

Regularization of Current Source Localization Problems In Neuroimaging Using Multi-frequency Constraints

Matteo Cantenne⁽¹⁾, Angelo Faccia⁽¹⁾, Ermanno Citraro⁽¹⁾, Adrien Merlini⁽²⁾, and
Francesco P. Andriulli⁽¹⁾

⁽¹⁾ Politecnico di Torino, Torino, Italy

⁽²⁾ IMT Atlantique, Brest, France

The localization of neuronal current sources is achieved through postprocessing the solution of an inverse source problem. The associated linear system is ill-posed, meaning it lacks a unique solution for a set of measured data and it is highly sensitive to the presence of noise. These problems are usually underdetermined due to the limited number of sampling points compared to the number of unknown current sources in the forward model. Moreover, the presence of evanescent modes, especially at low frequencies, results in a loss of information.

Said evanescence translates into the presence of a nullspace in the forward operator, making the inverse problem ill-conditioned. This can be mitigated by employing regularization strategies, such as truncated Singular Value Decomposition (SVD) or Tikhonov regularization. These techniques ensure a unique and stable solution but do not guarantee the accuracy of current reconstruction. As alternative, the introduction of regularization approaches based on the physical property of the problem can improve the accuracy of the solution.

Another factor that could play a fundamental role in reducing the effect of ill-posedness is the exploitation of multi-frequency information which is what this work has been focusing on. When dealing with current sources radiating at different frequencies, in fact, it is possible to couple multi-frequency data to achieve a reliable regularization of the problem. Solving a multi-frequency inverse source problem consists in identifying position and intensity of a source from measurements and analysis of the field acquired at multiple frequencies.

This talk will present a strategy for the resolution of multi-frequency inverse source problem with leadfields at different frequencies. It will start from an analysis of different theoretical approaches for the simultaneous minimization of an objective function and then will study the enforcement of coupling solutions based on a-priori hypothesis on spectral behaviors. Coupling constraints will be adapted to ad-hoc scenarios. These will include the penalization of solutions with non-smooth transitions in source activity across frequencies and the promotion of solutions where close sources have similar activity at very close frequency. All spectral constraints will be translated into linear formulations which regularize the null space of the inverse operator and incorporate a priori information on the spectral behavior of the sources. This will result in more reliable estimates of the source localization.

Numerical and real case scenarios validations will show the effectiveness of all newly proposed multi-frequency regularizations strategies together with their practical relevancy.