Parallel Transmit RF Design with Local SAR Constraints

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Introduction

Parallel transmit (pTx) applications in MRI are limited by local SAR constraints. SAR estimation in high-resolution segmented tissue models computationally very demanding, so while it's desirable to incorporate an exhaustive search over local SAR into pTx pulse design, it is not feasible. The model compression method of local SAR [1] can be used to determine the candidates of hot spots (the voxel with the maximum local SAR) and dramatically decreases the complexity of the prediction of the local SAR calculation while effectively capturing regions of large local SAR. We present a novel Magnitude Least Squares (MLS) spoke design method [2] that incorporates local SAR constraints via the model compression method.

Methods

The dissipated power at a voxel v can be calculated as

$$\sum_t q(t) = \sum_t \mathrm{Re}(\vec{E}_v(t)\cdot \underline{\underline{\sigma_v}} \cdot \overline{\vec{E}_v}(t)) = \sum_t \mathrm{Re}\left(\sum_{k=1}^{N}\sum_{l=1}^{N}\left(b_k(t)\cdot \bar{b}_l(t)\right)\left(\vec{S}_{k,v}\cdot \underline{\underline{\sigma_v}}\cdot \overline{\vec{S}}_{l,v}\right)\right),$$

where the electric field, E_v, and the complex conductivity tensor σ_v , $b_k(t)$ is the RF pulse on transmit channel k, $S_{k,v}$ is the pre-calculated electrical field vector that is caused by a unit signal of channel *k* in voxel *v*, and N is the number of transmit channels. By concatenating the RF pulse as a vector b, we can simplify the dissipated power as $\sum_t q(t) = b' S_v b$.

The electrical fields and magnetic fields on the HUGO model [3] for an eight-channel pTx body system at 3T were estimated with the Transient Solver in Microwave Studio (CST AG, Darmstadt, Germany) with a local SAR over a 10 g volume. By the model compression method, the dominant local SAR regions are captured by 36 virtual hot voxels. With these pre-calculated hot directions, we implement the Maximum Least Square (MLS) spoke design [2] with the additional local SAR constraints as,

$$\left\| m_d - |Ab| \right\|_w^2 + \lambda_1 \max_{v\in HV}\{b' S_v b\}$$, where *HV* is the set of 36 virtual hot voxels.

We developed an iterative process to find the optimum solution of the pTx RF pulse. For every iteration step, we approximate the maximum of the local SAR from the 36 voxels as the weighted sum of the local SAR from the individual 36 voxels: $\max_{v\in HV}\{b' S_v b\} \approx \sum_{v\in HV} w_v b' S_v b$, where w_v are the weighting factors. The summation of all 36 weighting factors is 1. We assign the uniform weighting over the 36 directions as an initial solution and design the 1st pTx pulse in the iteration. In each iteration step, we calculate the local SAR of all the 36 voxels with the designed pulse. Then, we increase the weighting factor of the voxel with the maximum local SAR and normalize the weighting factors so that the summation of all 36 weighting factors is 1. For each λ_1, we iterate the process to optimize the weighting factors.

As a performance comparison, we also designed conventional MLS spoke pTx pulses with a global power constraint:

$$\left\| m_d - |Ab| \right\|_w^2 + \lambda_2 \| b \|_2^2 .$$

Results

Based on the pre-caculated matrix S_v for 36 virtual hot voxels, we have designed the RF pulse with four spokes to mitigate the B1+ for an iso-center slice in our body model. Fig. 1 shows the maximum local SAR vs. the root-mean-square error of the mitigation, and demonstrates that by optimally designing the pulse by incorporating the model compression of local SAR, the maximum local SAR is decreased by 25~90% compared to the design with the global power constraints. The computation time of each iteration step is almost the same as the computation time of conventional MLS spoke design with the global power constraints.

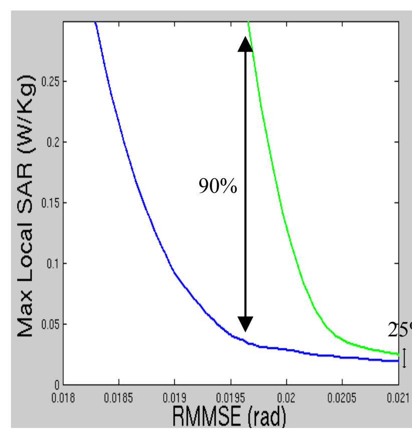

Fig.1: Performance of the pulse Design: global power constraints (green) and local SAR constraints (blue)

Conclusions

The model compression method for local SAR estimation dramatically decreases the complexity of the prediction of the local SAR calculation and enables the incorporation of local SAR constraints in pTx MLS RF design. Compared to conventional pTx MLS design with only an average SAR constraint, the local-SAR-constrained design decreased local SAR by 25~90% for a fixed mitigation performance.

References: [1] Matthias, submitted, ISMRM 2010, [2] Setsompop, MRM 2008 [3] Gabriel, Brooks AFB, TX, Tech. Rep. 1996.
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