Individual FEM Pipeline for EEG Source Analysis Requiring Minimal User Intervention

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I INTRODUCTION

Individual, realistic volume conductor models improve EEG source analysis accuracy. Still, these models have not found widespread application in the EEG community. Reasons for this are the challenges of tissue segmentation and mesh generation. Here, we are presenting a complete pipeline for creating and using individual, realistically shaped head models for EEG source analysis. Minimal user interaction is required, and computations are sufficiently fast. The efficacy of our pipeline is demonstrated on two exemplary data sets showing that the more realistic head models improve the source reconstruction compared to a spherical model and a standardized, realistic model.

II MATERIALS and METHODS

MRI Pre-processing

- Reading MRI and input of user-defined landmark points ~ 3min user interaction.
- Intensity inhomogeneity correction with extended Adaptive Fuzzy C-Means (AFCM) [1] algorithm.
- Robust scalp surface reconstruction (Fig. 1) using multi-resolution Active Regions approach [2].
- White matter segmentation and cortex surface reconstruction (Fig. 1) using Markov Random field (MRF) classification [3].

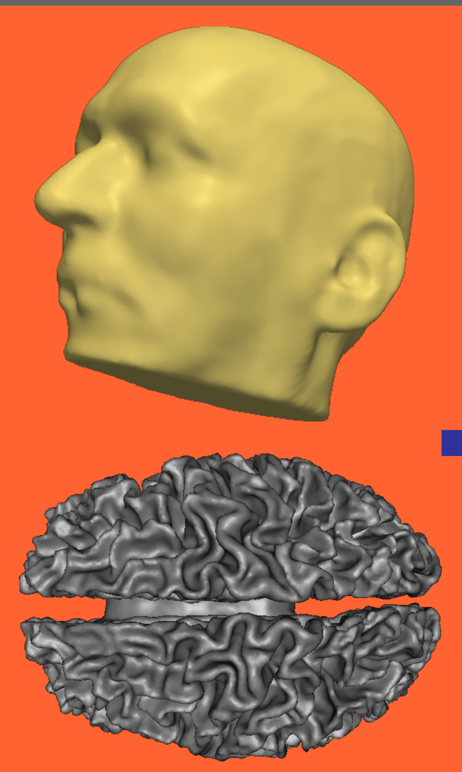

Figure 1: Exemplary scalp (top) and cortex (bottom) surface reconstructions.

Volume Conductor Segmentation

- Segmentation of tissues most relevant for volume conduction.
- First, segmentation into 9 different tissue regions using newly developed method [4].
- MRF model representing layered structure of head tissues (Fig. 2).
- Tissue probability atlas based on distances to reference surfaces.
- Optimization of image parameters and labels using Expectation-Maximization type procedure and Iterated Conditional Modes algorithm [5].

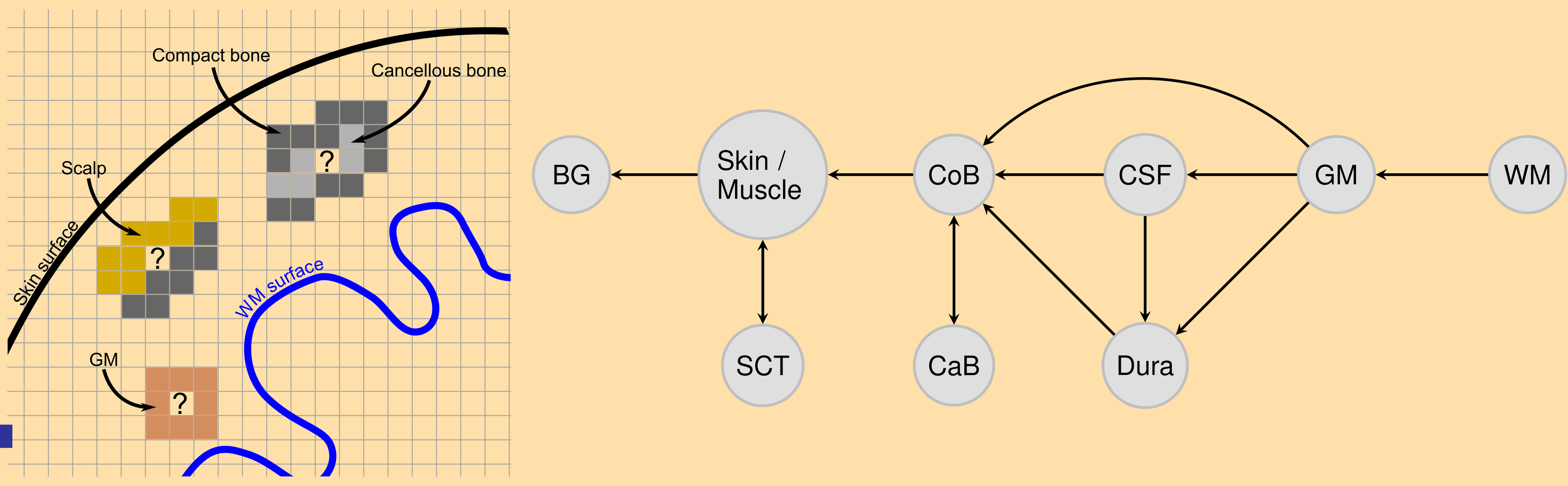

Figure 2: Illustration of the classification problem (left) and an adjacency graph describing the layered structure of head tissues in the upper part of the head. For explanation of abbreviations see legend of Fig. 3.

