High-quality and high-resolution fMRI enabled by multiplexed parallel reconstruction of segmented EPI data

Hing-Chiu Chang[1], Pooja Gaur[2], Ying-Hui Chou[1], and Nan-Kuei Chen[1]

[1]*Brain Imaging and Analysis Center, Duke University Medical Center, Durham, NC, United States,* [2]*Department of Biomedical Engineering, Vanderbilt University, Nashville, TN, United States*

Target Audience: Researchers and clinicians who are interested in high-resolution fMRI studies and technical improvement of segmented EPI

Purpose: It is well known that the spatial resolution and fidelity are limited in single-shot EPI based fMRI data. Even though the spatial resolution of fMRI data can be significantly improved with segmented EPI acquisition [1], segmented EPI based fMRI is highly susceptible to undesirable aliasing artifacts originating from subtle subject motion, B0 drifting, and other types of signal inconsistencies among multiple EPI segments of each fMRI volume. These aliasing artifacts are unstable over time, leading to increased time-domain signal fluctuation in dynamic segmented EPI scans and difficulty in reliably detecting subtle BOLD contrast. Here we report a novel algorithm, termed multiplexed parallel reconstruction, to effectively remove undesirable aliasing artifacts in segmented EPI based fMRI. Using the developed methods, high-quality, high-resolution and high-SNR fMRI can be achieved much more reliably, without relying on any external navigator signal.

Methods: Two conventional approaches may potentially be used to produce images with reduced artifact from segmented EPI data. First, information derived from external navigator echoes may be used to suppress artifacts in segmented EPI data [2]. However, the low-resolution navigator echoes may not precisely measure signal variations due to local motion (e.g., in the brainstem). Second, parallel reconstruction (e.g., SENSE) may be used to produce aliasing-free images from each of the EPI segments, and the generated magnitude images can subsequently be combined to form a final image. However, the noises are usually undesirably amplified by the conventional parallel reconstruction when the number of EPI segment (e.g., 4) is not significantly smaller than the number of RF coils (e.g., 8). To simultaneously address the above two limitation, we design a novel navigation-free multiplexed parallel reconstruction algorithm consisted of the following steps.

Step 1: The conventional SENSE parallel algorithm is first used to produce images from each segment of segmented EPI data. Even though the images produced in this way are affected by amplified noises, they are sufficient for an initial estimation of phase inconsistencies among multiple segments.

Step 2: Instead of reconstructing a noisy SENSE image from an individual EPI segment, here we use a multiplexed parallel reconstruction that jointly estimates the magnitude proton density values of multiple overlapping voxels using all EPI segments in each fMRI volume. The phase inconsistency information derived from step 1 needs to be spatially smoothed and incorporated in the multiplexed parallel reconstruction, to produce a single set of magnitude proton density maps from the joint estimation of multiple EPI segments.

To evaluate the performance of the purposed and conventional segmented EPI reconstruction methods, high-resolution resting-state fMRI images (1.5x1.5 mm2) were acquired from 9 volunteers on a 3.0T MRI scanner (GE MR750, Waukesha, WI) using 4-shot segmented EPI with an 8-channel phase array coil. The scan duration was 5 min, and imaging parameters included: in-plane matrix size 140 x 140, FOV 21x21 cm2, thickness 3.0mm, TR 2000ms, and TE 25ms. All data were processed with three different reconstruction pipelines: a) the conventional segmented EPI reconstruction with sliding window averaging, b) the conventional SENSE reconstruction followed by sliding window summation, and c) the developed multiplexed parallel reconstruction with sliding window summation. Three produced image data sets were then compared in terms of 1) the level of time-domain signal fluctuation, 2) signal to fluctuation noise ratio (SFNR), and 3) the detectability of the default mode networks.

