A Strategy for the Combined Estimation of Tissues Properties and Brain Sources in EEG-MEG Analysis

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Abstract—**The estimation of human brain cellular activity from EEG/MEG signals requires a rather accurate knowledge of the living tissues electrical properties. The identification of these properties from joint EEG/MEG measurements as well as from impedance tomography has been investigated in literature. In this paper, an assessment of the information coming from each diagnostics, and their possible interactions, are presented and discussed.**

Index Terms—**Inverse Electromagnetic Problems, Magneto-Encephalography, Electro-Encephalography.**

I. Introduction

Human brain functional imaging is an appealing field of research, involving the contribution of several disciplines from biophysics to electrical engineering, to signal processing and so on. Among the possible diagnostic techniques, Electro-EncephaloGraphy (EEG) and Magneto-EncephaloGraphy (MEG) should be mentioned because of their high time resolution. They are based on the measurement and processing of the electromagnetic signals coming from human brain [1], i.e. the scalp potential and the extra-cranial magnetic flux density, respectively. The origin of the electric and of the magnetic signals is the neural cells activity arising in the dendrite trunks, defined *primary currents* in specialized literature, and usually modeled as impressed currents in the equivalent models. Moreover, the brain tissues, modeled as equivalent conducting materials [1], are interested by return path currents, defined *volume currents*. The quantity to be estimated in brain functional imaging is the time evolution of the primary currents because, when interpreted on neuro-physiological bases, gives important information to the main cognitive processes.

The identification of impressed currents in a conducting material from boundary voltage measurements and/or external magnetic field measurements is a challenging inverse problem because of its nonlinearity and ill-posedness.

Living tissues are highly complex non-homogeneous, anisotropic, time-varying structures whose modeling plays a key role in the EEG and MEG inverse problem theory [2]. As a matter of fact, scalp voltage measurements are strongly sensitive to the living tissues electrical resistivity which, in turn, is an uncertain data. Also MEG data, on the other hand, are characterized by a non negligible dependence on tissues resistivity [3] when realistic head modeling is considered. As a consequence several advantages can be taken from a joint EEG and MEG analysis. Indeed an overall improvement in the signal to noise ratio (SNR) is expected by combining EEG and MEG [4, 5]. The estimation of tissues properties from an EEG and MEG simultaneous analysis has been also proposed [6] leading to the conclusion that even a rough improvement in the initial estimate of the tissues resistivity could lead to a significant increase in the accuracy of the reconstruction. More recent papers assessed the difficulty of estimating the details of some anatomical parts such as the skull compartment [7]. For these reasons the introduction of prior information coming from other diagnostics has been investigated [8]. In particular the estimation of the resistivity distribution by using the Electrical Impedance Tomography (EIT) has been proposed [4, 9]. EIT it is a powerful diagnostic tool that, when used for diagnostic applications, is able to provide an estimate of the electrical admittivity profile inside human body by injecting a suitable set of alternated current patterns and processing the corresponding voltage patterns. EIT, similarly to EEG and MEG, is also characterized by high time resolution and low spatial resolution compared to other diagnostics. EIT is well suited especially for non-invasive tissue electrical characterization in vivo as it is safe, cheap, and quick and, in addition, the equipment is small and portable.

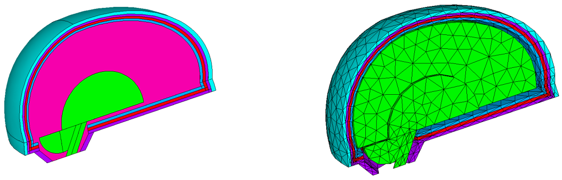
The impact of the iterative updating of the tissue resistivity using EIT in the EEG and MEG sources estimation has been recently investigated [10].

In this paper, the performances of two different updating schemes are compared. In the first one (EM Strategy) EEG and MEG measurements only are processed and the lower sensitivity of the MEG measurements with respect to the EEG is exploited. In the second one (EMT Strategy), an iterative EIT scheme is combined with a simple Moore-Penrose pseudo-inversion of EEG and MEG data. In both cases, the identification of the resistivity is based on the minimization of the regularized weighted residual between measured and calculated data, by using a zero order non linear optimization algorithm.

