High SNR and High-Resolution fMRI using 3D OSSI and Tensor Model Reconstruction
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Introduction

Oscillating Steady-State Imaging (OSSI)
- A new fMRI acquisition approach, exploits a large and oscillating signal
- Provides inherent $T_2^*$-weighting at time of excitation

Compared to standard fMRI (GRE)
- Can provide 2 times higher SNR, well-suited for high-resolution fMRI

Challenges for high-resolution fMRI
- $n_c$ time points in an oscillation slows acquisition by this factor
- Short TR for each image limits k-space extent

Patch-Tensor Low-Rank Model

High-dimensional and local spatial-temporal low-rankness

Reconstruction Problem

\[
\min_X \frac{1}{2} \|A(X) - y\|^2_2 + \frac{3}{2} \lambda \|P(X)\|_0,
\]

- $X \in \mathbb{C}^{x \times y \times n_c \times t}$ denotes the OSSI fMRI images to be recovered,
- $A(\cdot)$ represents the MRI physics, $y$ contains sparse k-space data,
- $P(\cdot)$ partitions and reshapes its input into locally low-rank patch-tensors.

3D Sparse Acquisition

Variable-density spirals with good temporal incoherence

Prospectively Undersampled Results

2D spatial resolution 1.3x1.3x2.5 mm$^3$, volume TR 150 ms

3D spatial resolution 1.3x1.3x2.5 mm$^3$, volume TR 2.1 s (12 slices)

fMRI Experiment

- 3T GE MR750 scanner, 32-channel head coil, 3D oblique slab
- OSSI acquisition: TR/TE = 15/10.3 ms, $n_c = 10$, FA = 10$^\circ$
- fMRI task: left vs. right reversing-checkerboard visual stimulus
- Compared to the standard multi-slice Ernst-angle GRE fMRI at TE = 30 ms with matched spatial-temporal resolution

Summary: High-resolution 3D OSSI for fMRI

- 10-fold acceleration, 1.3 mm spatial resolution, 2.1 s volume TR
- 2 times more functional activation and 2 times higher temporal SNR

Figure: OSSI fMRI compared to GRE fMRI.

Figure: OSSI images with periodic oscillation pattern ($n_c = 10$).

Figure: A 3D patch-tensor unfolds to 3 low-rank matrices.

- Patch tensor dimensions: vectorized space $\times$ fast time $\times$ slow time
- Low-rank constraint on all the matrix unfoldings of a tensor

Figure: In-plane VD spiral with 12-fold acceleration. (b) Incoherent rotations in both fast time and slow time. (c) 3D prospectively undersampling with increased sampling density in central $k_z$.

- Acquires less than 10% of the fully sampled k-space data ($R = 10$)

Figure: OSSI images compared to GRE fMRI.

Figure: Activation maps, time courses, and temporal SNR maps of the proposed approach, CG-SENSE reconstruction, and GRE fMRI.