Fast 3D Algorithm for Coil Localization as an Aid in Estimation of B1 Distribution

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Introduction: Parallel transmit arrays have been widely used to compensate B_1 inhomogeneity at high field. However, interventional MRI is another application requiring localized transmission for minimal coupling to guide-wire devices or implants. Since the Tx array location can vary, and experimental B_1 mapping is time-consuming, we aim to automate B_1 estimation using coil RF current sensors and fiducial markers for finding coil location and orientation. Sample loading tends to cause a first order perturbation on coil current and B_1 scaling, and is detectable by a current sensor. The overall RF profile varies with relative location of coil to sample (Fig 1) and geometric information is needed. In this study, we evaluate an algorithm to compute the transmit coils in the imaging space. Based on coil location, 3 dimensional B_1 estimates of a target region are extracted from pre-computed field profiles in the imaging space.

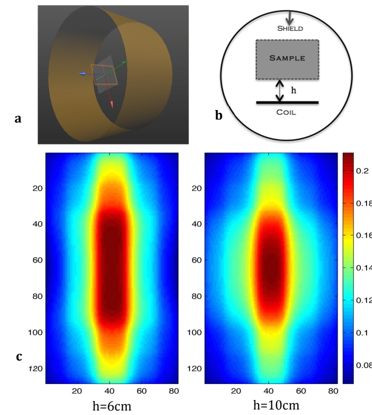

Figure 1: We aim to map known coil geometries in simulation space (a) and simulated $|B_1^+|$ distributions (b) to physical coil-sample locations (c) using markers.

Method: To identify coil location, 3 fiducial markers (either vitamin E or fluorine markers) [1] are placed on the conductor edges of a loaded transmit/receive coil that is tuned only to the proton Larmor frequency at 1.5 T (63.9 MHz). Fluorine (60.1 MHz) generates background-free usable SNR despite the coil tuning. The markers are excited by half passage adiabatic pulses due to their robustness to B_1 inhomogeneity near conductive edges. Then, a set of 1D projections are acquired along specified directions. The peak to marker correspondence problem is solved as follows [2]: 1) The peaks are identified along each projection by removing background signal and noise. Only projections with 3 identified peaks are accepted. 2) Among all projections, the 3 projections with the largest minimum distances between peaks are selected. Back projection of the markers yields 27 points, shown in Fig. 2. 3)To determine the location of the points that represent marker positions among all 27 possible points, a 4th projection is acquired, and the projections of all 27 points are calculated along the 4th projection and compared with the location of pre-identified peaks along the 4th projection. The closest points to the peaks are accepted. If the number of accepted points is more than the number of markers, step 4 is repeated with additional projections until converging on the 3 marker coordinates. Since the relative orientation of the 3 markers on the coil is known, the optimal transformation matrix that maps the initial location of the coil to the update location can be computed by Kabsch algorithm [3]:If $H = \sum_{i=1}^{3}(P_A^i - \mathrm{centroid}_A)\,(P_B^i - \mathrm{centroid}_B)^T$ is the covariance matrix, and P_A and P_B are initial and updated location of markers in Cartesian coordinates, respectively. The rotation (R) and translation (T) matrix would be:

$$R = VU^T$$
$$T = -R \times \mathrm{centroid}_A + \mathrm{centroid}_B$$

where $[U, S, V] = \mathrm{SVD}(H)$ .FDTD based simulation software SEMCAD X is used to calculate the magnetic field distribution for initial orientation of a coil in simulation space shown in Fig.1. Then, inverse transformation is done to map back the target region in imaging space to the corresponding region in simulation space.

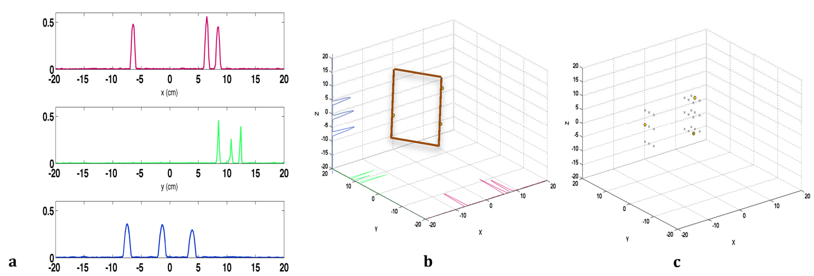

Figure 2: a: 1D projections of Vitamin E markers. **b**: Orientation of 3 markers on coil in 3D with the corresponding 1D projections along x, y, and z. c: 27 points from back projection of the peaks

Result: To assess the accuracy of the localization method, the algorithm was implemented in MATLAB and tested for a set of randomly generated points. Figure 3 represents the algorithm success rate as a function of required number of projections. The simulation result confirms that the localization algorithm requires a limited number of projections in predefined directions to find the accurate location of markers. To validate the proposed RF profile estimation method, an experimental double-angle B_1 map was acquired in a phantom and compared with the FDTD based simulated transverse B_1 map to within a scale factor for an arbitrary orientation of coil relative to the target plane in imaging space (Fig. 4).

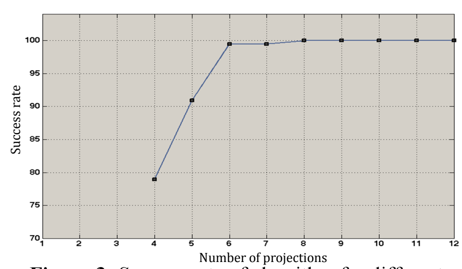

Figure 3: Success rate of algorithm for different number of projections

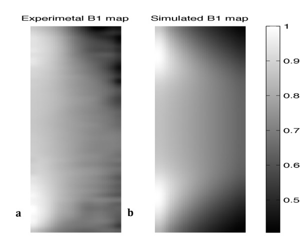

Figure 4: a: Double angle B_1 map. **b:** Simulated field with SEMCAD

Discussion and conclusion: A robust method for localizing fiducial markers on transmit coils is evaluated, and the proposed method for calculating the optimal translation matrix is demonstrated to map the field profile from simulation to imaging space. Knowing the coil orientation, the *incident* magnetic field distribution for each channel is estimated from pre-computed simulation data by avoiding time consuming experimental 3D B_1 mapping. Future work will explore complex coil-tissue scattering perturbations. Moreover, by adding current sensors to the coils, sensor measurements can be combined with knowledge of the RF profile estimation for auto-calibration and B1 shimming in parallel transmit system.

References:[1]P.Zarghamravanbakhash et al., ISMRM,1457, 2013. [2] D. Brujic et al., ISMRM, 2946, 2012. [3] Kabsch W. *A solution for the best rotation to relate two sets of vectors.* Acta Crystallogr. 1976.Grant support: R01EB019241, R01EB008108, P01CA159992. GE research support