Comparisons are based on the analysis of the convergence of the two schemes on FEM simulated measurements, taking into account the robustness against measurements errors.

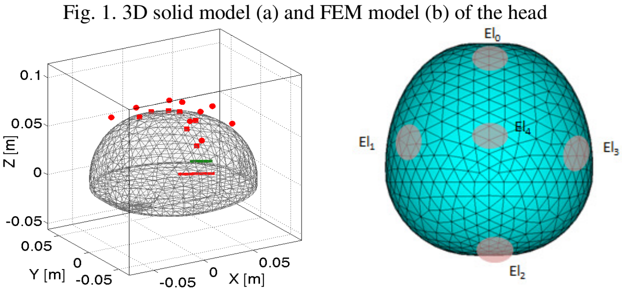
II. Numerical Example

A simplified geometry (Fig. 1a), yet modeling realistically a human head, was generated to simulate brain activity measurements. The "head" is modeled using six concentric layers, whose resistivity values are reported in Table I [10]. FEM mesh comprises 34170 nodes and 23470 1st order elements, Fig. 1b. The scalp potential and the radial components of the extra-cranial magnetic field are evaluated in 9 observation points respectively (Fig. 2a). Moreover, EIT measurements are simulated by applying 5 electrodes on the scalp (Fig. 2b).



(a) (b)

Fig. 1. 3D solid model (a) and FEM model (b) of the head



(a) (b)

Fig. 2. EEG and MEG sensor montage (a) and EIT sensor montage (b)

TABLE I. HEAD LAYERS RESISTIVITY

Compartment (layer)	**Resistivity[Ωm]**
Scalp	2.30
Skull hard bone	160
Skull soft bone	109
Skull hard bone	160
Cerebro-Spinal Fluid	0.65
Brain	5.00

In order to compare the two proposed procedures, 18 measurements (9 MEG + 9 EEG or 9 MEG +8 EEG +1 EIT) have been processed. As anticipated, the two procedures for resistivity estimation have been compared both in terms of accuracy and computational burden. To this aim, the convergence sequence of the two processes has been examined.

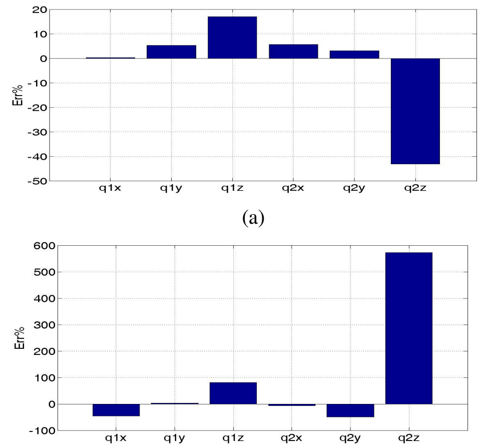
The numerical test on the EMT Strategy converges after a few iterations, the number depending on the initial guess and the required accuracy; a quite fast pseudo-inversion of the electromagnetic Green's matrix is then performed to estimate the sources.

The EM Strategy appears less effective requiring almost twice the iterations number to converge. In addition, the single iteration is more expensive because it requires the update of the Green's matrix.

In both cases, a vanishing error in both dipole moment and brain resistivity estimation is achieved if no measurements errors are considered.

In particular the estimation of two dipole moments (one assumed in the cortical region and the other one deep in the brain as shown in fig. 2a) is performed. In order to compare the effectiveness of the two strategies, the two processes have been interrupted after four iterations (initial guess: resistivity affected by an error of 500%). The results (Fig. 3) confirm the beneficial impact of the EIT in the general robustness.

In the full paper an extensive comparison of the two strategies will be presented, not only from accuracy and CPU time points of view: additional comparison elements will also be considered as the reliability and the robustness versus some uncertainty sources.



(b)

Fig. 3. Relative error in the estimation of the dipole moment components after four iterations by using: (a) EMT Strategy, (b) EM Strategy

III. CONCLUSIONS

The reconstruction of neuronal electromagnetic sources from EEG/MEG data requires the simultaneous evaluation of the resistivity profile in the head tissues. Unfortunately, due to its non-linear impact on the Green's operator, such process is very complex, rather costing and quite sensitive to uncertainties. However, if adding further information coming from EIT measurements the effectiveness of the reconstruction is strongly improved.

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