Global sensitivity analysis of the EEG forward problem

1152

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INTRODUCTION

When carrying out an EEG experiment for source reconstruction, one has to provide both accurate geometry and electrical properties of the head tissues. Authors usually set the electrical conductivities based on values reported in the literature which have been shown to vary widely[1] (**Fig. 1**).

Here we propose a method to assess the sensitivity of the EEG forward problem to those parameters using a realistic finite element (FEM) head model including white matter anisotropic tensor. The chosen sensitivity descriptor are the first and total order Sobol indices.

METHODS

We generated the model using the following steps:

- The structural T1 image was segmented using a combination of MARS[2] and Unified Segmentation[3].
- The mesh was generated using both CGAL[4] and Gmsh[5] directly from the segmented volume (**Fig. 2**).
- White matter anisotropic conductivity was approximated by the diffusion tensor derived from dw-MRI[11].
- Sensors were added based on the 10-10 electrode system for EEG recording.

The continuous ranges recorded for each tissue electrical conductivity defined a 5D space Ω. As it is impossible to compute the EEG leadfield matrix for each point of Ω, we produced a surrogate model.

- The design points were selected using a Leja adaptative quadrature rule[6] considering uniform distributions for all the tissues electrical conductivity.
- The EEG leadfield matrices have been computed using the reciprocity principle[7] implemented in GetDP[8] for each design point.
- Because of the very large number of elements in the FEM, we reduced the size of the obtained matrices by keeping equidistant elements with a fixed distance of 5 [mm].
- The surrogate model was generated using Gaussian processes[9] with a radial basis function kernel.

Using the surrogate model, we computed the first and total order Sobol indices[10] using Monte Carlo integration on the expression:

$$\Delta = \frac{\|L - L_{ref}\|_F}{\|L_{ref}\|_F}$$

where L_{ref} is the leadfield matrix computed using the midrange electrical conductivity.

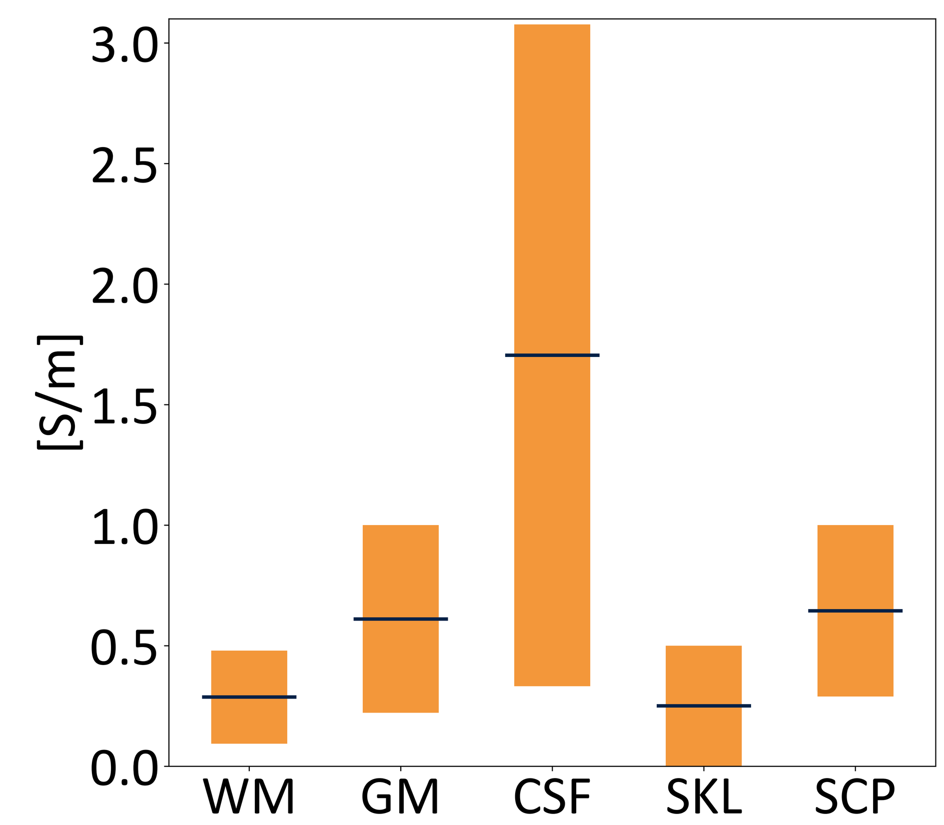

Fig. 1: Electrical conductivity σ [S/m] ranges for the five tissues included in the finite element model. Those ranges were extracted from the literature. The mid-range values denoted by blue lines were used as the reference values for the sensitivity analysis.

