

Sensitivity of inverse source reconstruction results towards forward model inaccuracies: Application of a universal sensitivity analysis software framework on different tissue conductivity ratios

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Abstract

The analysis of errors in inverse source reconstructions due to errors, inaccuracies and simplifications of the forward model is of major interest for the practical use of source reconstruction methods as well as for the development of new models. Thus, a general software framework for the analysis of errors in inverse results due to errors in forward models was developed. It allows flexible combinations of forward simulators, inverse algorithms and source configurations. This framework was used for the determination of errors of inverse results due to different tissue conductivity estimates. This subject is of major interest, since the values of the conductivity ratios, which are commonly used for inverse source reconstruction, probably have to be corrected due to recent investigations. Used conductivity ratios for the head compartments were 1-1/80-1 and 1-1/15-1. For single dipoles placed on 1204 regular spaced positions differences of the reconstructed dipole positions were determined. Two electrode configurations were used: 31 electrodes, 31 + 8 electrodes inferior to standard 10-20 electrodes.

The conductivity ratio of 1-1/80-1 yielded reconstruction results, which were closer to the brain surface. Using 31 electrodes, displacements increased from superior to inferior source positions. This result was less prominent using the additional electrodes but displacements were still not negligible, e.g., up to 2.6 cm inside the temporal lobe.

Application of a novel sensitivity analysis framework showed that relevant localization errors occur due to an insufficient knowledge about the actual tissue properties. These errors can be reduced by means of an application of additional electrodes.

1 Introduction

The uncertainty of inverse results due to errors, simplifications and inaccuracies of the head model used for forward calculation is an important issue as well for the practical use of inverse source reconstruction methods as for developers of new, probably more sophisticated models. Previous studies related to this topic addressed for example errors in inverse results due to simplifications of the head geometry [1], uncertainties of the actual tissue resistivities [2], and electrode localization errors [3]. Changes of the forward solution for human MEG and EEG by taking the anisotropy of the brain tissue conductivity into account were investigated in [4]. The latter study addresses the question to what extent a more complex and realistic head model influences forward results and as a consequence inverse reconstructions. The objective of the software framework, which will be presented in this paper, is the generation of a flexible toolbox, which

allows the investigation of the listed and related topics in a simple and systematic way. It can be used for any kind of head models for forward calculations, any kind of inverse procedure and arbitrary source configurations.

This software framework was applied to the investigation of the displacement of dipole localizations due to different conductivity ratios used in a realistic boundary element (BEM) model. The actual in vivo tissue conductivities are difficult to obtain [5], [6]. The results of the cited papers using sophisticated methods for the estimation of the bone conductivity indicate that the commonly used conductivity ratio of 1-1/80-1 probably has to be corrected to a ratio of 1-1/15-1. This huge difference in the conductivity ratios may lead to substantial differences in inverse results. Thus, differences in dipole localizations between both conductivity ratios were determined for a huge number of regularly spaced source positions.

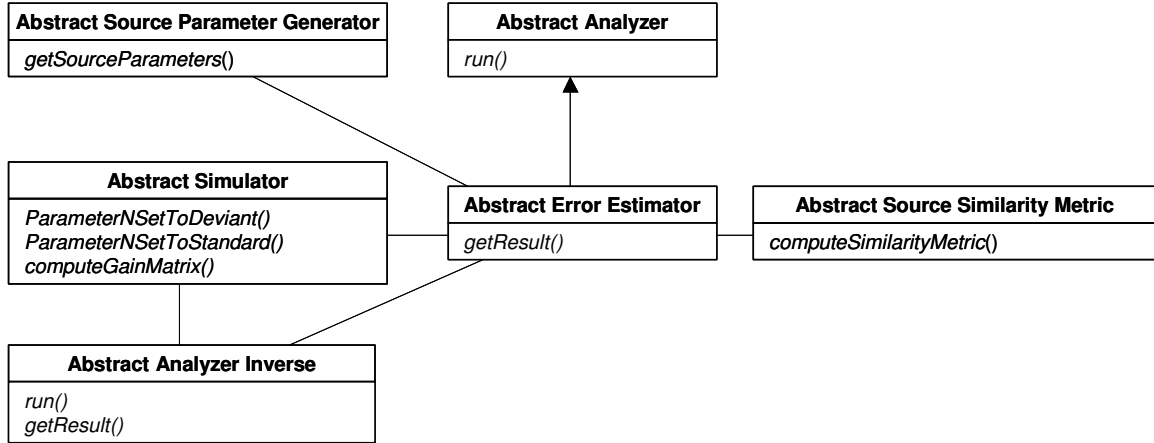


Fig. 1 Class diagram of the sensitivity analysis framework showing abstract classes and their most important methods: 1. Abstract Analyzer: Base class for all types of analyzers. 2. Abstract Error Estimator: It controls the sensitivity analysis procedure. All other classes of the framework are member of this class. 3. Abstract Source Parameter Generator: Source configurations are generated in derived classes. 4. Abstract Simulator: Provides an interface for forward computations. There are additionally interfaces to access parameters of the simulator. 5. Abstract Analyzer Inverse: Inverse procedures are derived from this class. 6. Abstract Source Similarity Metric: Defines an interface to compare inverse results obtained by standard and deviant simulator parameters.

