Average SAR Constrained Local RF Shimming

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Introduction

Achieving given homogeneity and SAR constraints in RF shimming process is an important problem in high field MRI. There are different studies in the literature which dealt with the optimization of these parameters by using non-convex optimization techniques. In a previous work whole body SAR constrained RF shimming problem was solved in order to achieve whole slice transmit homogeneity [1]. For the cases in which a smaller target is imaged it might be sufficient to obtain a homogenous transmit profile in the vicinity of the target organ/tissue. In a previous work local shimming problem was solved for prostate imaging with local SAR constraints [2]. Although both local and whole body SAR are important limitations in high field MRI we focused on the relation between whole body SAR and transmit field homogeneity for local targets In this work an optimization method called Particle Swarm Optimization (PSO)[3] is used to solve the RF shimming problem mentioned above. The method is verified by phantom simulations of a 16 channel transmit coil array at 7 T.

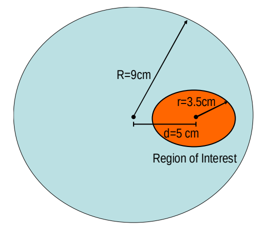

Figure 1 Location of the region of interest

Theory

Solving an RF shimming problem for a given coil geometry requires non-linear optimization algorithms. The initial point of the non-linear algorithms should be chosen in a rational manner in order to come up with useful solutions. Let α denote the set of complex currents on the channels of a given coil and let b denote the values of the forward polarized magnetic field H_f at a given point interest (x_0, y_0) when each channel is fed with a zero phase unit current. In this case $b\alpha$ gives the value of H_f at the point of interest for arbitrary currents. Among infinite solutions that equates H_f to an arbitrary value k at the point of interest, the one that minimizes whole body SAR is chosen as an initial point of the non linear optimization. For this purpose α that satisfies $b\alpha = k$ and minimizes $\alpha' R\alpha$ should be found. α that solves this problem can be expressed as $\alpha_0 = R^{-1}b^* / (bR^{-1}b^*)$. The SAR due to the α_0 currents is the minimum SAR value required to image a single point of interest. In order to solve the RF shimming problem, flatness ratio in the given region of interest will be minimized within a given SAR bound, using the particle swarm optimization method. Let S be a circular region with a radius of r_S, centered at the point of interest (x_0, y_0). B is a matrix constructed in a manner such that $B\alpha$ denotes the value of H_f at an array of points inside the region S. Then the objective function to be minimized can be written as $M * \left[\max\left(|B\alpha|\right) / \min\left(|B\alpha|\right)\right]$ M is a function whose value is extremely large if the SAR constraint is violated and 1 if the SAR constraint is not violated.

Methods and Results

A 16 element RF strip line array[1] mounted on a cylindrical former of diameter 32 cm is simulated using the program XDFTD software (REMCOM inc). The electric and magnetic fields are calculated in a uniform spherical phantom model of diameter 18 cm. The conductivity, of the phantom was taken as 1 S/m respectively. PSO algorithm was implemented using MATLAB (MathWorks inc.)Number of particles, and maximum iteration number were chosen as 80 and 5000 for all simulations. As a demonstration x=5 cm, y=0 is chosen as point of interest, for whole body SAR minimization. The diameter of the circular region S (region of interest) (Figure1) is taken as 7 cm. 230 points that are randomly distributed in the region S was used to calculate the flatness coefficient for the objective function. The minimum SAR solution for the point of interest resulted in a highly non uniform field distribution with flatness ratio of 21.5 at the region of interest. In order to fix the homogeneity problem flatness ratio is minimized. For the SAR constraint function M is chosen in a way such that M>>1 for $SAR > p \cdot SAR_{\min}$ and M=1 for $SAR < p \cdot SAR_{\min}$ where $SAR_{\min}$ is the minimum SAR solution in order to obtain unity H_f at the point of interest. In order to demonstrate the performance of the method the SAR and values obtained for different p, are compared to the SAR of the special case $\alpha = [1, e^{j2\pi/16}, ...e^{j30\pi/16}]$. Table 1 shows the flatness ratio and SAR reduction due to optimized α for different p values. In figure 2 the H_f map due to optimized α for p =20 is presented. Figure 3 shows the corresponding SAR map.

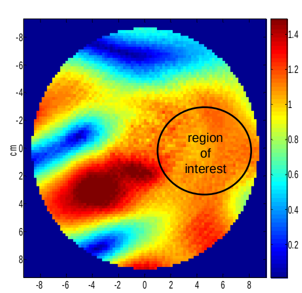

Figure 2 H_f map due to optimized currents

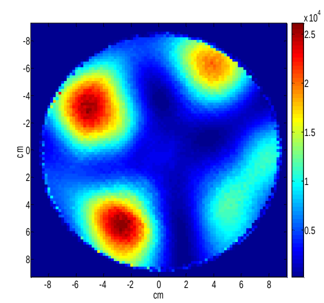

Figure 3 Square of the electric field due to optimized currents

	FLATNESS COEFFICIENT	SAR REDUCTION
p=5	1.76	11.62
p=10	1.63	5.73
p=15	1.45	4.48
p=20	1.22	3.71
p=50	1.18	2.05

Table 1 Flatness coefficient and SAR reduction due to optimized currents

Discussion

The starting point of the non linear optimization is a solution with low SAR and high flatness ratio. As the optimization code is initiated the flatness ratio is minimized however convergence to different local minima may be possible. To overcome this problem PSO parameters including number of particles, number of iterations and the dimension of the search space can be modified to obtain the best convergence performance.

Conclusion

A local RF shimming method that uses particle swarm optimization is presented. The overall optimization process starts with a global minimum solution by finding the minimum whole body SAR for to obtain H_f value of 1 at a point of interest. Flatness ratio is minimized in a region centered at that point of interest given that SAR remains bounded by a SAR constraint. The results are demonstrated for a local region of interest using phantom simulations of a 16 element RF strip line array.

References [1]Chang et al. "Transmit B1 Shimming at High Field with SAR Constraints: A Two Stage Optimization Method Independent of The Initial Set of RF Phases and Amp"ISMRM 2008 p 1088 [2] Metzger et al "Local B1 Shimming for Prostate Imaging with Tranceiver Arrays at 7T Based on Subject-Dependant Transmit Phase Measurements" Magnetic Resonance in Meidicine 59:396-409 [3]Robinson et al. "Particle Swarm Optimization in Electromagnetics" IEEE Transactions on Antennas and Propagation 2004;52(3)397-407