A *k-d* space acceleration strategy for HARDI with compressed sensing

Tzu-Cheng Chao[1,2], Jr-Yuan Chiou[3], Cheng-Wen Ko[4], Ming-Ting Wu[5], Stephan E. Maier[3], and Bruno Madore[3]

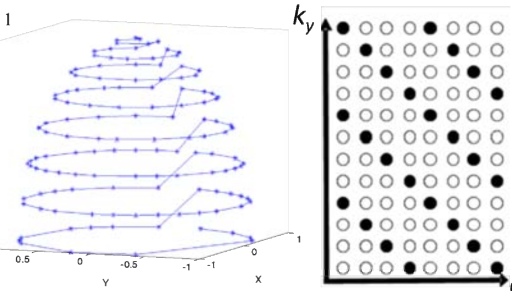
[1]*Department of Computer Science and Information Engineering, National Cheng-Kung University, Tainan, Taiwan,* [2]*Institute of Medical Informatics, National Cheng-Kung University, Tainan, Taiwan,* [3]*Department of Radiology, Brigham and Women's Hospital, Harvard Medical School, Boston, Massachusetts, United States,* [4]*Department of Computer Science and Engineering, National Sun Yat-Sen University, Kaohsiung, Taiwan,* [5]*Department of Radiology, Kaohsiung Veteran General Hospital, Kaohsiung, Taiwan*

Target Audience: MR physicists and brain researchers with an interest for novel diffusion-imaging schemes.

Purpose: High Angular Resolution Diffusion Imaging (HARDI)[1] has been extensively used to explore microstructure in human brain, and a single-shot EPI sequence is typically employed for data acquisition. However, especially as field strength increases, geometric distortions caused by field inhomogeneities tend to severely degrade image quality. The main solution toward alleviating such distortions involves reducing the length of the EPI echo train, and this can be achieved, for example, through parallel imaging (PI) and/or through segmented (i.e., multi-shot) imaging[2]. Two completely different strategies are combined here, for added effect, with the goal of achieving fast segmented diffusion-weighted imaging (DWI) acquisitions featuring minimal geometrical distortion. The compressed sensing algorithm Crossing Fiber Angular Resolution of Intra-Voxel structure (CFARI)[3] was employed to decrease the number of diffusion encoding directions that need to be acquired, while the recently-proposed segmented method[4] is adapted here to the HARDI encoding scheme to reduce the number of *k*-space interleaves that are sampled.

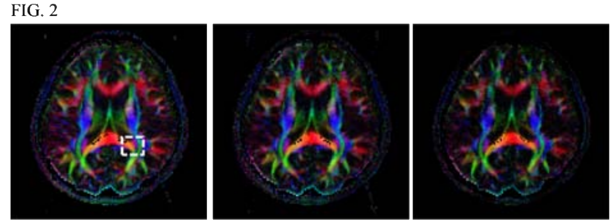
Methods: A fully-sampled HARDI dataset was acquired, and then subsampled by using only a subset of all k_y locations and/or a subset of all diffusion directions in the reconstruction. Results reconstructed from the fully-sampled dataset were used as a reference. Volunteer studies were performed with informed consent from an approved protocol (1.5 T system, 8 slices, slice thickness = 5 mm, TR = 6 sec, TE = 102 ms, four b≈0 T_2-weighted images were acquired and averaged, diffusion-weighted images were acquired along 128 non-colinear diffusion encoding directions using b = 1000 s/mm^2). The sampled diffusion-encoding directions are represented in Fig 1a. The spiral trajectory in Fig. 1a was designed to create smoothly-varying signal in *d*-space, so that the signal might be sparse and well recovered in its Fourier dual domain, k_d space[4]. A four-fold accelerated shear-grid sampling function was used, as depicted in Fig. 1b. The central 32 phase encoding lines were extracted, to simulate the navigator signal used for both phase correction and regularization purposes. The regularization scheme employed here was similar to that proposed in kt-BLAST[5].

