3D Parallel Excitation Pulse Design Using Interleaved Sparse Approximation and Local Optimization

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Introduction

Determining optimal phase encoding locations for three dimensional parallel excitation spokes pulses is a non-trivial problem. Several algorithms have been developed (e.g., [1-3]), and can be partitioned into two classes: sparse approximation-based methods [2,3], and methods that locally optimize the encoding locations [1]. The two approaches have complementary features: sparse approximation-based methods approach global optimality when the target excitation phase is fixed and time-dependent effects (such as off-resonance) are ignored, while local methods can be performed jointly with target phase optimization and can account for time-dependent effects, but are only locally optimal. Recently, a greedy method that solves the sparse approximation problem and can account for off-resonance effects was introduced [4]. In this work we introduce a new algorithm similar to that method which interleaves greedy sparse approximation-based phase encoding selection with local gradient and target phase optimization. Because the new method also jointly optimizes the target phase, it is capable of multiband pulse design [5].

Design Algorithm

The algorithm starts with a DC spoke, and then optimizes the RF and target excitation phase for this single spoke. Least-squares spatial-domain pulse design is used to design the subpulse weights [6], and optimization transfer [7] is used to locally optimize the target phase. Once the local optimization converges, the target pattern for each off-resonant frequency is phase-shifted to accommodate a new subpulse placed before or after the current one, and an orthogonal matching pursuit (OMP) method is used to choose the new encoding location from a grid of candidates [3] to minimize error jointly across the frequency bands. Then, the local method is again used to optimize the encoding locations (also using optimization transfer), target phase and RF. Once the local method converges, OMP is used to choose a new location, and this process continues until all spokes have been added.

Simulation

Simulations were performed to compare the new method (Interleaved OMP + local) to OMP and OMP followed by local optimization (Sequential). B_1+ and B_0 maps were measured in a volunteer's brain on a 3T GE scanner (GEHC, Waukesha, WI, USA) using an 8-channel parallel excitation system with a head array. Pulses were designed to excite uniform flip angle patterns across a 400 Hz (3 ppm) bandwidth, sampled at 5 frequency locations. Figure 1 shows the results of this simulation, and illustrates that the new Interleaved OMP + local method achieves the lowest error for more than 2 spokes and that the addition of a new spoke is guaranteed to decrease the error, which is not true for the other two methods. Figure 2 shows that by adding new spokes before, after, or on either side of the current pulse at each iteration, one obtains minimum, maximum, and linear phase pulses and may thus approximately specify the TE period start.

Experiment

Using the same scanner and parallel transmit system, B_1+ maps were measured in a 16 cm silicon oil phantom using Bloch-Siegert B_1+ mapping [8], and 15 degree pulses were designed using the three methods to excite uniform patterns over a +/- 85 Hz bandwidth sampled at 3 frequency locations with an 11 spoke (11.7 ms) flyback trajectory. The pulses were then played on the scanner to image the resulting excitation patterns. Figure 3 shows the excitation patterns obtained after removing receive sensitivities. The new method produces more homogeneous excitation patterns at all frequencies and the lowest pooled pattern variance.

Conclusion

We have introduced a new method for designing three-dimensional spokes pulses. The method combines the strengths of greedy and local optimization methods, in that it simultaneously searches over a large region of candidate phase encoding locations, is compensated for time-dependent effects such as off-resonance, and relaxes the target excitation phase. The method also allows predictable placement of the TE period's start. Furthermore, the method has the desirable property (as in sparse approximation-based methods) that the addition of new phase encoding locations is guaranteed to reduce excitation error.

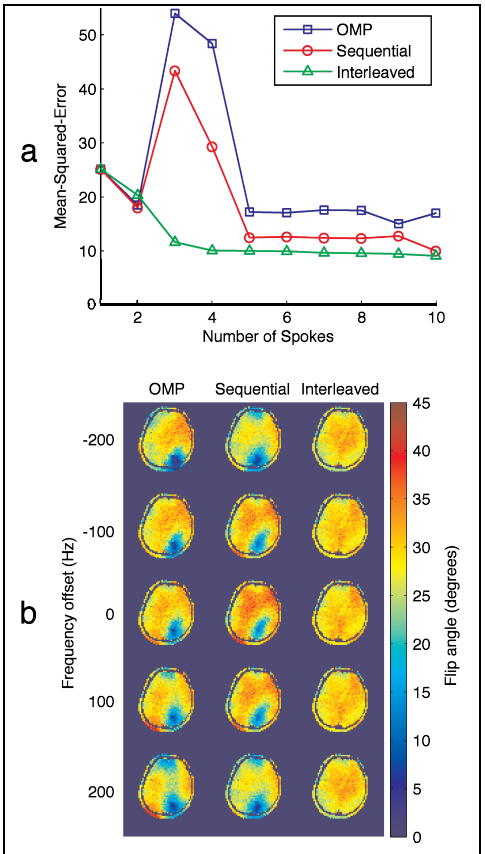

Figure 1: Simulation (a) Mean-squared-error versus number of spokes for the three methods. The error of the new Interleaved OMP + local method always decreases with the addition of a new spoke. (b) For a 3-spoke pulse (2.9 ms), the Interleaved OMP + local method excites a uniform pattern across all frequencies; the other two methods produce patterns with large voids.

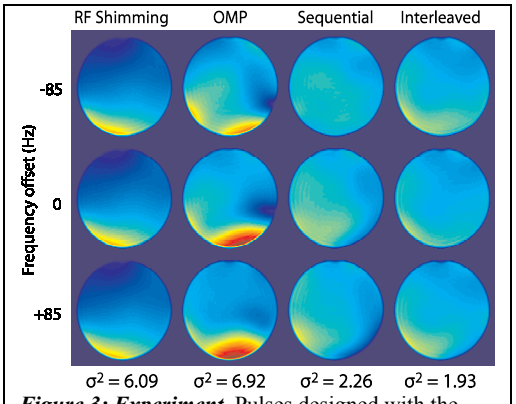

Figure 3: Experiment Pulses designed with the Interleaved OMP + local method excite the most uniform patterns across the +/- 85 Hz bandwidth.

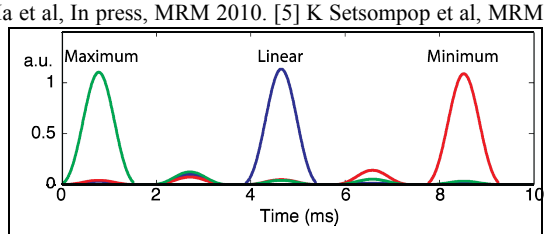

Figure 2: By adding new spokes only after, only before, or before and after the current spokes, a maximum-phase, minimum-phase, or linear-phase pulse, respectively, is obtained.

References

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