Optimal combination of a multi-receive coil for conductivity mapping using phase based MREPT

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Introduction: Phase based Magnetic Resonance Electrical Property Tomography (MREPT)[1-3] reconstructs images of electrical conductivity of the subject at the Larmor frequency using measured transceive phase, i.e. the sum of the transmit phase and the receive phase. The performance of the method depends on the spatial variation of the magnitude B_1^+, which affects the accuracy of the phase based approximation[1,3]. If the magnitude B_1^+ is constant, the approximation becomes exact and the conductivity can be reconstructed with only the phase of B_1^+. In MRI, the transmit phase is not acquired alone but combined with the receive phase. For a single transmit channel system, no methods are available to extract the transmit phase without any assumptions on the transmit and receive coils. For a quadrature transmit/receive coil, the transmit phase is approximately the same as the receive phase[2,3] at low fields such as 1.5T, 3T and center locations in 7T. In addition, using a quadrature body transmit coil and a quadrature head receive coil, the conductivity can be estimated without separating the transmit phase and receive phase[2]. However, no methods were reported using a single transmit coil and multiple receive coils which is a commonly used clinical configuration. In this work, we propose a method of optimal coil combination for phase based conductivity mapping using multi-receive coil. The performance was evaluated by phantom experiments.

Methods: Phase-based conductivity reconstruction using a multi-receive coil: Over a homogeneous region of electric conductivity and permittivity, the Helmholtz Eq. of magnetic fields[3] not only satisfies for transmit coil but also for each individual receive coil elements (Eq. 1). Hence, the Helmholtz Eq. also satisfies for any linear combination of the receive coil elements (Eq. 2). If the magnitude of B_1^+ and the magnitude of the combined receive profile are constant, conductivity can be determined from the phase of the B_1^+, ϕ_p, as well as the phase of the combined receive profile, ϕ_m (Eq. 3). In this case, without needing to separate the transmit and receive phase, the conductivity can be measured directly from the transceive phase, ϕ_{pm} (Eq. 4).

Equations:

$$\nabla^2 H_k^- = i\omega\mu_0(\sigma + i\omega\varepsilon)H_k^- \quad (1)$$

$$\nabla^2\left(\textstyle\sum_k c_k H_k^-\right) = i\omega\mu_0\left(\sigma + i\omega\varepsilon\right)\left(\textstyle\sum_k c_k H_k^-\right) \quad (2)$$

$$\sigma = (\omega\mu_0 V)^{-1}\int_V \nabla^2\varphi_p\, dv = (\omega\mu_0 V)^{-1}\int_V \nabla^2\varphi_m\, dv \quad (3)$$

$$\sigma = (2\omega\mu_0 V)^{-1}\int_V \nabla^2(\varphi_p + \varphi_m)\, dv = (2\omega\mu_0 V)^{-1}\int_V \nabla^2\varphi_{pm}\, dv \quad (4)$$

$$I_k(r) = W(r)\sin\left(\theta(r)\right)|H_k^-(r)|\exp\left[i\left(\varphi_p(r) + \varphi_{m,k}(r)\right)\right] \quad (5)$$

$$\{c_k\} = \underset{\{c_k\}}{\operatorname{argmin}}\left\{\textstyle\sum_{r\in D(r_0)}\left\|\left|\sum_k c_k I_k^-(r)\right| - 1\right\|^2 + \lambda\sum_k\|c_k\|^2\right\} \quad (6)$$

