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A Method for Quantitative Imaging of Electrical Properties of Human Tissues

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Abstract—The knowledge of the electrical properties (EPs), namely conductivity and permittivity, of living biological tissues has an intrinsic interest for its relevance in different biomedical applications. EPs are indeed fundamental in hyperthermia treatment planning and electromagnetic dosimetry, as the accuracy of the assumed electrical model plays a key role on actual performance of the treatment and on the proper evaluation of field exposure. Moreover, EPs are also relevant for diagnostic purposes and can give rise to unconventional check-up and follow-up techniques. Indeed, the values of EPs can be related to the health condition of biological tissues so that anomalies with respect to expected reference values may represent a warning about pathologies.

Nowadays, the EPs values are derived from ex-vivo measurements. For instance, virtual patients for bio-electromagnetic applications are developed starting from the tissue anatomy derived by segmented magnetic resonance imaging (MRI) or computed tomography (CT) images, and by associating to each tissue the EPs taken from existing databases wherein such ex-vivo measurements are collected. However, the agreement between the EPs measured ex-vivo and the in-vivo values of living tissue still represents an open problem and some recent papers have shown that a difference between the ex-vivo and in-vivo EPs exists.

As a consequence, several studies have been focused on the development of non-invasive techniques to retrieve EPs in-vivo, directly in the human body. To this end, one possibility is given by a recently introduced imaging modality based on a proper processing of the magnetic field acquired by an MRI system. This technique can reach a spatial resolution of the order of a few millimeters and high accuracy in determining the electrical parameters of the scenario. However, this mapping can be performed only at the resonance frequency of the MRI apparatus. As a consequence, a dispersion relation (to extrapolate data from the MRI Larmor frequency to the ones of interest) is needed. In addition to this, the measured data are affected by phase uncertainty. Indeed, while various methods have been proposed to measure the magnitude of B_1^+ map, there is no way to quantitatively measure the absolute phase. To cope with this issue, MRI based EPs tomography (MR-EPT) should rely on a procedure able to deal with phaseless data.

As an alternative, microwave tomography can be exploited to image EPs. As a matter of fact, it provides a low-cost and non-invasive modality to investigate the human body in a whole spectrum of frequencies of interest. On the other hand, as compared to MRI and CT, microwave EPs tomography (MW-EPT) exhibits a low spatial resolution, which may ultimately impair the creation of reliable and accurate electrical models. In addition, although phase measurements are of course possible at microwave frequencies, MW-EPT can take a remarkable advantage from only amplitude data, in terms of a significant reduction of the complexity (and cost) of the required hardware. In particular, simpler MW-EPT devices are more easily integrable within existing clinical systems, such as hyperthermia applicators and MRI machines. For instance, clinical systems already adopted for microwave hyperthermia treatment could be enhanced with the capability of performing, without significant modifications, a pre-treatment patient-specific estimation of the electromagnetic scenario at the exact frequency of interest. Finally, the possible exploitation of minimally-invasive only-amplitude probes would yield a higher MRI compatibility of microwave system, thus allowing a simultaneous acquisition of MRI and microwave signals.

Accordingly, both MR-EPT and MW-EPT are potential candidates for EPs mapping of living tissues, but they would both take great advantage from the chance of using only-amplitude data to adopt devices as simple as

possible. However, both these modalities involve the solution of a non-linear and ill-posed inverse problem, whose difficulties significantly worsen when phase measurements are not available or cannot be performed.

With respect to this framework, this contribution explores the possibility of estimating EPs using phaseless electromagnetic data, by relying on a regularization by projection, which benefits from the tissue segmentation extracted from MRI or CT. More in detail, the available spatial priors are exploited to build a patient-specific representation basis of the unknown EPs, which are then encoded by means of a set of (complex) coefficients. By doing so, the anatomical information is exploited to achieve a significant reduction of the number of unknowns, which allows to mitigate or even overcome the unavoidable loss of information associated with the lack of phase measurements. Notably, there is no restriction on the number of tissues, nor assumptions on some tissues or the need of selecting any regularization parameter.

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