MREIT conductivity imaging based on the local harmonic B_z algorithm: animal experiments

Kiwan Jeon [1] , Chang-Ock Lee [1] , Eung Je Woo [2] , Hyung Joong Kim [2] and Jin Keun Seo [3]

1) *Department of Mathematical Sciences, KAIST, Daejeon, Korea*

2) *College of Electronics and Information, Kyung Hee University, Korea*

3) *Department of Mathematics, Yonsei University, Seoul, Korea*

Corresponding Author : Kiwan Jeon, Jeonkiwan@kaist.ac.kr

ABSTRACT

Numerous phantom experiments and numerical simulations show that the harmonic B_z-algorithm in magnetic resonance electrical impedance tomography (MREIT) provides cross-sectional conductivity images of an electrical conducting subjects with high spatial resolution and accuracy. However, in animal experiments, the conventional harmonic B_z-algorithm shows poor performance in providing accurate conductivity reconstruction near boundaries of problematic regions including bones, lungs, air-filled stomach, and the subject boundary. The recent MREIT algorithm called *local harmonic B_z-algorithm* is designed to deal with image defects caused by the presence of those problematic regions. In this talk, we examine the local harmonic B_z-algorithm [13] using the B_z-data from animal experiments. We take advantage of a level set based segmentation method to extract problematic regions automatically and a hybrid denoising technique to carry out the noisy B_z data near problematic regions. Incorporating these efficient techniques into the local harmonic B_z-algorithm, we produce conductivity images with higher spacial resolution.

INTRODUCTION

Magnetic resonance electrical impedance tomography (MREIT) attempts to provide static conductivity images of an electrically conducting object with high spatial resolution [1]-[11]. We sequentially inject multiple currents through chosen pairs of surface electrodes to produce internal current density $\mathbf{J} = (J_x, J_y, J_z)$ and also magnetic flux density $\mathbf{B} = (B_x, B_y, B_z)$ distributions inside the object. In order to reconstruct conductivity images, MREIT uses an MRI scanner to measure a set of B_z data where z is the direction of the main magnetic field of the scanner.[12]

The conductivity image reconstruction in MREIT is based on the relationship among the conductivity distribution σ, the applied current I, and the measured B_z data;

$$B_z(\mathbf{r}) = \frac{\mu_0}{4\pi} \int_\Omega \frac{\sigma(\mathbf{r}) \ [(x-x')\frac{\partial u}{\partial y}(\mathbf{r}')-(y-y')\frac{\partial u}{\partial x}(\mathbf{r}')]}{|\mathbf{r}-\mathbf{r}'|^3} \, d\mathbf{r}' \\ + \text{lead wire effects,}$$

where u is the electrical potential generated by the injection current I that satisfies the following mixed boundary value problem:

$$\begin{cases} \nabla\cdot(\sigma\nabla u)=0 \quad \text{in } \Omega \\ I=\int_{\mathcal{E}^+}\sigma\frac{\partial u}{\partial \mathbf{n}}\,ds=-\int_{\mathcal{E}^-}\sigma\frac{\partial u}{\partial \mathbf{n}}ds \\ \nabla u\times\mathbf{n}=0 \ \text{ on } \mathcal{E}^+\cup\mathcal{E}^- \\ \sigma\frac{\partial u}{\partial \mathbf{n}}=0 \quad \text{on } \partial\Omega\setminus\overline{\mathcal{E}^+\cup\mathcal{E}^-} \end{cases} \tag{1}$$

Here, $\mathbf{n}$ is the unit outward normal vector, $\mathbf{r}=(x,y,z)$, $\frac{\partial u}{\partial \mathbf{n}}=\nabla u\cdot\mathbf{n}$, and μ_0 the magnetic permeability.

The first B_z-based MREIT reconstruction algorithm called the harmonic B_z algorithm was proposed in [3]. Since then, various other methods were also developed to improve the image quality [6]-[10]. Numerous numerical and experimental studies have shown that it is quite successful in producing high resolution conductivity images. All the previous MREIT reconstruction algorithms require generation of at least two non-parallel internal current density distributions by sequentially injecting multiple independent currents. However, in animal experiments, the conventional harmonic B_z-algorithm shows poor performance in providing accurate conductivity reconstruction near boundaries of problematic regions including bones, lungs, air-filled stomach, and the subject boundary. The recent MREIT algorithm called *local harmonic B_z-algorithm* [13] is designed to deal with image defects caused by the presence of those problematic regions.

In this talk, we examine the local harmonic B_z-algorithm using the B_z-data from animal experiments. From a careful understanding of the structure of internal current density, the local harmonic B_z algorithm based on a divide-and-conquer strategy has proposed. It consists of three major steps: (1) separation of problematic regions where we expect almost parallel current densities, (2) conductivity reconstruction in regions away from problematic regions and (3) recovering of conductivity values inside problematic regions. For the first step, we adopt an image segmentation method utilizing the available MR magnitude image. For the second step, we use the harmonic B_z algorithm among many B_z-based methods since there exist numerous previous results for comparisons. Incorporating these efficient techniques into the local harmonic B_z-algorithm, we produce conductivity images with higher spatial resolution.

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