Optimal combination of multiple receive coils - Locally homogeneous magnitude: Using multiple receive coils, the reconstructed spin-echo image can be written as Eq. 5, where the weighting factor, W(r), is used to represent all possible weightings, T1, T2, T2* (except transmit and receive coil profiles), $\theta(r)$ is the flip angle, and $\varphi_{m,k}(r)$ is the phase of the k^th receive coil element. In this work, we assume that the weighting factors, W(r), were also uniform inside the same tissue and the B_1^+ magnitude is slowly varying. The proposed combination method is to achieve locally homogeneous magnitude of the combined receive coil. Instead of homogenizing the magnitude of combined receive coil profiles, the proposed approach aims to homogenize the magnitude of the combined image. Furthermore, instead of homogenizing globally, which could be hard to achieve in the presence of tissue heterogeneity, we homogenized the magnitude of the combined image for a local region around each voxel r_0, $D(r_0)$ (Eq. 6). Then, the conductivity at the voxel r_0 was determined from Eq. 4, where φ_{pm} is the transceive phase of the combined image. The minimization in Eq. 6 was performed by magnitude least square (MLS) approach[4] to homogenize the magnitude of the combined image. A regularization parameter, λ, trade-offs the uniformity of the magnitude and the SNR of the combined image. As a comparison, the conductivity was also computed by a conventional coil combination approach where images from the multi-receive coil were summed after the phase of each individual coil element was equalized in the center of the receive coil. phasing.

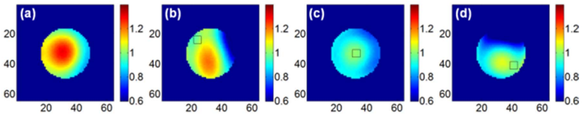

Fig. 1: Magnitude of the combined image at iso-center: (a) conventional method, (b-d) proposed method optimized for the blank square, (b) Voxel at (24,24), (c) Voxel at (31,31), (d) Voxel at (41,41)

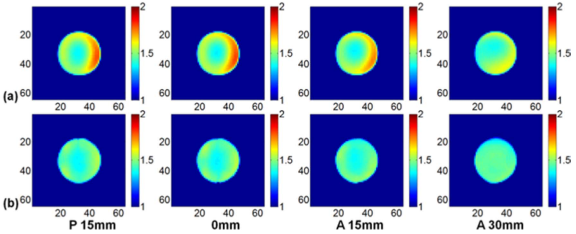

Fig. 2: Conductivity estimates of the homogeneous phantom at four coronal slices: (a) conductivity estimates using conventional coil combination (c) conductivity estimates using our proposed approach

Phantom experiments: The phantom experiments were performed on a 3T Siemens Tim Trio scanner. Using a 12 channel receive head coil, i.e., a multi-receive coil, MR images were measured from a homogeneous cylindrical phantom filled with saline water. The concentration of NaCl and $CuSO_4$ was 0.8% and 0.05%. The transceive phase of the coils were measured by 3D balanced steady-state free procession (bSSFP) with resolution of $3\text{mm} \times 3\text{mm} \times 3\text{mm}$. The other imaging parameters were field of view (FOV) $384\text{mm} \times 192\text{mm} \times 180\text{mm}$, image size $128 \times 64 \times 60$, the flip angle 30°, TE 1.8ms, TR 3.6ms, total scan time 10 minutes with 44 averages.

Results: As seen in Fig. 1(a), the magnitude of the combined image using the conventional coil combination is not constant. The proposed approach locally homogenizes the magnitude of the combined image for a local region shown as the black square in the Fig. 1(b-d). The conductivity estimates using the transceive phase acquired by conventional method shown in Fig. 2(a) are not constant inside the homogeneous phantom. The proposed coil combination method results in much more homogeneous conductivity estimates as seen in Fig. 2(b).

Conclusions & Discussions: A novel method of locally optimized combination of multi-receive coil was proposed for phase based MREPT. The proposed approach locally homogenizes the magnitude of the receive profile and thus can reduce the possible errors in phase based MREPT. The performance of the proposed method was verified in a 12 channel multi-receive head coil and compared with the performance of one conventional coil combination method. Other conventional methods for coil combination can be also compared but the performance was not presented here. Many clinical systems are operated using multi-receive coils, therefore our method can be useful in clinical imagers.

References: [1] Voigt et al, MRM, 66:456-466, 2011, [2] Voigt et al, MRM, 68:1117-1126, 2012, [3] van Lier et al, MRM, 67:552-561, 2012, [4] Setsompop et al, MRM, 59:908-915, 2008.

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