High temporal resolution BOLD fMRI based on partial separability model with L2 norm constraint

caiyun shi[1], xiaoyong zhang[1,2], guoxi xie[1], lijuan zhang[1], chunxiang jiang[1], and xin liu[1]

[1]*Shenzhen Key Lab for MRI, Shenzhen Institutes of Advanced Technology, Chinese Academy of Sciences, shenzhen, guangdong, China,* [2]*Centers for Biomedical Engineering, College of Information Science and Technology, University of Science and Technology of China, Hefei, China*

Introduction: Over the last decade, BOLD fMRI has become a powerful tool for human brain researches[1]. However, conventional method for BOLD fMRI is EPI which has difficulty to realize high spatial and temporal resolutions. As BOLD fMRI requires repeatedly scanning the same region to capture neuronal activities, the sampling data is very sparse along the temporal direction. Thus, BOLD fMRI can be considered as a dynamic imaging approach and some model based dynamic techniques can be used to realize high spatial or high temporal resolution BOLD fMRI. In this work, a dynamic model, partial separability (PS) with L2 norm constraint, was introduced to improve the temporal resolution of BOLD fMRI from 2000 ms to 200 ms.

Method: The partial separability (PS) model[2] assumes that dynamic MR signal $\rho(r,t)$ can be expressed as $\rho(r,t)=\sum_{\ell=1}^{L}\psi_\ell(r)\varphi_\ell(t)+\xi$, where $\{\varphi_\ell(t)\}$ is the ℓ th temporal basis functions obtained by applying a SVD method on a dataset (training data), $\{\psi_\ell(r)\}$ is the spatial basis functions obtained by fitting $\{\varphi_\ell(t)\}$ to another dataset (image data), and ξ is noise. As BOLD signal is often corrupted by noise, regularization reconstruction is needed to determine the spatial basis functions for PS reconstruction. Considering the BOLD signal changes little (~3%) with and without neuronal activation, a L2 norm penalty was used to suppress the noise but little affect the BOLD signal as Eq. (1):

$$\psi = \arg\min_{\psi\in\mathbb{C}^{N\times L}} \|d-\Omega F\Phi\psi\|_2^2+\lambda\|\psi\|_2^2 \qquad (1)$$

where d is the image data, Ω is the sparse sampling operator, F is Fourier transform operator, Φ is the temporal basis functions, Ψ is the spatial basis functions, and λ is regularization parameter[3]. The solution of Eq. (1) can be written as $\psi=(E^HE+\lambda I^HI)^{-1}E^Hd$, which can be quickly evaluated using a conjugate gradient algorithm. Where, $E=\Omega F\Phi$ and H is the Hermitian transpose.

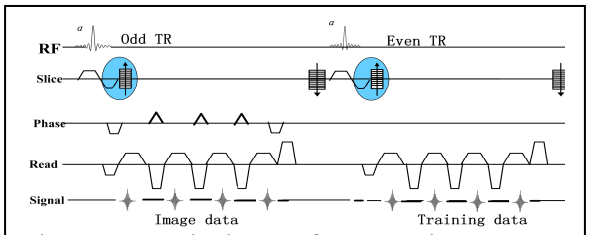

Fig.1: A schematic diagram of the customized sequence for the proposed method

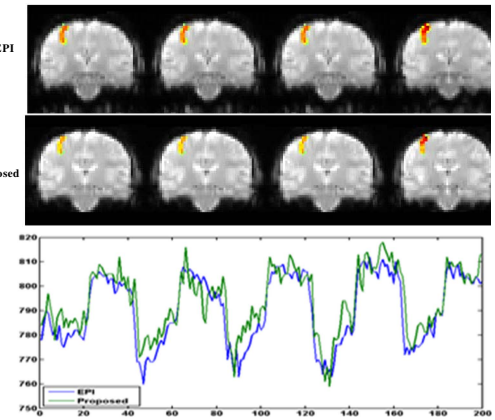

Fig.2: Simulation results of the proposed method. The activation map and curve are well agreement with the references obtained by conventional EPI.

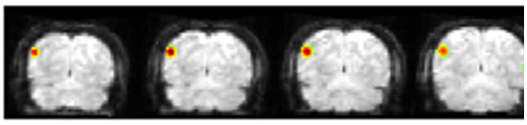

Fig.3: Neuronal activation can be found in the in vivo experiment results using the proposed method

Experiments: *(1) Numerical Simulations:* A 40s periodic block design paradigm with the left finger tapping task was performed on a 3T MRI (SIEMENS Tim Trio, Germany) to acquired raw data for simulations. The raw data was acquired by conventional EPI sequence with following parameters: TR/TE = 2000/30 ms, matrix size =64 × 64, slice thickness=3.5 mm with 1.5mm gaps, slice number = 32, temporal resolution = 2000 ms. The acquired EPI images were treated as reference and used to simulate the training and image data. The training data was collected by repeatedly sampling the phase encodings near the center of referred k-space while the image data was collected by orderly sparse sampling the phase encodings of the referred k-space[4,5]. After the training and image data were collected, image reconstruction was performed using the proposed method. And then the reconstructed images were processed using SPM software to generate the neuronal activation map.

(2) In vivo study: A healthy volunteer participated in the study and written consent was obtained. The in vivo experiment was performed on the same 3T MRI scanner. Training and image data were acquired using a customized ADC-shifted GRE sequence (Fig. 1). The same finger tapping task was performed during data acquisition. Scan parameters included: TR/TE = 100/20ms, matrix size =64 × 64, slice thickness=4mm, and 32 slices, bandwidth=880 Hz/pixel, flip angle=10°. As the image temporal and spatial resolutions determined by the training and image data respectively, BOLD fMRI with temporal resolution of 200 ms and spatial resolution of 3.5×3.5×4.0 mm^3 were thus achieved in this study.

Results: The simulation results of the proposed method are well agreement with the references obtained by conventional EPI (Fig. 2). This demonstrates that the proposed method can accurately recover the BOLD signal with sparse sampling data. In the in vivo experiment, the neuronal activation was found and a much higher temporal resolution of 200 ms was achieved (Fig. 3). Compared Fig. 2 and Fig. 3, the location of neuronal activation using proposed method (Fig. 3) was found to be different with the standard reference (Fig. 2-EPI), which needs to be further evaluated and interpreted in next step.

Conclusion: A novel method based on PS model was introduced for realizing high temporal resolution BOLD fMRI. Numerical simulation and preliminary in vivo experiment results demonstrate the feasibility of the proposed method for high temporal resolution of BOLD fMRI. Further evaluation and optimization of the proposed method need to be carried out in next step. **Reference:** [1] Ogawa et al.,PNAS, 1990.[2] Liang,ISBI,2007.[3] Brinegar et al., EMBS,2009. [4] Haldar et al., MRM, 2008. [5]Zhao et al., IEEE TMI, 2012.