COMBINATION OF MULTICHANNEL RECEIVE DATA FOR LOCAL CR-MREPT

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Target Audience: Researchers interested in electrical property imaging using MRI and novel image contrast.

Introduction: Convection-reaction equation based Magnetic Resonance Electrical Properties Tomography (cr-MREPT) has been recently proposed to calculate the electrical properties (EPs, conductivity σ and permittivity ε) of tissues including the transition regions where EPs vary[1]. In cr-MREPT, a partial differential equation (PDE) which is in the form of a convection-reaction equation is derived, and is solved for EPs using triangular mesh based finite difference method. It has advantages over standard MREPT methods[2-3] in terms of being capable of reconstructing the transition regions and being more resistant to noise. However cr-MREPT cannot successfully reconstruct the EPs in the regions where the magnitude of the convection term is close to or less than noise. To deal with this problem a method has been proposed[4] based on the use of a multichannel receive coil where the distribution of the convective field and hence the location of the low convective field region differ from one channel to another. In many applications, instead of calculating EPs in the whole object, it is sufficient to reconstruct EPs in a "local region of interest". For instance calculating the EPs of a brain tumor it is sufficient to make the calculations in the local region that encloses the tumor. In this study, we propose a local cr-MREPT algorithm that reconstructs EPs in a desired local region using an appropriate combination of data received by multi-channel receive coils.

Theory: Principle of B_1^- based cr-MREPT method has been explained previously[4]. Starting from the Maxwell's equations, the 2D governing convection-reaction PDE (Eq. 1) is derived for each receive coil element, (assuming that the spatial derivatives of B_z and the derivatives of B_1^- in z- direction are negligible). In Eq. 1, $\mathbf{F}^-$ is the convective field and $u = 1/(\sigma + i\omega\varepsilon)$. In order to solve this equation, the knowledge of the complex B_1^- sensitivities of each coil are required. Calculation of the B_1^- is not straightforward since B_1^- is generally coupled with the proton density, M_0. For this purpose, two experiments with identical sequence parameters are performed. In the first experiment quadrature body coil (QBC) is used for both transmission and reception, and transverse magnetization ($M^+ = |M^+|e^{i\varphi^{(+)}}$) can be estimated (Eq. 2) using the assumption of ($B_1^+ \approx B_1^-$) in QBC. Here $|B_1^+|$ can be found using a B_1 mapping technique. In the second experiment, QBC is used for transmission and multi-channel receive array is used for reception. By using the transverse magnetization found in the first experiment, B_1^- of each coil can be calculated using Eq. 3-4.

<u>*Governing convection-reaction equation*</u>

For the k[th] receive coil,

$$\mathbf{F}^- \cdot \nabla u + \nabla^2 \left(B_{1,k}^-\right)^* u - j\omega\mu \left(B_{1,k}^-\right)^* = 0 \quad (1)$$

$$\mathbf{F}^- = \begin{bmatrix} \partial\left(B_{1,k}^-\right)^*/\partial x + i\,\partial\left(B_{1,k}^-\right)^*/\partial y \\ -i\,\partial\left(B_{1,k}^-\right)^*/\partial x + \partial\left(B_{1,k}^-\right)^*/\partial y \end{bmatrix}, \nabla u = \begin{bmatrix} \partial u/\partial x \\ \partial u/\partial y \end{bmatrix},$$

<u>*Calculation of $\left(B_{1,k}^-\right)^*$*</u>

1st experiment: (Tx and Rx from QBC) ($B_1^+ \approx B_1^-$)

$$|S_{QBC}|e^{i\varphi_{QBC}} \approx |M^+|e^{i\varphi^{(+)}}|B_1^+|e^{i\varphi^{(+)}} \quad (2)$$

$$|M^+| = M_0 \sin(\gamma\tau|B_1^+|) = |S_{QBC}|/|B_1^+|$$

$$\varphi^{(+)} = \varphi_{QBC}/2$$

2nd experiment: (Tx from QBC and Rx from receive array)

$$|S_k|e^{i\varphi_k} \approx |M^+|e^{i\varphi^{(+)}}|\left(B_{1,k}^-\right)^*|e^{i\varphi_k^-} \quad (3)$$

