MR-EPT Reconstruction Using an Inverse Formulation

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Abstract: The electrical conductivity of soft tissues can be reconstructed from imaging with MR Electrical Properties Tomography (MR-EPT). The reconstruction method used here is based on an inverse problem formulation, with two advantages over a direct inversion approach: a) no spatial differentiation is needed and b) the regularization term determines the resolution of the reconstructed data. The process is exemplified using phantom (gelatine and saline) data.

1 Introduction

Magnetic Resonance Electrical Property Tomography (MR-EPT) is a relatively new strategy for estimating a tissue's electrical conductivty and permittivity distribution. It offers the potential of high resolution admittance mapping as compared to electrical impedance tomography (EIT) without the need for electrodes as are needed for magnetic resonance EIT (MR-EIT). The general approach for conductivty imaging with MR-EPT is to obtain a phase image and/or B1 map image of the RF field produced using specific pulse sequences. This image can be manipulated to estimate the conductivity distribution. Typically, this manipulation requires second derivatives be computed from the phase data. This is an undesirable process that is prone to amplify noise. Other approaches have included algorithms that lower this requirement to first derivatives, reducing sensitivity to noise. Here we describe an alternative method that solves the MR-EPT problem using an inverse problem formulation that does not require differentiating the input image.

2 Methods

2.1 Inverse approach formulation

In MR-EPT, the electrical conductivity σ can be shown to be proportional to the Laplacian of the phase of the transmit B1 field:

$$\sigma(r) \approx \frac{1}{\omega\mu}\Delta\phi\big(H^{+}(r)\big). \qquad (1)$$

The inverse is true as well: if $\sigma(r)$ is known, the phase can be obtained by solving $\Delta\phi = \omega\mu\sigma(r)$. Using an iterative inverse formulation approach, the updated value of σ is given by $\sigma_{new} = \sigma + \delta\sigma$ where

$$\delta\sigma = (J^{T}J + \alpha L^{T}L)^{-1}\Big(J^{T}\big(\phi\big(H^{+}(r)\big) - \phi + \alpha L^{T}L\sigma\big)\Big). \qquad (2)$$

Here J is the Jacobian of the conductivity to phase mapping, L is a regularization matrix, and α is a regularization parameter used to stabilize the inversion. We have implemented this inversion using two different regularization terms: a) a quadratic/Laplacian approach and b) a Total Variation functional approach [1,2]. A Primal Dual Interior Point Method optimization scheme is used for the Total Variation approach, which produces images with sharper contrasts at boundaries.

2.2 Data acquisition

A custom gelatin phantom (10% gelatin, 1% NaCl) was constructed with three rows of circular wells with increasing diameters (5, 10, 15mm). Each series of wells was filled with saline solutions with increasing conductivities (~3, 5, 8 S/m). Cupric sulphate was added for MR contrast (Figure 1). Data was acquired on a Philips Achieva 3T platform, with a standard 3D SE sequence; phase images were used for reconstructing the conductivity. Two-dimensional reconstructions of the electric conductivity based on our inverse approach are presented in Figure 2.

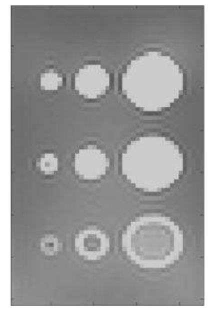

Figure 1: Phantom geometry (MR magnitude).

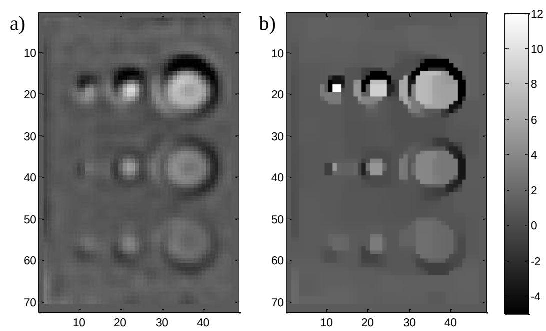

Figure 2: MR-EPT reconstruction with the inverse formulation approach: a) with quadratic regularization; b) with Total Variation regularization.

Conclusions

Reconstruction of MR-EPT conductivity data based on an inverse formulation approach is demonstrated here. The primary advantage of this approach is that is does not require differentiation of the phase data. An additional advantage is that custom regularization approaches can be considered for enahncing image quality. For instance, a priori anatomical information obtained from other MR variants (i.e. T2-weigted imaging) might be used as spatial priors.

References

[1] Borsic A, Graham BM, Adler A, Lionheart WRB, IEEE Transactions on Medical Imaging, 29, 1, 44-54, 2010.

[2] Borsic A, Adler A, Inverse Problems, 28, 095011, 2012.