The Generalized 2D-PSWF Method for Tracking Dynamic Signal with High Temporal Resolution

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Introduction

The two-dimensional prolate spheroidal wave function (2D-PSWF) method [1-4] offers an efficient way of trading-off between spatial and temporal resolution for dynamic MRI, with minimal penalty due to truncation and partial volume effects. To efficiently reduce the number of required data points, the 2D-PSWF method tailors the k-space sampling area according to the size and shape of the predetermined ROI and creates a matching 2D-PSWF filter to optimally reduce truncation effects. In this method, the spatial information in the reduced k-space data is used to calculate the total image intensity over a non-square ROI instead of producing a low-resolution image. This method can be used for tracking dynamic signals from non-square ROIs using a reduced k-space sampling area, while achieving minimal signal leakage. This report presents a generalized method that allows for application of the 2D-PSWF method to an arbitrary k-space trajectory. An implementation of this method to a spiral trajectory is demonstrated with a high temporal resolution fMRI study.

Theory

The 2D-PSWF method calculates the optimal sampling region, A, of a predetermined size a, which maximizes the total signal over an ROI, B, in image-space and combines this with a matched two-dimensional filter that maximizes the energy concentration in B. The key to the method is finding the matched filter function $g(\mathbf{k})$, that vanishes off A and whose inverse Fourier transform, $G(\mathbf{x})$, has maximal signal concentration in B. Once $G(\mathbf{x})$ is obtained, the total signal intensity over the ROI B can be evaluated directly from the reduced k-space area. The original 2D-PSWF theory [1, 2] was developed only for the rectilinear sampling case. To further develop the method, increasing its suitability for dynamic MRI and CSI studies, a generalized 2D-PSWF theory was presented [4] that can be applied to non-rectilinear data acquisition methods. This generalization is important, as k-space is typically sampled in a non-rectilinear fashion for dynamic MRI studies, due to hardware limitations.

Methods

The experimental data was collected on a 3.0 T whole body scanner (GE magnet, General Electric Medical Systems, Milwaukee, WI, USA). The images were acquired in a oblique slice containing both primary visual and motor cortices using spiral trajectories with TR 60 ms, TE 30 ms, flip angle 15 degrees, field of view 240×240 mm^2, slice thickness 10.3 mm, matrix 24×24 and bandwidth 12.5 kHz.

The fMRI experiment was designed to use the generalized 2D-PSWF method to simultaneously track the hemodynamic signals in the visual and motor cortices while the subject undergoes a visual-motor activation paradigm. The activation paradigm consisted of six cycles of 30 s intervals. At the beginning of each interval a 100 ms light flash was presented. The subject was instructed to press a button immediately after the appearance of the flash, thereby leading to activation of the motor cortex. During the 30 second interval, 500 images were acquired rapidly every 60 ms. The sequence was repeated six times, each time producing a new sequence of 500 time points. Following the generalized 2D-PSWF method, two circular regions of interest (ROI) with a radius of 8 *mm* were chosen with one ROI placed in the primary visual cortex and the other placed in the primary motor cortex (Fig. 1). The predetermined k-space sub region, consisting of 3628 points in the given slice, was sampled once every 60 ms, and the resulting data was used to determine which regions of the brain were active. As the ROIs were chosen to be circles, the optimal sampling in k-space is also a circular region [3]. The k-space data was sampled using a spiral trajectory (Fig. 2), as this is the most time-efficient way to sample a circular region of k-space.

Results

Applying the generalized 2D-PSWF method to the experimental data, time series plots were obtained showing the dynamic signal change over each of the two ROIs. Fig. 3 shows a plot of the signal change in the visual cortex (bold line) and the motor cortex (light line). Typically under the conditions needed to increase the temporal resolution, tracking the hemodynamic responses is difficult because the image SNR is significantly attenuated by the drastically reduced TR. But, as seen in Fig. 3, the 2D-PSWF method provides adequate SNR for dynamic studies. With the increased temporal resolution, we can more precisely determine the delay in motor activation to be approximately 300 *ms*. The experimental result demonstrates that the 2D-PSWF method can be a valuable tool for the studies of functional neuron-neuron interaction, synchronization and connectivity.

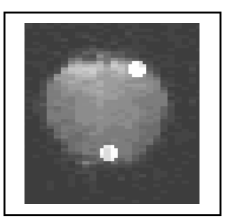

Fig. 1. The two ROIs (21 voxels) in the motor (upper) and visual (lower) cortices superimposed on an image of the slice.

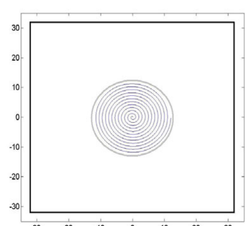

Fig. 2 The optimal sampling region corresponding to the ROIs in Fig 1. The trajectory used in the experiment is superimposed. Compare this with full k-space (64×64) which is marked by the black box.

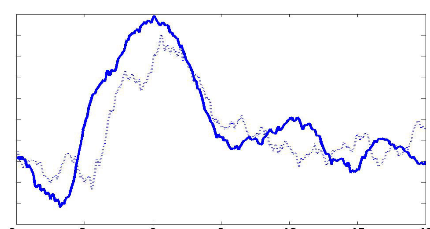

Fig. 3. The dynamic signal change over the visual (bold) and motor (light) cortex. for the first 18 s following visual stimuli. The delay in time-to-peak between the two curves is approximately 300 *ms*.

References

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