Multi-Equivalent Dipoles Fitting for Magnetoencephalography Research

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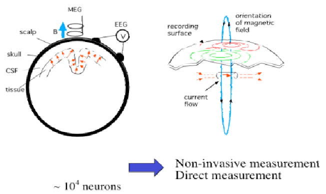
Introduction

The neurons of the brain communicate using electrical signals. These signals give rise to minute magnetic fields in the brain. Magnetoencephalography (MEG) uses ultra-sensitive detectors to measure these magnetic fields from outside the head. Among the many emerging technologies for measuring brains in action, MEG is perhaps the most exciting, because it pinpoints brain activity with great precision in both space (1cm) and time (1ms).



MEG signals are recorded in a magnetically shielded room with a 160 channel whole-scalp Neuromag-160 neuromagnetometer, which is sensitive to small magnetic field as 10fT.

Motivation

- Why fit two dipoles?
  MEG responses to auditory stimuli typically give independent spatial field distributions on each hemisphere of the brain, generated by two independent neural sources.
- Why simultaneously fit two dipoles?
  Previously, two dipoles were fit separately, so different sequences of dipole fitting gave inconsistent results.

Approach

- The whole-head magnetic field is calculated using the spherical head model.

$$\mathbf{b}(\mathbf{r}) = \frac{\mu_0}{4\pi F^2(\mathbf{r},\mathbf{r_q})}\left(F(\mathbf{r},\mathbf{r_q})\mathbf{q}\times\mathbf{r_q} - (\mathbf{q}\times\mathbf{r_q}\cdot\mathbf{r}\nabla F(\mathbf{r},\mathbf{r_q})\right) \qquad \mathbf{b}(\mathbf{r}) = \mathbf{A}\mathbf{S}^T$$

$$F(\mathbf{r},\mathbf{r_q}) = d(rd + r^2 - (\mathbf{r_q}\cdot\mathbf{r})) \qquad \nabla F(\mathbf{r},\mathbf{r_q}) = \left(\frac{d^2}{r} + \frac{(\mathbf{d}\cdot\mathbf{r})}{d} + 2d + 2r\right)\mathbf{r} - \left(d + 2r + \frac{(\mathbf{d}\cdot\mathbf{r})}{d}\right)\mathbf{r_q}$$

r: sensor locations; r_q: dipole locations; q: dipole moment; A: lead field matrix; S: dipole magnitudes.

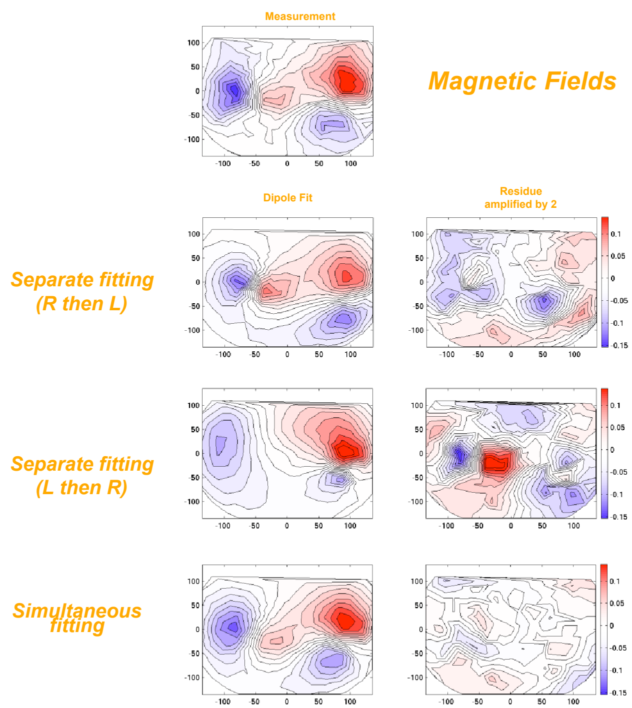
- Least-Squares (LS) estimation is used to achieve a minimum of the cost function.

$$\mathbf{J}_{LS} = \left\|\mathbf{M} - \mathbf{A}\mathbf{S}^T\right\|^2 = \left\|\mathbf{M} - \mathbf{A}(\mathbf{A}^+\mathbf{M})\right\|^2 = \left\|(\mathbf{I} - \mathbf{A}\mathbf{A}^+)\mathbf{M}\right\|$$

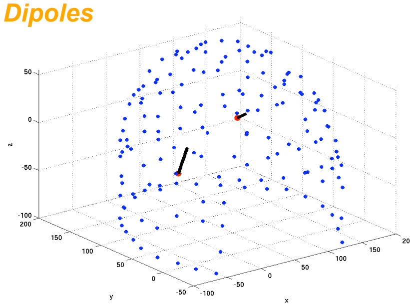
M: magnetic signals from MEG.

- Pyramid search: coarse search in the whole head, then fine search in region of interest (ROI).
- By searching finite pair sources in the right and left hemispheres simultaneously, the pair of source locations minimizing the value of the cost function give the corresponding two equivalent dipoles locations.

Results

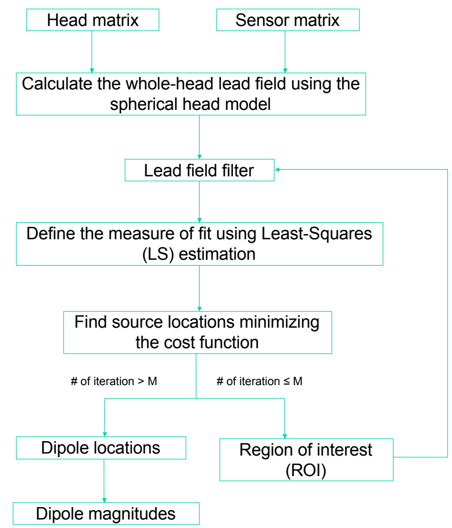


Sensors & Equivalent Dipoles



- The simultaneous fitting of two source dipoles significantly improved the accuracy compared to the separate fitting and does not have the sequence problem.
- Comparing the measured magnetic fields from the MEG signals with the calculated magnetic fields from the two equivalent dipoles, the small residue indicate the two simultaneously fit dipoles represent well the current sources in the brain.
- The coarse and fine searches require 16 hours and 2 hours each.

System Diagram



Conclusions

- Using the proposed method the two simultaneously fit dipoles represent well the current sources in the brain.
- Speed up by factor of 8 already in progress.

References

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