2 Methods

2.1 Sensitivity Analysis Software Framework

To obtain a general and flexible software framework the concept of abstract classes, which is available in the C++ and other object oriented computer languages, is used. Abstract classes define interfaces. For these interfaces implementations have to be written in derived implementation classes. For example forward simulators for a spherical, boundary element or finite element head model can be derived from an abstract forward simulator using an interface definition, which is defined by the abstract forward simulator class. Thus, for a complete inverse procedure, e.g., for example dipole fit, going from a spherical to a BEM head model, only the simulator has to be exchanged. No need to change other parts of the code exists. The sensitivity analysis software framework makes use of a flexible inverse toolbox, which is designed using the described principles of abstract class interfaces [7]. It provides a wide range of inverse procedure, e.g., dipole fit, linear estimation, goal function scan, music. For the sensitivity analysis package a general way to access forward simulator parameters is defined. Especially methods are provided to set them to a deviant value to be able to estimate the sensitivity of inverse results by shifting a simulator parameter to a slightly different value. Further abstract classes define a general interface to generate artificial sources and a metric to compare source reconstruction results. An over-

view about the classes of the sensitivity analysis framework is shown in **Fig. 1**. The interfaces of abstract classes define the coupling of the modules and give prescriptions, how to add new modules to the sensitivity analysis package.

2.2 Investigation of different tissue conductivity ratios

To investigate the sensitivity of inverse results to different conductivity ratios a realistic BEM model with 3 compartments was. The boundaries consisted of 1016 elements and 512 nodes for the scalp, 1228 elements and 616 nodes for the skull and 1716 elements and 860 nodes for the brain. Two different conductivity ratios for the compartments were used: 1-1/80-1 and 1-1/15-1. Calculations were made for two different electrode configurations with 31 electrodes of an extended 10-20 system and for 39 electrodes. Additional electrodes of the second configuration were positioned inferior to the positions of the standard 10-20 electrode positions. Electrical fields generated by single simulated dipoles using a conductivity ratio of 1-1/15-1 were used to reconstruct dipole positions for both conductivity ratios. Dipole fit was performed using a Marquardt algorithm. The resulting positions were compared for 1204 different artificial sources, which were regularly distributed on a cubic grid. The minimal distance between sources and the brain boundary of the BEM model was 7 mm to avoid instabilities of the forward calculations.

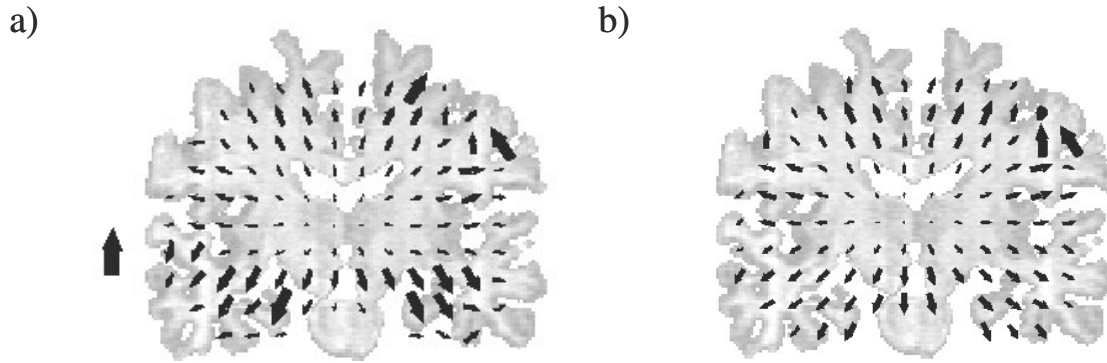


Fig. 2 Displacement of dipole localizations using a conductivity ratio of 1-1/80-1 instead of 1-1/15-1: a) results using 31 Electrodes, b) using 8 additional electrodes. Scaling arrow on the left represents 4 cm.

3 Results

The maximum localization error using the conductivity ratio 1-1/15-1 was smaller than 0.1 mm. The conductivity ratio of 1-1/80-1 resulted in dipole localizations closer to the brain surface. The displacements of the source reconstructions for the different conductivity ratios are overlaid to corresponding MRI slices (see **Fig. 2**). Using the electrode set up with 31 electrodes a greater displacement is obvious for source positions in the inferior part of the brain than for the electrode configuration with additional inferior electrode positions. For the temporal lobes, an area of major interest for clinical source reconstruction applications, maximum source displacements were 4.2 cm (31 electrodes) in comparison to 2.6 cm (39 electrodes).

4 Discussion

A universal and flexible software framework to investigate errors of inverse results due to errors, simplifications and inaccuracies of the forward model was set up. This framework allows the investigation of a couple of problems related to the accuracy of inverse results as well as for the practical use of source localization procedures as for developers of new head models for forward simulations. The flexibility of the software framework is obtained by state of the art concepts of object oriented software design.

The application of the software framework for different conductivity ratios shows that errors due to the different ratios are far from being negligible. Thus, further investigations to obtain reliable tissue properties should be encouraged. At least the increase of localization errors in the inferior part of the brain can be reduced to some amount by applying additional electrodes inferior to the positions of the standard 10-20 system. This result shows that the sensitivity analysis

toolbox can be used to derive results, which give practical useful advice to diminish source localization errors.

5 Acknowledgements

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6 Literature

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