On the Use of a Full-Wave Solver in the Solution of the Electroencephalography Forward Problem

C. Henry, A. Merlini, L. Rahmouni, and F. P. Andriulli
Politecnico di Torino, Turin, Italy

Brain imaging plays a crucial role in numerous applications ranging from life-saving pre-surgical analyses to the control of systems via Brain Computer Interfaces (BCIs). Non-invasive brain imaging relies on measurements of the electromagnetic fields outside the head to reconstruct the brain activity within the area of interest. The different acquisition methods include magnetic resonance imaging (MRI), electroencephalography (EEG), magnetoencephalography (MEG), functional MRI (fMRI), among others. The EEG source imaging (ESI) is one of the most used technique thanks to high temporal resolution, affordability and ease of use. ESI maps scalp potential measurements obtained from EEG to the volume brain currents by leveraging on a anatomical model of the patient's head (typically obtained from MRI) and algorithms solving the so-called inverse problem (IP).

The IP is enabled by the solution of the EEG forward problem (FP), where an unknown potential at the scalp is obtained starting from an unknown current in the brain volume. A classical way to solve the EEG forward problem is to leverage on Poisson's equation and static solvers. These quasi-static approximations are an ad-hoc way to handle signals in the order of few Hertz but are quite rigid as pertains to their modelling capabilities.

High frequency solvers, on the other hand, directly follow from Maxwell's equations and can fully grasp all possible electrostatic and dynamic scenarios. These schemes, however, are often unstable towards the low frequencies which partially explains the popularity of Poisson's solvers for EEG imaging.

In this work we present a different approach to the EEG imaging problem by proposing a formulation which models the EEG problem starting from high-frequency integral equation formulations which are stabilized before being used in the low-frequency regime. In doing this, we focus on the Helmholtz components which are properly tracked, re-scaled and spectrally regularized.

We will show the advantages of using our new full-wave strategy in EEG imaging both in terms of achievable resolution and in modelling scope. The performance assessments will take place both at the level of the forward model and within the inverse source algorithm.

Theoretical developments will show the effectiveness and numerical robustness of our scheme. Moreover the theory will be complemented and corroborated by numerical results which will include realistic scenarios and head models obtained from MRI data. This will show the practical impact of the newly developed strategies and their applicability in realistic EEG neuroimaging scenarios.