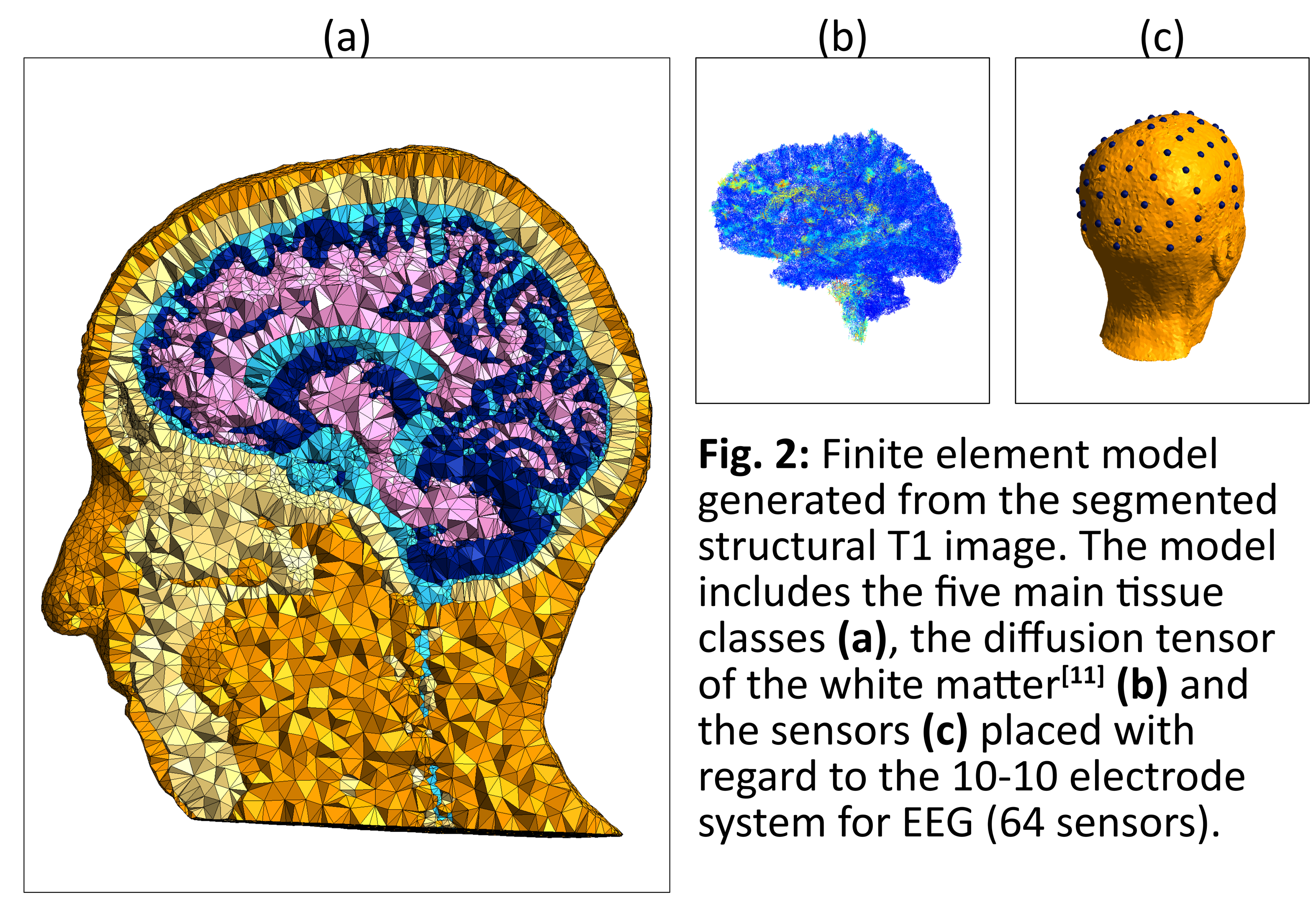

Fig. 2: Finite element model generated from the segmented structural T1 image. The model includes the five main tissue classes **(a)**, the diffusion tensor of the white matter[11] **(b)** and the sensors **(c)** placed with regard to the 10-10 electrode system for EEG (64 sensors).

