NFT - Neuroelectromagnetic Forward Head Modeling Toolbox

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May 25, 2010
NFT: Introduction

- MATLAB Toolbox for realistic head modeling and forward problem solution.
- Ability to use available subject information
  - T1-weighted 3D MR images
  - Digitized sensor (electrode) locations
- Implements all steps of head modeling
  - Segmentation of MR images
  - Mesh generation
  - Warping of a template head model to sensors
  - Sensor co-registration
  - Forward problem solution
NFT External Programs

- **3rd Party Tools and Libraries Used:**
  - **ASC:**
    - High quality triangulation
  - **Qslim**
    - Mesh Coarsening
  - **MATITK**
    - MATLAB interface to ITK image processing toolkit
  - **METU-BEM**
    - Boundary Element Method (BEM) Solver

- Source code is available for all these components.
NFT: Operation

T1 MR Images
- Choose subject
- Generate head model for subject
  - Segmentation
  - Mesh generation
- Register sensors to mesh
  - Each set of sensors is a separate session
- Generate forward model
- Generate LFM for each session

Template Mesh
- Choose subject
- Select subj sensors
- Warp template to sensors
- Generate forward model
- Generate LFM for sensors
Subject Selection

- Select subject folder
- Specify subject name
- Specify session name
Head Modeling from MR Images

- **From a magnetic Resonance Image**
  - Image Segmentation
  - Mesh Generation
  - Source Space Generation
  - Electrode Co-Registration

- **T1-weighted**

- **MR image**

- **Segmentation**

- **Electrode Registration**

- **BEM mesh**
Preparing MR image for segmentation

Using FREESURFER:

- Inhomogeneity correction
- Convert to 1x1x1 volume
- Arrange direction of the image
- Save in analyze format
Image Segmentation

♦ Interface for Segmentation of MR Images
Image Segmentation Flowchart

Classifies four tissues from T1-weighted images
– Scalp, Skull, CSF and Brain
Mesh Generation

Generate Mesh for a 3 or 4 layer head model
- Triangulation, correction, coarsening, refinement
Source Space Generation

- Generate a simple source space
  - Regular Grid inside the brain
  - With a given spacing and distance to the mesh
Electrode Co-Registration

- From a magnetic Resonance Image
  - Image Segmentation
  - Mesh Generation
  - Source Space Generation
  - Electrode Co-Registration

- Head Modeling Toolbox: Electrode Co-Registration
  - Load sensor locations
  - Electrode file name: D:\WHM_Toolbox_Subjects
  - Mesh Folder
  - Initial co-registration
    - Translation
    - Rotation
  - Complete co-registration
    - Translation
    - Rotation
  - Save initial reg.
  - Save complete reg.
Warp a template mesh to electrode positions
- When no MR images are available
- Non-rigid thin-plate spline warping
Template Warping

From electrode Position Data

Template Warping
Forward Model Generation

- Generates the Forward Model from Meshes
  - Uses the Boundary Element Method

- Three Structures
  - Mesh
  - Model (Mesh + Electrical Properties)
  - Session (Model + Sensors)
Forward Problem Solution

BEM Mesh Info
- Mesh Name
- Show Mesh
- Number of Layers
- Number of Nodes
- Number of Elements
- Number of Nodes/Element

BEM Model
- Enter conductivity values:
  - Scalp: 0.33
  - Brain: 0.0042
  - Skull: 0.33
- Modified (Isolated Problem Approach)
- Create Model
  - No Model

Session
- Session Name
- Load Sensors
  - Mesh Node List
  - Mesh Coordinates
- Generate transfer matrix
  - No Session

Forward Problem Solution
- Load Source Space
- Compute Lead Field Matrix
- Plot Potential Distribution
  - For Dipole

Forward Model Generation
Forward Problem Solution

- Mesh
- Model param.
- BEM Matrices
- Sensor locations
- BEM Matrices
- Generate RHS, Multiply
- Transfer Matrices
- Dipole Field
- Invert Sensor Columns

BEM Matrix Generator

BEM Matrices

Transfer Matrices

Lead Field Matrix

[# of sensors x # of dipoles]

[# of sensors x # of nodes]
Forward Problem Solver

- MATLAB interface to numerical solvers
- Boundary Element Method
  - EEG Only (for now)
  - Supports IPA and Accelerated BEM
  - Interfaces to the Matrix generator executable written in C++
- Other computation done in MATLAB
- Generated matrices are stored on disk for future use.
- Other solvers under construction
  - Finite Element Method (FEM)
  - Analytic
Solution of inverse problem
# Results on Mesh Complexity

<table>
<thead>
<tr>
<th>Mesh Name</th>
<th>Layers</th>
<th>Nodes</th>
<th>Elements</th>
<th>LMR Ratio</th>
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<td>Mesh 3</td>
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<td>10337</td>
<td>20678</td>
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<td>Mesh 3_1</td>
<td>3</td>
<td>12057</td>
<td>24118</td>
<td>2</td>
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<tr>
<td>Mesh 3_2</td>
<td>3</td>
<td>14769</td>
<td>29542</td>
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<td>27550</td>
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<td>Mesh 4_1</td>
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<td>18499</td>
<td>36998</td>
<td>2</td>
</tr>
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<td>Mesh 4_2</td>
<td>4</td>
<td>20789</td>
<td>41578</td>
<td>1.6</td>
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<table>
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<tr>
<th>Mesh Name</th>
<th>Emean</th>
<th>Emin</th>
<th>Emax</th>
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<tbody>
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<td>Mesh 3_1</td>
<td>16.12</td>
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<td>Mesh 3_2</td>
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<td>4.07</td>
<td>29.31</td>
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<tr>
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<tr>
<td>Mesh 4_2</td>
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<td>0</td>
</tr>
</tbody>
</table>

Localization error (mm) Compared with Mesh 4_2
Source localization comparisons

- MNI head model
- Warped MNI head model
- 4-layer MR-based realistic head model
- 3-layer MR-based realistic head model
3- and 4-layer MR-based realistic head model

Scalp maps of 2 components
Sources of 2 components
- green dipoles - 4-layer
- yellow dipoles - 3-layer
Warped MNI head model

Scalp maps of 2 components

Sources of 2 components
MNI head model

Scalp maps of 2 components

Sources of 2 components
Future Functions

- Magnetic field calculations.
- Analytical solutions for spherical models.
- Use of T2-weighted and PD images in segmentation => better CSF segmentation.
- 4-layer template head model.
- Finite Element Method.
Neuroelectromagnetic Forward Head Modeling Toolbox

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ARTICLE INFO

Article history:
Received 10 September 2009
Received in revised form 28 April 2010
Accepted 29 April 2010

Abstract

This paper introduces a Neuroelectromagnetic Forward Head Modeling Toolbox (NFT) running under MATLAB (The Mathworks, Inc.) for generating realistic head models from available data (MRI and/or electrode locations) and for computing numerical solutions for the forward problem of electromagnetic source imaging. The NFT includes tools for segmenting scalp, skull, cerebrospinal fluid (CSF) and brain tissues from T1-weighted magnetic resonance (MR) images. The Boundary Element Method (BEM) is used for the numerical solution of the forward problem. After extracting segmented tissue volumes, surface...
Thank You ...