A fast parallel excitation pulse design for efficient selection and ordering of PE locations with B0 field inhomogeneity

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Introduction

We propose a novel fast algorithm to select and order Phase-Encoding (PE) locations of an Echo-Volumar (EV) trajectory for parallel excitation [1] in the presence of strong B0 field inhomogeneity. Recently, several algorithms [2-3] based on various sparse approximation theories [4-5] were presented to enforce sparsity on the PE locations to limit the RF pulse length. However, none of these included B0 field inhomogeneity in selecting and ordering PE locations. We found from computer simulation that ignoring off-resonance in establishing PE locations may lead to significant degradation in the excitation accuracy and also that previously used heuristics to order PE locations such as shortest-path [2] or spiral-in [3] can be quite suboptimal. We developed a fast novel greedy algorithm to determine PE locations that considers B0 field inhomogeneity. We demonstrate from simulation results that our new approach not only improves the excitation accuracy but also provides an effective ordering of the PE locations unlike previously developed algorithms.

Theory

The problem description and our new algorithm are described briefly in the box on the right. As in the previous approaches [2-3], we attempt to choose optimal PE locations from a set of discrete PE locations (F) formed by sampling a 2D spatial frequency space at Nyquist rate. Our greedy algorithm iteratively determines one PE location at a time in a reverse time order. The key idea of our method is that we maintain a small set of candidate PE locations (C) that show high correlation values with the current residual or the previous residual. We then project the excitation pattern onto a new set formed by the previously chosen PE locations and a candidate PE location in the set C to find out which best spans the excitation pattern. Running projection tests only for a small number of candidate PE locations avoids exhaustively checking all the candidate PE locations with computationally demanding orthogonal projections. Including candidate PE locations showing high correlation values in the previous step compensates for those candidates which are necessary but linearly correlated with the previously chosen PE locations. Without this, they would not have been included in the current projection test because their correlation with the current residual would be low.

Problem description (Assume a small tip angle domain)

$$\min_{b_j^n, \mathbf{f}_n \in \mathbf{F}} \|\mathbf{r}\| \quad \text{where} \quad \mathbf{r} = \mathbf{d} - \sum_{n=1}^{N} \sum_{j=1}^{J} \mathbf{W}_n \mathbf{S}_j \mathbf{f}_n b_j^n$$

d : vector containing samples of the desired excitation pattern
W_n : diagonal matrix of phase accrual from B0 off-resonance for the n-th PE location. n=1 for the last PE location, and n=2 for the second last PE location, and so on.
S_j : diagonal matrix of the j-th transmission coil sensitivity
F : matrix of candidate 2D spatial frequency column vectors
f_n : 2D spatial frequency vector for the n-th PE location.
b_j^n : weight of the subpulse deposited at the n-th PE location for the j-th coil.

Algorithm layout

Initialize C as an empty matrix.
Set the initial residual $\mathbf{r}_0 = \mathbf{d}$. Set n = 1, m = 3. No PE locations are selected initially.
Loop until the magnitude of the residual $\|\mathbf{r}_{n-1}\|$ is sufficiently small. {

- Find m columns of F having highest cumulative correlation[1] with $\mathbf{r}_{n-1}$
- Add those m columns to C.
- For each column in C, minimize $\|\mathbf{r}\|$ by setting it as the n-th PE location and setting the 1st to the n-1 th PE locations with those selected in previous iterations.
- Select the column of the minimum $\|\mathbf{r}\|$ value as the n-th PE location.
- Set the new residual $\mathbf{r}_n$ as the $\mathbf{r}$ having the minimum norm in the previous step.
- Discard columns of C except those with m-1 smallest $\|\mathbf{r}\|$ values and set n = n+1.

}

[1]For the n-th PE location, cumulative correlation between **x** and **y** is defined as follows:

$$\sum_{j=1}^{J} \left| \langle \mathbf{W}_n \mathbf{S}_j \mathbf{x}, \mathbf{y} \rangle \right|^2$$ where j is a coil index.

Experiments and Results

We applied our algorithm to the problem of B1 field inhomogeneity correction in attempt to excite a uniform excitation pattern. The excitation field of view was 24cm x24cm with a 64 x 64 uniform sampling grid for 5 mm thick slice. The number of transmission coils was 8 and the number of selected PE locations is 5. Figure 1 shows the region of interest and the B0 field map acquired from in-vivo scans of human brains. First we tested all possible orderings of PE locations chosen by [3] to see how ordering can affect excitation accuracy. Figure 2 presents the test result for the slice 2 showing no relationship between the normalized excitation error and the length of k-space trajectory. We found similar results in other slices. For each slice in Figure 1, the in-plane excitation profile was simulated (Figure 3). Our greedy method achieves higher excitation uniformity than the other methods suggesting that considering B0 field inhomogeneity for PE location selection and ordering is very important to excitation performance. Also, as we see in Figure 2, our new algorithm performed better than even the best ordering of [3], and similar trends were observed in other slices too. Our algorithm is computationally efficient because it does not need a combinatorial search on orderings.

Figure 1. Fieldmap in Hz(top row) and ROI(bottom row)

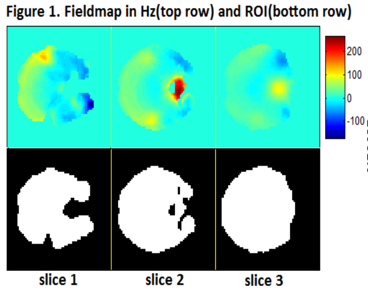


Figure 2. K-space trajectory length v.s. excitation error

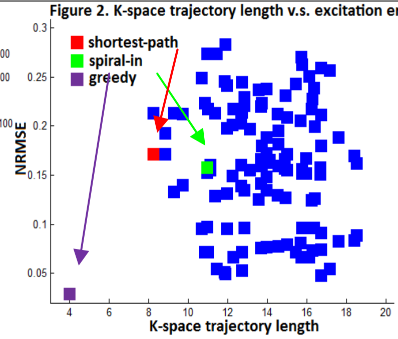
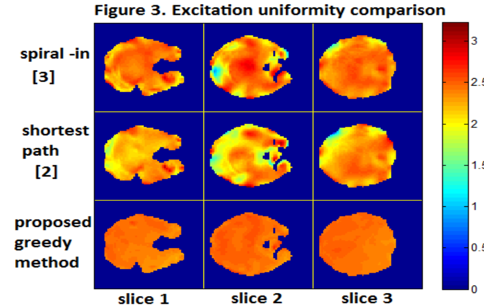


Figure 3. Excitation uniformity comparison



Conclusion

Our new algorithm uses B0 fieldmap information to efficiently select and order PE locations for a EV excitation k-space trajectory and we demonstrated that it significantly improves the performance compared to previously developed algorithms that ignore B0 field inhomogeneity when selecting and ordering the PE locations.

References & Acknowledgement

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