Mesh Generation and FEM Leadfield Computation

- Geometry-adapted hexahedral FE mesh generation [6].
- FE mesh resolutions of 2mm and 1mm possible.
- Simplification of CSF compartment to avoid problems with complex source spaces and some inverse methods [7].
- Source space information derived from brain compartment of FE mesh.
- Leadfield computation on regular, 2mm grid covering entire brain.
- Venant dipole source model.
- Fast and memory-efficient row-wise leadfield computation employing transfer matrix approach [8].

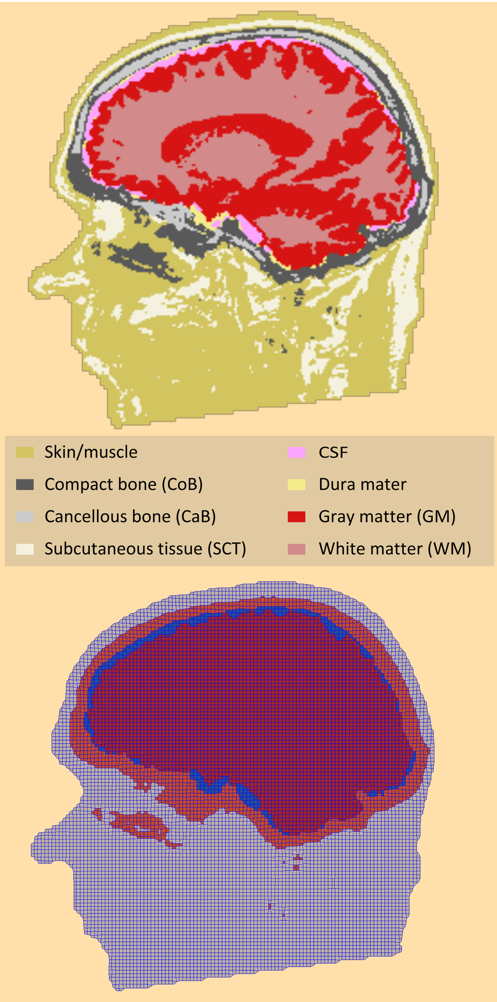

Figure 3: Detailed segmentation into 9 different tissue regions (top) and resulting 2mm geometry-adapted cubic mesh with 4 different tissue types (scalp, skull, CSF, brain) (bottom).

Forward Computation

- Output of previous steps is a pre-computed leadfield matrix for given source space.
- Leadfield for sources inbetween nodes of the source space grid is interpolated.
- Fast and accurate interpolation using second-order Bezier spline interpolation [9].

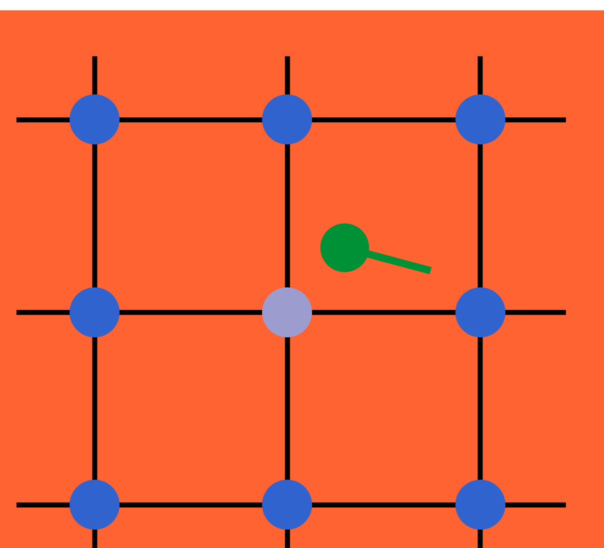

Figure 4: Illustration of the leadfield interpolation. Leadfield for green dipole source is interpolated from pre-computed leadfields at blue source space grid nodes.

III RESULTS

Source Analysis of Basal Temporal Lobe Epilepsy

- Patient with basal temporal lobe epilepsy.
- Dipole source analysis with three different head models:
  - Four-shell ellipsoidal
  - Standard FEM model
  - Individual FEM model
- Reconstructed location with individual FEM best fits the expected spike location.
- Other models result in too superior source locations.
- Dipole orientation for individual FEM also consistent with general curvature of cortical surface.