$$\left(B_{1,k}^-\right)^* \approx S_k/M^+ \quad (4)$$

Methods: Local EP reconstruction algorithm is implemented in MATLAB (The Mathworks, USA). Prior to reconstruction the user chooses a region on the MR magnitude image as shown in Fig. 1 and 2. Triangular mesh is generated on the selected region and the experimental data are interpolated to the triangular mesh nodes. A Gaussian filter with standard deviation of 0.0028 m is applied to measured $B_1^{(+)}$ and each $B_1^{(-)}$ complex data. First and second derivatives of B_1^- at the mesh nodes are calculated using the method proposed by Fernandez et. al[5]. Eq.1 is approximated for each triangle using u values at the nodes and a final matrix equation for the whole domain, $\mathbf{Au} = \mathbf{b}$, is constructed, where $\mathbf{u}$ is the vector of all unknown u values. To combine multi-channel coil data, $\mathbf{A}$ and $\mathbf{b}$ of all coils are concatenated and $\mathbf{u}$ is solved in the least square sense using Dirichlet boundary conditions on the boundary of the selected region. For each coil, triangles which have a lower convective field than the specified threshold value are discarded from the matrix equation. This threshold value is taken as the standard deviation of the noise in the convective field images. The method is demonstrated in both a phantom experiment and *in-vivo* reconstruction of brain conductivity of a healthy volunteer (according to the Institutional Review Board of Bilkent University). For the phantom experiment background is prepared using an agar/saline solution (20 gr/l Agar, 2 gr/l NaCl, 0.4 gr/l $CuSO_4$) and a higher conductivity cylindrical anomaly is prepared using only a saline solution (8.8 gr/l NaCl, 0.4 gr/l $CuSO_4$). Experiments are performed on a 3T MR scanner (Siemens, Erlangen, Germany) using a quadrature body coil (QBC) and 12-channel receive only phased array (PA) head coil. For phantom experiment, $|B_1^{(+)}|$ map is obtained using actual flip angle (AFI) method (Tx: QBC, Rx: PA, FA=60°, TR1/TR2=50/250 ms, FOV=200 mm, 1.56x1.56x4 mm, NEX=20, total scan time~13min). For complex $\left(B_{1,k}^-\right)^*$ estimations two balanced SSFS sequences with the same parameters (Tx/Rx: QBC, FA=60°, TE/TR= 2.09/4.18 ms, FOV=200 mm, 1.56x1.56x5 mm, NEX=32, total scan time~40 sec) are used. In the first SSFP sequence (Tx/Rx: QBC), $\varphi^{(+)}$ and M^+ are estimated using Eq. 2. In the second SSFP sequence (Tx: QBC, Rx: PA), multi-channel receive data from PA head coil is acquired (Eq. 3-4). For the volunteer experiment, sequence parameters are: AFI method (FA=60°, TR1/TR2=40/200 ms, FOV=250 mm, 1x1x4 mm, NEX=20, total scan time~20 min) and balanced SSFP sequences (FA=50°, TE/TR=2.3/4.6ms, FOV=250mm, 1x1x5 mm, NEX=32, total scan time ~1 min).

Results: For phantom measurements, reconstructed conductivity image for the selected region is given in Fig.1. Contrast between background and the anomaly is well reconstructed and the image has no boundary artifact or low convective field distortion. For the volunteer experiment, three different regions in the volunteer brain are selected and the conductivity map of these sections are shown in Fig.2. Conductivity maps are consistent with the anatomical structure of the brain and the conductivity values are within the expected range. EPs at the boundaries of selected regions are taken as σ=0.6 S/m and ε_r=77. It is found that the exact value assigned to the boundary is not critical except for a narrow band around the boundary.

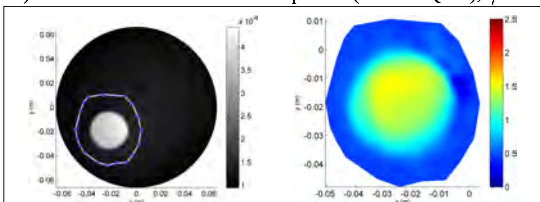

Fig. 1. (left) Local area selection on the SSFP magnitude image. (right) Reconstructed conductivity distribution (in S/m) in the specified local area for phantom experiment.

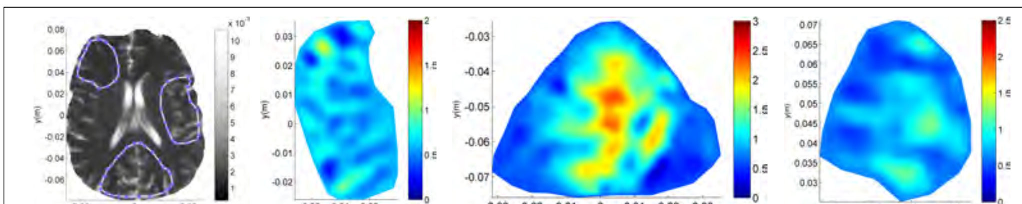

Fig. 2. Conductivity maps (in S/m) of three different local regions in a volunteer brain with the selected regions

Discussion and Conclusion: In this study, local cr-MREPT method is proposed for the artefact free reconstruction of EPs in the selected region using the appropriate combination of multi-channel receive coil data. The method is demonstrated in both phantom and volunteer experiments. Results are promising for the interpretation of conductivity maps for the clinical purposes.

References: [1] Hafalir et al. IEEE Trans. Med Imaging, 2014;33(3) 777-793 [2] Katscher U et al. IEEE Trans Med Imaging 2009;28(9):1365-1374. [3] Voigt T et al. Magn. Reson. Med. 2011;66(2):456-466 [4] Gurler et al. ISMRM22(2014):3247 [5] Fernandez et al. MIKON-2004;2:585-588

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