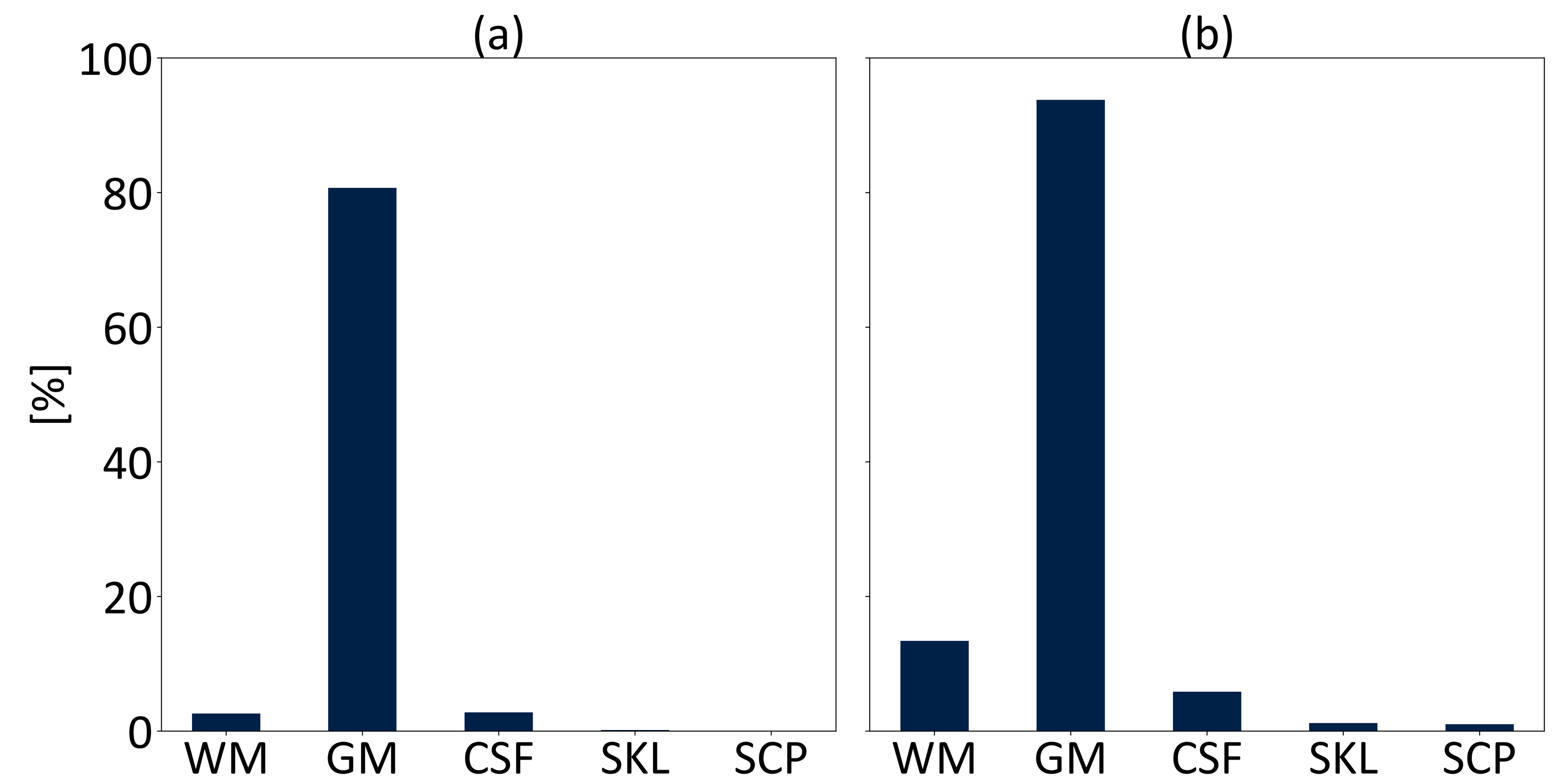

Fig. 3: First order **(a)** and total order **(b)** Sobol indices computed for the five tissue classes included in the finite element model shown in **Fig. 2** for the value ranges recorded in **Fig. 1**.

RESULTS

As a result of this pipeline, we got both a surrogate model allowing us to generate any leadfield matrix for a set of electrical conductivities and statistical descriptors. The surrogate model showed an overall standard deviation of Δ of 28%. Moreover, the first and total order Sobol indices (**Fig. 3)** provide information on how to reduce the sensitivity by giving the parameters inducing the biggest variability in the results.

CONCLUSION

The present method provides a workflow not only to generate a parametric leadfield matrix which can produce any specific leadfield when given a set of electrical conductivities but also to perform a global sensitivity analysis.

The results obtained for the considered finite element model and the chosen electrical conductivity ranges demonstrate that, globally, the uncertainty on the electrical conductivity of the tissues has a large impact resulting in a high standard deviation. In addition to that, the Sobol indices show which is the main parameter responsible for the variability (here it is the conductivity of gray matter). Focusing on reducing the range for te parameters with the highest indices would reduce the variability and thus result in more accurate leadfield matrices.

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