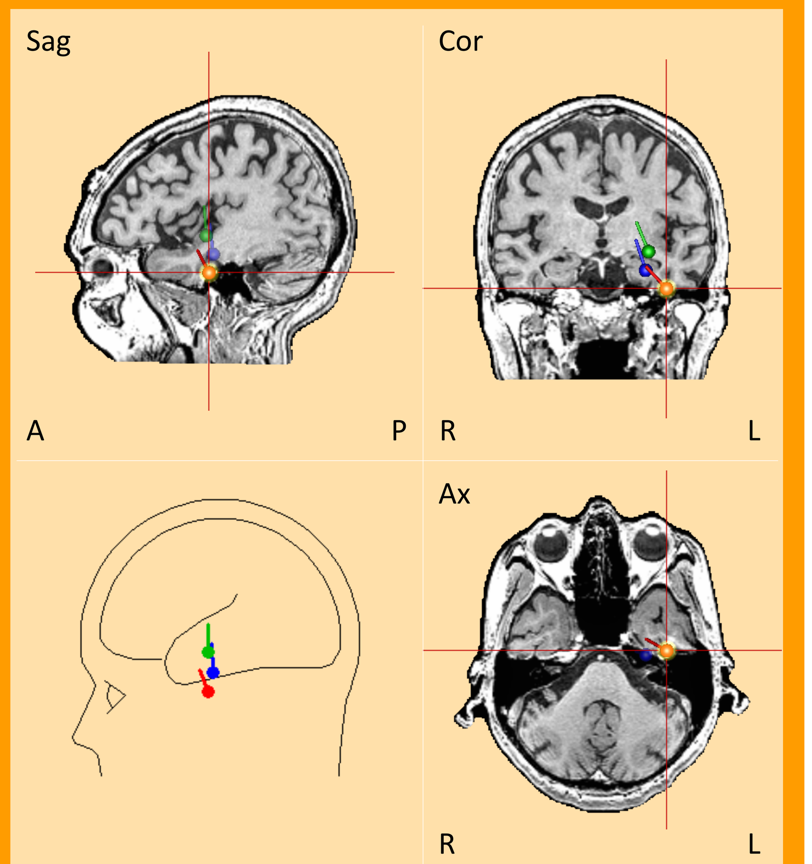

Figure 5: Dipole sources reconstructed from the interictal EEG. Green: Four-shell ellipsoidal model; blue: standard FEM model; red: individual FEM model.

Source Analysis of Auditory N1

- Auditory oddball paradigm.
- Standard condition with frequent simple tone at 1200Hz.
- Two head models:
  - Four-shell ellipsoidal
  - Individual FEM head model
- Fit two symmetrical regional sources.
- Fit interval: 80 to 110ms (N1).
- Sources reconstructed close to Heschl's gyrus for the individual FEM model.
- Reconstructed source positions too superior for ellipsoidal model.

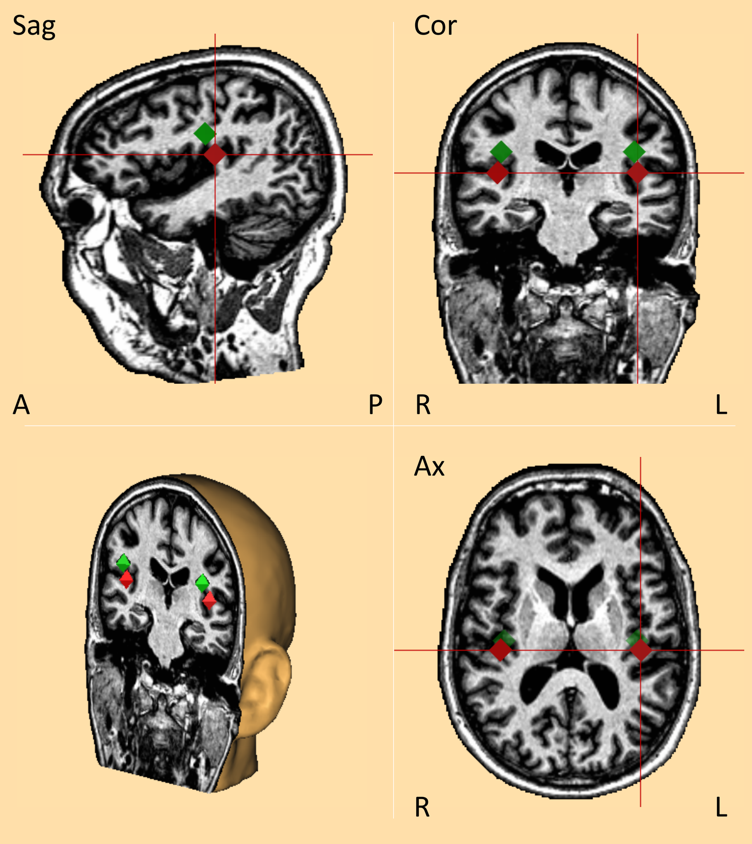

Figure 6: Regional sources reconstructed from the auditory N1. Green: Four-shell ellipsoidal model; red: individual FEM model.

IV CONCLUSION and OUTLOOK

The presented pipeline allows effortless creation of realistically shaped, individual head models for EEG source analysis. Due to the minimal required effort, individual models hopefully will find a more wide-spread application facilitating improved source localization accuracy for EEG source analysis.

In the near future the pipeline will be extended to be also applicable for MEG data. In addition, further segmentation tools will be integrated. Those tools will help to improve the segmentation for children and subjects with pathological anatomies (lesion, skull holes, ...).

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