Validation/Evaluation of Source Analysis Methods

Organizer: Carsten Wolters and Jens Haueisen

Room: # 104

Date and Time: Wednesday, October5 / 16:00-17:00

Validating and Evaluating New Methods for Source Analysis

In this session, new methods for EEG and MEG source analysis with regard to forward and inverse problem as well as with regard to source connectivity analysis are presented. A special focus is on validation and evaluation frameworks for these new approaches. On the lowest level, the methods are verified in computer simulations with regard to numerical errors using multi-layer sphere models and evaluations are carried out in realistic head models. Technologically, the session will introduce Whitney sources, the complete electrode model and mixed finite element methods to bioelectromagnetism. Source connectivity measures are evaluated with regard to volume conductor modeling defects. On a next higher level, rabbit measurements are used to validate and verify the methods with regard to the overall forward and inverse modeling accuracy and, more specifically, with regard to the impact of skull modeling defects. Finally, validation is brought to the new and multi-modal approaches on presurgical epilepsy diagnosis, where it will be shown, how a multi-focal epilepsy patient can be successfully diagnosed and treated using the presented state of the art methodologies. It is shown how combinations of EEG/MEG and EEG/fMRI can be carried out and that multimodal approaches outperform single modality analysis.

Speakers:

- **Sampsa Pursiainen** (Tampere Univ. of Tech., Finnland)
  "Validation of Whitney sources and evaluation of differences between the point (PEM) and the complete electrode model (CEM)"

  This presentation will concentrate on mathematically rigorous finite element modeling of EEG/MEG biopotential fields with respect to both the interior and the boundary part of the target domain. Here, the primary current distribution evoked by neuronal activity is assumed to be a divergence conforming vector field spanned by (Whitney) basis functions, which can be associated with dipolar sources. The boundary conditions are formulated via the complete electrode model (CEM). The resulting comprehensive model has certain advantages over the standard approach. Important aspects are, among other things, that it enables simulation and recovery of the primary current directly as a vector field and that it covers both stimulation and measurement electrodes. The present approach has been recently compared to the classical direct partial integration and St. Venant dipole approximation methods as well as to the point electrode model (PEM). This presentation will briefly review the theoretical basis of the CEM/Whitney model, show the connection to the classical version, and also include the central numerical comparison results.

- **Johannes Vorwerk** (Univ. of Utah, USA)
  "Avoiding Skull Leakages using Mixed-FEM approaches"

  The finite element method (FEM) allows for the easy computation of highly accurate EEG forward solutions using realistic head models. Approaches based on a conforming FEM formulation were shown to achieve high accuracies in multi-layer both sphere and realistic head models. Due to their easy generation, especially hexahedral head models are frequently used when applying FEM approaches in praxis. These have the drawback that in areas where the thickness of a conductive compartment is in the range of the mesh resolution, elements corresponding to originally separated compartments on the in- and outside might touch in single vertices. As a result, an unphysical leakage of volume currents through these vertices may appear and the numerical accuracy of the conforming FEM is decreased. This effect can, e.g., occur for CSF or gray matter and skin elements originally separated by the skull. It can be avoided by the use of FEM approaches that explicitly control the flow of volume currents, such as discontinuous Galerkin (DG) or mixed methods. Here, a mixed finite element method (Mixed-FEM) to solve the EEG forward problem is introduced and it is shown that the Mixed-FEM effectively prevents skull leakages in both sphere and realistic head models.

- **Jae-Hyun Cho** (Max Planck Inst. for Human Cognitive and Brain Sciences, Germany)
  "An evaluation of the sensitivity of EEG and MEG connectivity measures on the source level to head volume conductor properties"

  While the comparisons of the source estimation methods or connectivity measures in EEG and MEG source connectivity analysis have been investigated, the effects of the head volume conductor properties have not been studied sufficiently.
  In the present simulation study, we investigated the influence of particular properties of the head volume conductor on source connectivity analysis using a realistic head model. We considered the distinction between white and gray matter, the distinction between compact and spongy bone, the inclusion of a cerebrospinal fluid (CSF), and a simple 3-layer model comprising the skin, skull, and brain. The finite element method was applied to solve the forward problems. A beamforming approach was used to reconstruct source time courses, and the imaginary coherence (ICoh) and the generalized partial directed coherence (GPDC) were used as a measure of connectivity.
  In both EEG and MEG, neglecting the white and gray matter distinction or the CSF causes considerable errors in source connectivity analysis, while the distinction between spongy and compact bone has less impact on the results, provided that an adequate skull conductivity value is used. Moreover, the ICoh is less affected from the crosstalk effects caused by imperfect head models, as compared to the GPDC.

- **Stephan Lau** (St. Vincent's Hospital, Univ. of Melbourne, Australia)
  "Validating and evaluating the finite element method using controlled-source MEG-EEG rabbit measurements"

  Advanced finite element (FE) approaches have been developed for the localization of neuronal activity in the brain using simulation setups. The objectives of this study are to evaluate the concordance of such FE simulations with physical measurements and to identify model qualities that are important for accurate source analysis, especially in the presence of skull defects.
  A FE simulation of an in-vivo animal experiment with a conducting skull defect above a controlled source was constructed from MRI (0.4 mm^3) and CT. A 16-channel MEG and a 64-channel EEG were forward simulated (SimBio) above intact skull and above skull defects and compared to corresponding measurements. Source analysis from the MEG and EEG measurements, respectively, was performed using the FE head model.
  The forward simulation of the MEG and EEG signals reproduced the experimentally observed ones as well as characteristic magnitude and topography changes due to skull defects. Ignoring skull defects in the head model caused location, orientation and strength errors of the reconstructed source. An exact FE model enabled source reconstruction in the presence of skull defects. Detailed FE modelling approaches were validated. Spatial sampling density, co-registration accuracy, anatomical detail, and realistic tissue conductivities are important for accurate source analysis.

- **Ümit Aydin** (Concordia Univ., Canada)
  "Multimodal (EEG/MEG, EEG/fMRI) source analysis in epilepsy and controlled tasks"

  In this talk two multimodal studies will be presented. First study focuses on combined EEG/MEG source analysis (EMEG) of interictal epileptic discharges. A seven compartment finite-element head model with calibrated skull conductivity and anisotropic white-matter (derived from diffusion-tensor-imaging) was used to fully benefit from the complementarity of EEG and MEG. EMEG was performed near spike onset (to minimize propagation) and ZOOMit technology was used to acquire high-resolution images (0.5×0.5×0.5mm3) within a small region-of-interest highlighted by EMEG. ZOOMit revealed a subtle focal-cortical-dysplasia that was undetectable in lower-resolutions (1mm3) and these findings were confirmed by surgery outcome.

  The second study focuses on source analysis of hdEEG (high-density EEG, 256-channels) acquired simultaneously with fMRI. Combining the spatial-resolution of fMRI and temporal-resolution of hdEEG offers great benefits, however, this is not a trivial task mainly due to artefacts on hdEEG induced by MRI. In this context, benefiting from discrete wavelet decomposition to denoise the data, wMEM (wavelet-based Maximum Entropy on the Mean) source analysis showed promising results. Performance of wMEM was evaluated via simulations, with hdEEG data acquired from the same individuals and the same well-controlled tasks both inside and outside the MRI scanner, and by comparing wMEM results with the fMRI findings.