

Fast functional imaging using interleaved data acquisition and compressed sensing

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Introduction: The temporal resolution of conventional functional MRI (fMRI) is a limiting factor in some applications, e.g. functional connectivity. A temporal sampling frequency of 10Hz or more for whole brain coverage is desirable to better characterize the BOLD-response and to resolve physiological signal modulations (ECG, breathing) for subsequent removal. The temporal resolution can be increased by sampling only a small portion of the complete k-space per time frame. Undersampling artefacts (foldover, reduced spatial resolution) can be reduced using multi channel coil arrays, efficient trajectories and Tikhonov-regularized image reconstruction [1,2]. Further acceleration can be achieved using an interleaved acquisition and UNFOLD as demonstrated by Lee et al. [3]. In this contribution we aim to improve the spatial localization of activation by employing a bit-reversed interleaved data acquisition scheme combined with a KWIC (k-space weighted image contrast) trajectory combination [4] and nonlinear regularized reconstruction of each time frame with a compressed sensing penalty.

Methods: A gradient-spoiled FLASH-Sequence was used with TR=100ms and a flip angle of 15°. Each of the N_i interleaves of the trajectory consisted of N_p 3d radial k-space lines, which were connected using the shortest gradient scheme that was allowed within the hardware limits. The field of view had a size of 256³ mm. The radial spokes were arranged according to the sampling strategy presented in [4]. All experiments were performed on a 3T system. For signal reception, a 32-channel Siemens head coil was used. Visual and motor stimulation were performed in a block design using a checkerboard paradigm and bilateral finger tapping. Measurements were performed with $N_i=4$ and $N_p=20$ as trajectory parameters. The interleaves of this acquisition scheme are shown in Fig.1. In the current implementation the acquisition of one interleaf takes about 18 ms. Each timeframe of the time series was reconstructed by combining the data of N_i interleaves according to the KWIC scheme, i.e. only the interleaf of the current time point was fully used while an increasing portion of the k-space center was discarded in subsequent interleaves. The combined data was reconstructed by minimizing the l^1 -norm regularized cost function $f(z) = \|Az - b\|_2^2 + \lambda \|Wz\|_1$ using a nonlinear conjugate gradient algorithm. A is the forward operator describing the multi-coil measurement process, b contains the data within a time frame and W is a wavelet transform. The reconstructed image size was 64³. Activation maps were computed using SPM8 (www.fil.ion.ucl.ac.uk/spm). For comparison a regular reconstruction was performed using only one interleaf, i.e. every N_i -th time frame. The resulting reduction of the t-values due to the lower number of samples was compensated by a factor of $\sqrt{N_i}$.

Results: In Fig.2 the activation maps for the visual stimulation are shown. The results of the KWIC reconstruction (left) are compared to the regular reconstruction with only the data of one interleaf (right). The incorporation of information from all interleaves significantly increases the spatial resolution and therefore the ability to accurately localize the activation. In Fig.3 the results for the motor experiment can be seen. The response to the bilateral finger tapping is again more accurately resolved. The combination of several interleaves leads to an effective temporal filtering. Fig.4 shows a time course in the visual cortex and its spectrum. More importantly Fig.4 shows that the use of the KWIC scheme (black) is able to still resolve high frequency components in the time course, while they are strongly reduced in a simple sliding window reconstruction (red), in which all interleaves are treated equally.

Discussion: Using information from several interleaves to enhance the spatial resolution leads to unwanted temporal filtering. In this respect KWIC offers a much better performance than a standard sliding window reconstruction. The effective temporal resolution is therefore lower than $N_i \cdot TR$ even for high frequency components. Current results suggest that using interleaved acquisitions together with a nonlinear regularized reconstruction can be quite beneficial for undersampled functional MRI. Furthermore, the current TR is rather high compared to the actual acquisition time to shorten computation time, but in principle smaller repetition times can be used to further increase the temporal resolution. Optimization of the current trajectory is also expected to significantly lower the acquisition time and therefore either reduce the effects of field inhomogeneities or make way for additional k-space samples.

References:

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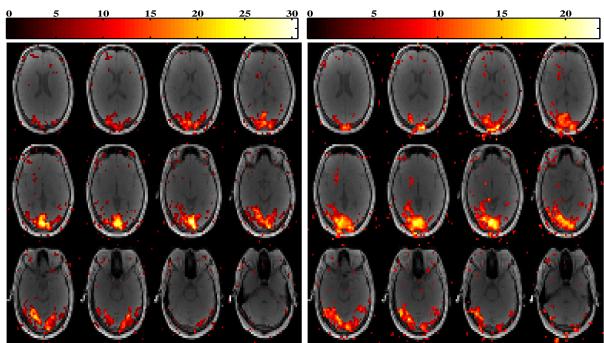


Fig.2. Activation maps for the visual stimulation overlaid onto a reference image. t-threshold is $t=4.8$, according to a corrected p-value of 0.05. KWIC reconstruction (left), regular reconstruction (right).

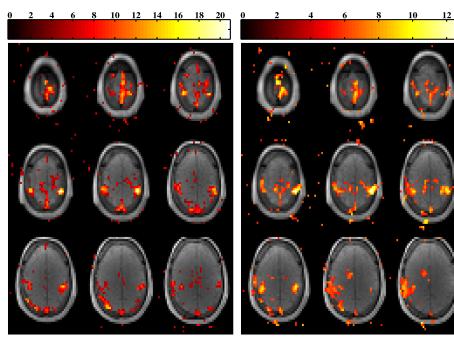


Fig.3. Activation maps for the bilateral finger tapping stimulation. t-threshold is $t=4.8$, according to a corrected p-value of 0.05. KWIC reconstruction (left), regular reconstruction (right).

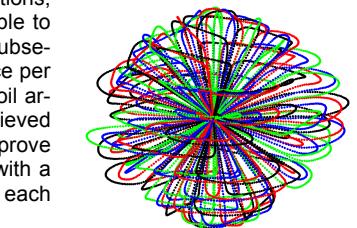


Fig.1. Plot of the four interleaves of an acquisition scheme with $N_i=4$ and $N_p=20$.

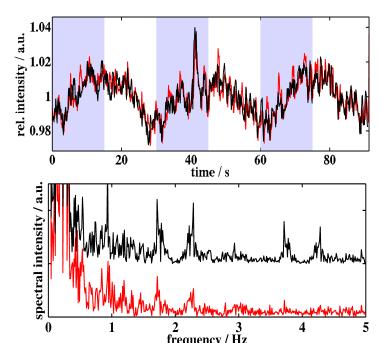


Fig.4. Time course in visual cortex and its spectrum for KWIC reconstruction (black) and sliding window reconstruction (red).