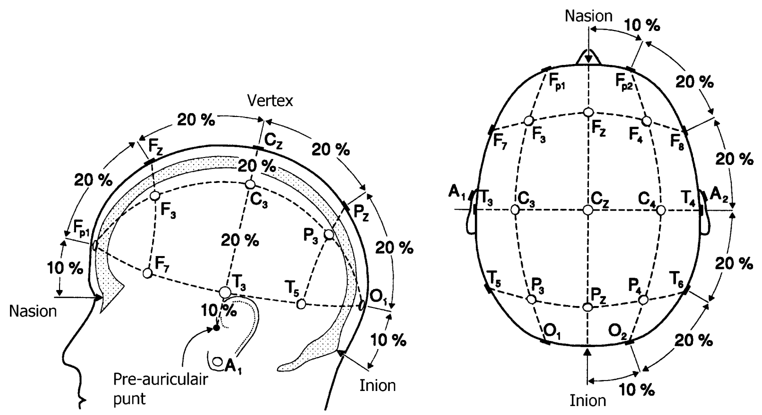

Figure 1: The 10-20 electrode setup

Preparation

Get the files EEGTools.zip from TOLEDO. Decompress the zip-files and put everything in one and the same folder. Include this folder in the MATLAB path settings (File -> Set Path… -> Add Folder).

1. Load the headmodel. You can find dat matlab datafile in EEGData.zip: `headmodel19.mat`. (the 19 stands for the number of electrodes and is in fact the setup that is used at the neurology department of the UZ Leuven). You should see two variable appearing in the workspace: `hm` and `grid`. The latter is of no importance throughout this practicum. `hm` is a structure of several fields. Investigate the structure by double clicking the matlab variable in the workspace. `hm` depicts a three-shell concentric spherical headmodel, where the radius of the three concentric spheres are found in the field `hm.radius` (check this). The unit is m.

2. Visualize the setup using `showelpos(hm)`. You can rotate the figure using the "Rotate 3D"-icon. The red ball indicates the front of the head (the nose, actually). The coordinate axes has an origin at the center of the spheres. The x-axis is directed to the right ear, the y-axis is directed to the nose and the z-axis is directed to the top. For the report, show the figure of the electrode positions. An electrode position consists of a letter and a number. What is the meaning of the letter? Do you see a pattern in the evenness or oddness of the numbers? Mention this in your report.

3. As you saw in the lectures, focal brain activity can be represented by a dipole. Let's place a dipole in our head model and show it. This can be done by the procedure

   `showdipole(dipole, hm)`

   where dipole is an array ($\mathbb{R}^{n\times 6}$) indicating the dipole location and component. The procedure can plot multiple dipoles, however for now we use only one so: $n = 1$. The first 3 elements of the array are the x, y and z coordinates of the dipole. Element 4,5 and 6 are the dipole components. To place a dipole in the center pointing upward execute `showdipole([0 0 0 0 0 1],hm)`. Now try to place a dipole halfway between the center and the right ear pointing to the right. Which matlab instruction did you use?

4. Simulate the electrode potentials caused by a source at the center. Therefore we use the function `[V,L]=solve_forward(hm,source)`. `source` is a structure (in matlab struct) with two fields (loc and ori). V is a matrix containing the potentials obtained by the dipole source and orientation. L is the leadfieldmatrix associated with the dipole location. Use `source.loc=[x y z];` and `source.ori=[dx dy dz];` where x,y and z are the coordinates of the dipole at the center and dx,dy and dz are the vector components of the dipole orientation. Generate the electrode potentials due to a dipole positioned at the center and oriented along the negative X-axis. `You can use showpotentials(V,hm)` where V is a 19x1 vector containing the potentials at the electrodes. For the report, show a visual plot of the electrode potentials caused by this dipole.

5. Now study the L variable in the workspace. When looking at equation 3, what do the column vectors of the leadfieldmatrix `L` represent? Compare the colums of `L` with what you calculated for `V`. Try to input each column of L in the `showpotentials` function instead of `V`. Or how can we obtain the column vectors as electrode potentials. Plot the electrode potentials (`showpotentials(V,hm)`) of each column of L and show this in your report. (hint: look at the figure result of the previous item and the dipole orientation)

6. Taking into account the linearity of the Maxwell equations, what would be the potentials generated by two dipoles at the center but one oriented along the X axes and one along the Z axes? Do this without invoking the `solve_forward` procedure again, but with the L obtained from the previous items. For the report, indicate how you obtained the electrode potentials (through formula's) and show a plot of the electrode potentials using `showpotentials(V,hm)`.

