A first order Induced Current Density Imaging and Electrical Properties Tomography Method in MRI

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Introduction

In this abstract we present a first-order Electrical Properties Tomography (foEPT) method to retrieve the Electrical Properties (EPs) of tissue and the radio-frequency electric field strength (E_z) within the mid-plane of a birdcage coil from measured B_1^+ data. The EPs and E_z are essential to determine the Specific Absorption Rate (SAR) and are important in many other medical application areas as well (e.g. hyperthermia treatment planning). As opposed to standard EPT methods based on Helmholtz's equation[1], our approach does not assume homogeneous media and first-order instead of second-order differentiation operators act on B_1^+ as in a Helmholtz-based approach. Our foEPT method can therefore handle inhomogeneous structures and is less sensitive to noise.

Method

The proposed method works in a non-iterative manner. In the first step, the induced current density (J_z^{ind}) is reconstructed by acting with a particular first-order differentiation operator on the measured B_1^+ field. Having the current density available, we determine the corresponding electric field strength (E_z) in the second step and, finally, from J_z^{ind} (step 1) and E_z (step 2), the EPs are determined in the third step of our method. The first step of foEPT can be carried out essentially in real-time and images the induced current density within the mid-plane of a birdcage coil.

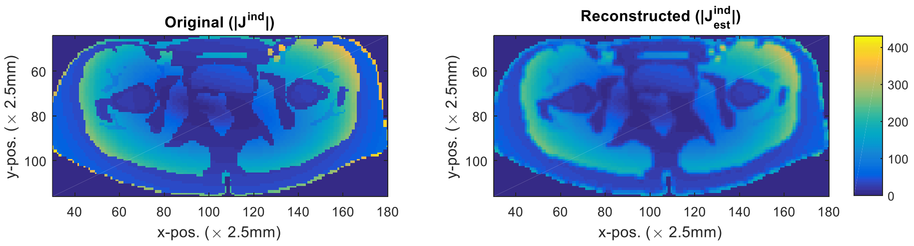

Figure 1 - Comparison of the original Induced current density and the reconstructed using the described first order differentiation method.

It has been shown that the field in the mid-plane of a birdcage coil is essentially a two-dimensional E-polarized field[2]. Using the measured B_1^+ field in this plane and the fact that the magnetic flux density is divergence free, Maxwell's equations show that the induced current density is given by

$$J_z^{\text{ind}} = \frac{2}{\mathrm{i}\mu_0}\left(\partial_x - \mathrm{i}\partial_y\right)B_1^+ \qquad (1)$$

Here i is the imaginary unit, μ_0 is the permeability of vacuum, and ∂_x and ∂_y denote differentiation with respect to the transverse x- and y-coordinates, respectively. Note that no assumptions on the homogeneity of the tissue have been made as in Helmholtz-based EPT methods.

The total induced current in the human body depends on the external sources, while the EPs of tissue do not dependent on these. Therefore it is possible to reconstruct the tissue parameters from a knowledge of the external (source) fields and the measured B_1^+ field. To this end, we setup a scattering formalism using an integral equation with J_z^{ind} as a source. The second step of foEPT consists of solving this integral equation and provides us with the total electric field strength E_z within the slice of interest.

Having J_z^{ind} and E_z available from steps 1 and 2, respectively, the tissue parameters can finally be determined in the final step from the constitutive relation $J_z^{\text{ind}} = (\sigma + \mathrm{i}\omega\varepsilon)E_z$.

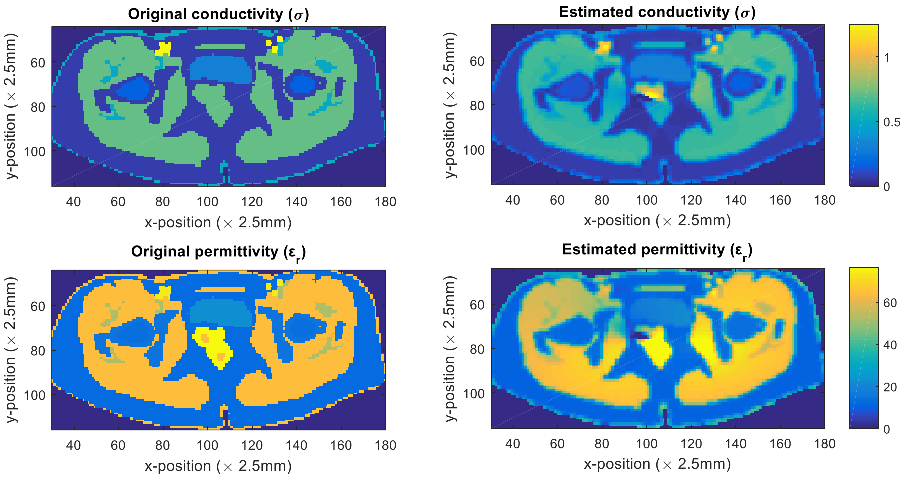

Figure 2: Comparison of the original conductivity and permittivity with those reconstructed using the foEPT method.

Results

To test the foEPT method, we consider a slice through the pelvis region of a female body model (Ella, 2.5mm resolution) from the ITIS foundation[3]. The birdcage coil operates in quadrature mode at 128MHz (3T). Having the B_1^+ field available, step 1 obtains the induced current density. The magnitude of the reconstructed induced current density is shown in Figure 1. We subsequently carry out steps 2 and 3 of foEPT. The reconstructed conductivity and permittivity are shown in Figure 2 and are in good agreement with the original conductivity and permittivity profiles. Finally, the magnitude of the reconstructed electric field strength is shown in Figure 3.

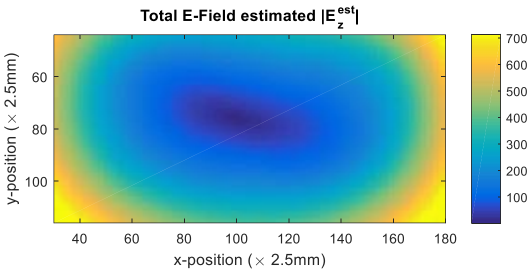

Figure 3: The reconstructed electrical field from step 2 of the foEPT method.

Conclusion and Discussion

The proposed foEPT method provides extremely fast current density imaging and electrical properties tomography within the mid-plane of a birdcage coil and with comparable quality to the recently proposed contrast source inversion method[4]. In addition to the tissue parameters, the electric field is reconstructed as well, which allows for determination of the SAR. In its present form, the method is restricted to the mid-plane of the coil and future work will focus on extending foEPT to slices located outside this mid-plane.

The electric field in the centre of the image is very low, which leads slightly over- and underestimates of the contrast on the right- and left-side, respectively. It is similar to the artefacts encountered in[4] and could possibly be alleviated through the use of multiple measurements with different antenna settings (shimming).

For the induced current density images the process introduces a slight blurring probably due to combining the (differentiated) x and y components of the B field. Nevertheless it is accurate, and robust to noise due to the low order of differentiation.

References

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