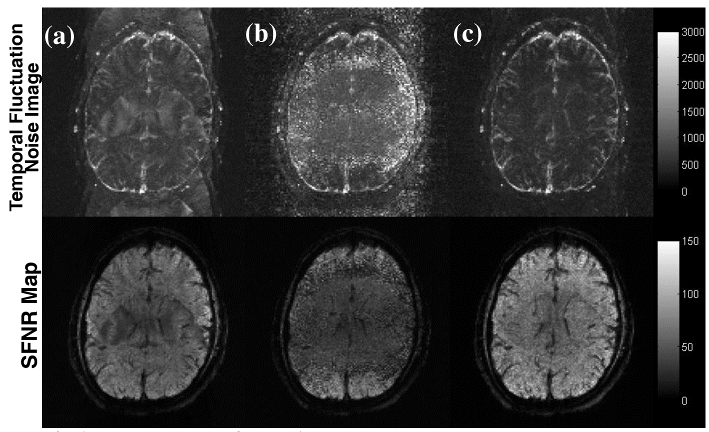

Fig.1 The temporal fluctuation measures (upper row) and SFNR maps (lower row) calculated form fMRI images produced by a) the conventional segmented EPI reconstruction, b) the conventional SENSE algorithm and c) the developed multiplexed parallel reconstruction.

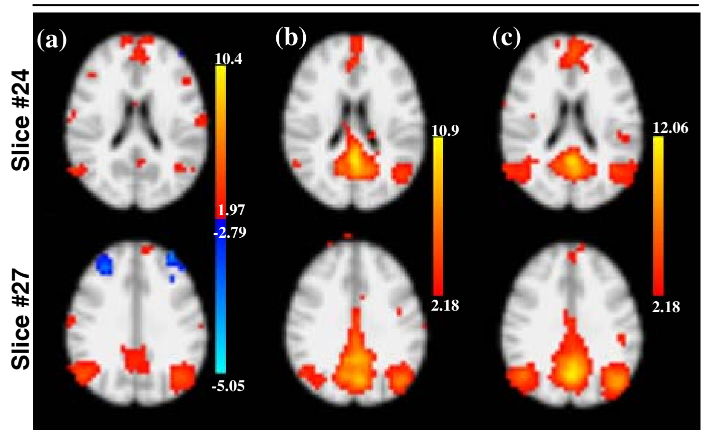

Fig.2 The default mode networks detected by the probabilistic ICA (FSL-Melodic) from a) the conventional segmented EPI reconstruction, b) the conventional SENSE algorithm, and c) the developed multiplexed parallel reconstruction.

Results: The temporal fluctuation (measured by the time-domain standard deviation) and SFNR maps were calculated from 145 dynamic time points of three data sets reconstructed with different pipelines. As shown in Fig.1, the proposed multiplexed parallel reconstruction algorithm (panel c) achieves the lowest level of temporal fluctuation (upper row) and the highest level of SFNR (lower row), indicating its higher BOLD signal detectability as compared with the conventional segmented EPI reconstruction (panel a) and conventional SENSE algorithm (panel b). As demonstrated in Fig.2, the default mode networks can be much more reliably detected (by FSL-Melodic ICA) from fMRI data produced with the multiplexed parallel reconstruction (panel c), as compared with the conventional reconstruction methods (panels a & b).

Discussion: The key improvement of proposed multiplexed parallel reconstruction algorithm is simultaneous suppression of aliasing artifact and noise amplification in segmented EPI based high-resolution fMRI. In comparison to the conventional segmented EPI reconstruction, the new algorithm can inherently correct for phase inconsistency among multiple EPI segments due to B0 drifting or subtle subject motions, producing images with significantly lower aliasing artifact with minimal noise amplification. As compared with the conventional SENSE algorithm, the developed multiplexed parallel reconstruction has a greatly improved matrix inversion conditioning (due to a smaller number of unknowns in joint estimation), through rightly assuming that the magnitude proton density maps are consistent among multiple EPI segments after the motion-induced phase errors are incorporated and corrected.

Conclusion: The novel multiplexed parallel reconstruction algorithm enables high-quality, high-resolution and robust fMRI based on a multi-shot acquisition scheme.

Acknowledgement: This research was supported by NIH grant R01-NS074045. **References:** [1] Lu H, et al, MRM, 50(2003). [2] Barry R, et al, Neuroimage, 39(2008).