7. We also want to simulate a time series of EEG. Here we can make use of equation 3. For one time instance d is a 3x1 matrix. Using the inner product we can extend d into a 3xn matrix where n is the number of samples or timepoints. Hence each row represents the strength of the dipole component along the X, Y or Z-axis. Construct a rotating dipole at position (0 -0.05 0.02) and rotating at 10 Hz in the YZ plane

(sampling frequency: 200 Hz) and with a duration of 3 seconds. (hint: think on how to represent a circle using two vectors). Use the obtained d to construct the EEG signals. Plot the EEG using eegplot (`eegplot(EEG,fs)`). Use `showpotentialsmovie(V,hm)` where V is a mxn matrix. m and n is the number of channels and time samples respectively. Note, one can use this also on real data. For the report, show a plot of the EEG. Save the EEG epoch, you will need this furtheron.

Now we know how to simulate EEG, we can go on to solve the inverse problem.

Inverse problem

The inverse problem involves the estimation of a source given the head model and the electrode potentials. The inverse problem is an optimization problem where the following cost function is minimized:

$$RRE = \frac{\sum_i \left(V_{in} - V_{dip}\right)^2}{\sum_i V_{in}^{\ 2}} \qquad (2)$$

where $\mathbf{V_{in}} \in \mathrm{IR}^{19\times1}$ is the electrode potentials measured at the patient and $\mathbf{V_{dip}} \in \mathrm{IR}^{19\times1}$ is the electrode potentials caused by a dipole calculated by the forward problem. Hence, we want to find the position with the minimal Relative Residual Energy. To solve the inverse problem we can use the matlab function `result=solve_invers_dipole_ana(V,hm)`.
The estimation is a optimization algorithm and it will randomly select 5 starting locations. Important is that V is a 27x1 matrix. The result is a (5x7) matrix where `result(:,1:3)` is the dipole location, `result(:,4:6)` is the dipole orientation and `result(:,7)` is the RRE. Hence, through finding the row with the minimal RRE we can obtain the best estimation. In matlab, we can use `[mmin idx]=min(result(:,7));`, where `idx` will provide us the row number of the best estimation.

Estimation of a dipole using a single time instance

1. Simulate the electrode potentials caused by a source at position (0.06 0 0.01) and with dipole components (1 0 0). The result is a set of electrode potentials V and a leadfieldmatrix L.
2. Use V to estimate the origin of the source by invoking `result=solve_invers_dipole_ana(V,hm).` The algorithm does the dipole estimation 5 times each starting with an initial dipole at a random position. Study the result does every starting position lead to the correct source? Why would that be? The correct source is the source you simulated in the previous point of course. What is the RRE? Is there a difference between the simulated dipole location and orientation and the obtained ones. Show the result and elaborate on it in your report. Indicate which result is the correct result of all the generated positions.

Estimation of a dipole using the simulated EEG

Using the generated signal in the previous section we want to estimate the dipole source again. Use the resulting electrode potentials at that time sample as input to the inverse problem. One way you could do this is by graphically selecting in the plot (using eegplot) a time point. This is done as follows:

To select a time point in an EEG epoch (EEG created in previous section), we can do this graphically as follows:

1. plot the EEG using eegplot(V,fs,1)
2. Select a point using [x,y]=ginput(1)
3. use V(:,round(x*fs)) as input to solve_invers_dipole_ana(V,hm)
4. get the best fit using the min function
5. use showdipole(dipole,hm), where dipole is a (n x 7)-matrix where n is the number of dipoles you want to show. For now, you pick only one.

Error due to not incorporating a malfunctioning electrode

Let's use the dipole position (0.06 0 0.01) and orientation (1 0 0). Simulate the potential V. Now assume one electrode is broken and we get wrong potential readings. Let's say electrode T8 is broken and gives zero potential. If you look at the potential map of V, you will notice that this is an important electrode. Why is this electrode so important? Compare the potential map in the case of the working and the broken electrode. Perform a dipole estimation. How large is the error we make if an electrode is broken. Repeat this for an electrode which is less sensitive for the dipole,(i.e. F7 is situated far away from the dipole location). Show plots and results of the dipole estimation to provide answers to the questions for your report.

Error by different conductivity of the tissues

In the headmodel the conductivity is a very imporatant parameter. In matlab we change the conductivity of the headmodel by changing the values of the fields `hm.condsoft`, `hm.condskull` and `hm.condratio`. `hm.condsoft` and `hm.condskull` is the conductivity in S/m for the soft tissue and skull respectively. `hm.condratio` is the skull-to-soft conductivity ratio, hence $hm.condratio = hm.condskull/hm.condsoft$. What is the dipole localization error when the conductivity of the skull is taken 1/80 of the conductivity of soft tissue?
Inspect this for a 10 dipoles randomly distributed in the brain compartment. Be sure that the dipoles are in the brain compartment by checking the distance to the origin and comparing this to the radius of the brain compartment. Provide your report with a table indicating the correct location and the estimated location. How large is the RRE in all cases?

Extra: Error due to misplacement of electrodes

What is the dipole localization error due to a location error of an electrode on the scalp by 1 cm? Inspect this for a 10 dipoles randomly distributed in the brain compartment.

Report

Provide your report with the necessary information to answer the questions.

Put structure in the report, use clear figures and concise explanations. The report should be 10 pages max.

Send your report to bart.vanrumste@kuleuven.be