B_1^+ Region of Interest Localization through Convex Optimization

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Introduction: High field MRI systems are known to exhibit B_1^+ non-uniformity due to shorter RF wavelengths. RF field propagation into a load causes interference patterns not significant in lower field strength systems. If these interference patterns could be controlled, there is the potential to steer a constructively interfering field to spatially correlate with an anatomic region of interest. The objective of this study was to develop a new technique for independently designing the phase and magnitude of the 16 elements of a transceive head coil array to target a local region of interest with a desired B_1^+ distribution. A 9.4 T magnet and 400 MHz 16 element microstrip TEM coil [1] with 23 cm inner diameter were used to steer B_1^+ field into an 18.5 cm diameter spherical phantom composed of an aqueous mixture of 90mM saline solution and 2mM $CuSO_4$.

Method: Convex optimization [2] was used in this study to design the 16 element drive weights, $\mathbf{w} \in C^{16}$, which define the transmit magnitude and phase for each individual element [3]. The convex optimization approach was chosen because problems formulated in a convex way are provably globally optimal. Additionally, solutions to convex formulations are obtained very efficiently. Time efficiency is significant if such an algorithm is to be used on human loads where time between patient movements is limited.

A B_1^+ map was generated for each of the transmit channels using a modified double angle method [4]. The result of this map was a complex matrix $\mathbf{B}_1{}^+{}_{ij}$. Each entry in this matrix corresponds to the phase and magnitude of the B_1^+ field at the j^{th} point on a grid in the load slice due to the i^{th} current element. When the weight vector, $\mathbf{w}$, is multiplied by $\mathbf{B}_1{}^+{}_{ij}$, the result, $\mathbf{w}^T\mathbf{B}_1{}^+{}_{ij}$, is the B_1^+ magnitude and phase at each point on a grid in the load slice. An optimization was formulated to minimize an upper bound on $|\mathbf{w}^T\mathbf{B}_1{}^+{}_{ij}|$ for j's in a desired suppression region of the load. In the localization region targeted to receive power, ideally a lower bound would be placed under $|\mathbf{w}^T\mathbf{B}_1{}^+{}_{ij}|$ and the objective function would raise this bound. However, such a formulation is non-convex and can be proven to be NP-Hard (due to a lower bound constraint on a second order cone). Instead, a single target point inside the load is chosen and constrained to unity. Around this point is a region where the value of $|\mathbf{w}^T\mathbf{B}_1{}^+{}_{ij}|$ is unconstrained (see Figure 1). This region serves to provide a transition between the targeted point and the suppression region. Also, since the rate of change of $|\mathbf{w}^T\mathbf{B}_1{}^+{}_{ij}|$ with respect to position is limited for a given $\mathbf{w}$, this region will also be partially filled with B_1^+ field. The optimization algorithm as stated in words is written mathematically as the second order cone program:

$$\begin{array}{lll} \text{minimize} & U & \\ \text{subject to} & |\mathbf{w}^T\mathbf{B}_1{}^+{}_{ij}| \le U & j \in \text{suppression region} \\ & \mathbf{w}^T\mathbf{B}_1{}^+{}_{ij} = 1 & j = \text{target} \end{array}$$

This optimization was setup and solved using the Matlab toolbox SeDuMi [5] through the CVX [6] user interface. After optimization, all weights were scaled to the maximum transmit power of the amplifiers and a final B_1^+ map was measured.

Results: The results of two localizations are plotted in Figure 1. The first run targeted a tight circular region at the center of the phantom. The second run targeted an off center region of interest. Here, some difference exists between the optimized design and the measured result. Also, there are a few locations where the B_1^+ map abruptly jumps to zero which was not the true value of the B_1^+ field in these areas. Both of these effects are caused by insufficient SNR in the B_1^+ mapping algorithm and are not a result of errors in the optimization.

Discussion: Although a phantom was used in this study, no properties of the phantom were relied upon in the design of the transmit weights. For this reason, weight design based on anatomy is possible. As mentioned previously, weight design computation time must remain low when used on living anatomy. Fast computation was achieved in this study through the use of convex optimization. As a point of reference, the optimization step in the procedure above required less than 10 seconds on a SunBlade 2500 desktop computer. Decreasing grid density of $\mathbf{B}_1{}^+{}_{ij}$ can be used to decrease computation time but for very sparse sampling, significant B_1^+ variation will result in a non-representative $\mathbf{B}_1{}^+{}_{ij}$ matrix. In this study a 5 mm grid was used. Note that during the above measurements, the power amplifier corresponding to weight number 16 was not functional. To accommodate this hardware problem, an additional constraint was included in the optimization to set the 16^{th} weight to zero magnitude.

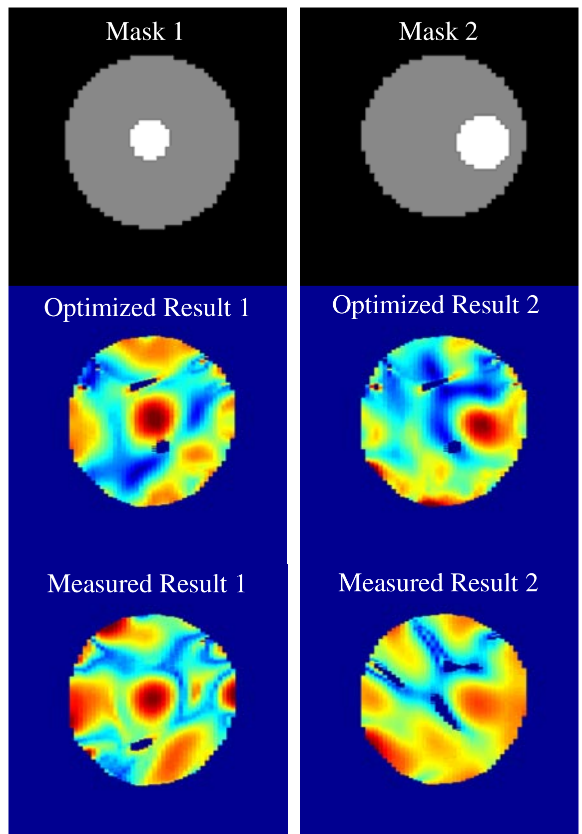

Figure 1: The top plots show the masks used in the optimization algorithm. The gray area represents the suppression region and the white area represents the 'transition' region. The targeted point in both cases is located at the center of the white transition region. The plots labeled 'Optimized Result' are plots of $|\mathbf{w}^T\mathbf{B}_1{}^+{}_{ij}|$ for the designed values of $\mathbf{w}$. The final plots show the measured B_1^+ map obtained by application of the designed weights.

Conclusion: A convex optimization method of steering the B_1^+ field for region of interest localization has simulated and validated by MRI measurement. This method may prove useful in MRI and MRS applications for optimizing the signal to noise and other NMR criteria in targeted anatomy.

References:

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Acknowledgements: We acknowledge Professor Zhi-Quan Tom Luo, Department of Electrical Engineering, University of Minnesota. Support from NIH-R01 EB000895, NIH-P41 RR08079, NIH-S10 RR139850, Keck Foundation