FIG. 1



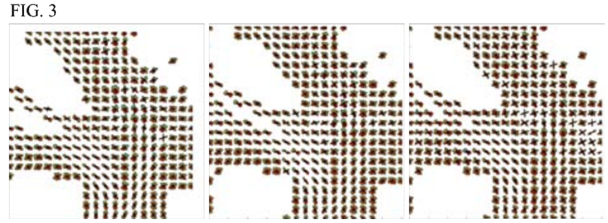
(a) Trajectory of Diffusion Encoding Gradients (b)*k-d* Sampling Function

FIG. 2



(a) Full K-space + 128 Dirs (b)1/4 K-space + 128Dirs (c)1/4 K-space + 64 Dirs

FIG. 3



(a) Full K-space + 128 Dirs (b)1/4 K-space + 128Dirs (c)1/4 K-space + 64 Dirs

The reconstruction process generated usual tensor results such as a measure of fractional anisotropy (FA) and an estimate of the principal diffusion direction. Furthermore, the CFARI algorithm allowed the intra-voxel orientation information to be resolved. A set of 64 prolate-shaped bases, for which the ratio of the three principal diffusion coefficients was set to 4:1:1, were homogenously distributed over a unit spherical shell. In a first step, these bases were used for a coarse estimation of the orientation information. In a second step, the most dominant bases were carried on with a set of higher angular resolution bases (512 bases) to further improve the reconstruction accuracy[3]. Finally, the orientation distribution of the intra-voxel structure could be generated based on the CFARI results.

Results: Figure 2 shows the color FA maps obtained when reconstructing the full dataset (Fig. 2a), a set with only one quarter of all k-space locations (Fig. 2b), and a set with one quarter of the k-space locations and half the diffusion directions (Fig. 2c). The total acceleration in Fig. 3c is equal to 8-fold. Reduction in FA value can be noticed as acceleration is increased, from Fig. 2a to 2b and 2c. In highly anisotropic regions such as the corpus callosum the decrease is hardly noticeable, but decreases in the area of temporal lobe are more sizeable. But overall, the accelerated data reconstructed with the proposed acceleration scheme retained similar image resolution, FA, and orientation distribution to the non-accelerated reference case (Fig 3). Similar peak orientation was maintained in both uni-structural the fiber-crossing regions, although some degree of shape swelling can be noticed in the accelerated versions in Figs 3(b) and 3(c).

Discussion: Results in Figs. 2 and 3 suggest that the proposed method appears capable of accelerating HARDI acquisitions by at least 8-fold, to reduce both scan time and the EPI echo-train length (and associated geometric distortions), at a minimal loss in terms of diffusion-related information (reduced FA values in Fig. 2 and related swelling in the orientation distributions in Fig. 3 for accelerated results). While acceleration tended to make the orientation distributions slightly more isotropic in shape, the orientation information was still clearly resolved. The *k-d* space acceleration scheme for segmented EPI used here is readily compatible with parallel imaging[4]. Including parallel imaging is expected to allow for further reductions in EPI echo-train lengths and geometric distortions, and/or to more accurate accelerated results.

Conclusion: **A**n accelerated segmented EPI scheme in *k-d* space was combined with compressed sensing to reduce both geometric distortions and scan time in HARDI acquisitions.

Reference: 1. D. S. Tuch, *Mag Res in Med*, 52:1358-72, 2004. 2.D. Atkinson, et al, *Mag Res in Med*, 56:1135-39, 2006. 3. B. A. Landman et al, *NeuroImage*, 59:2175-86,2012. 4 B. Madore, et al in *ISMRM*, 1886, 2012. 5. J. Tsao et al, *Mag Res in Med*, 50:1031-42, 2003
Support is acknowledged from grants NSC100-2218-E-006-038-MY2, R01CA149342, R01EB010195 and P41EB015898.