Parallel Line Scan Diffusion Imaging with 2D Acceleration

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Introduction Line scan diffusion imaging (LSDI) [1] is a one-dimensional Fourier encoding techniques. The absence of phase encoding provides considerable robustness against motion and immunity to artifacts due to magnetic field inhomogeneities and susceptibility. Parallel imaging has been successfully applied to accelerate 2D and 3D Fourier imaging by reducing phase encoding steps. Here we propose a novel line scan diffusion imaging technique with parallel imaging acceleration along two directions. The standard 90° and 180° pulses employed in line scan imaging are modulated with a cosine waveform to yield double column excitation in two dimensions (2D) simultaneously. Four-fold acceleration can be achieved, without any SNR loss.

Methods: Fig. 1 shows the parallel line scan diffusion imaging pulse sequence with two-dimensional acceleration. The cosine-modulated pulses in both 90° and 180° pulses shown in the insert generate a double slice excitation along both y and z axes prescribed in Fig. 2. Therefore, for every excitation (TR_{col}), four columns are excited simultaneously. After a 1D FFT, four overlapping lines of image data are obtained. Diffusion gradient amplitudes and directions are alternated between excitations. To avoid saturation and interference from earlier excitations with 90° and 180° pulses, sequential acquisition of columns is performed along the diagonal direction of the volume as shown in Fig. 3. The first sweep excites odd columns (white squares) and the second sweep excites even columns (dark squares). After scanning is completed, different diffusion weighted raw data are separated. A 1D-FT along the frequency encoding columns of the raw data is performed and 3D aliased images are obtained. Un-aliased 3D images can then be obtained using the SENSE algorithm.

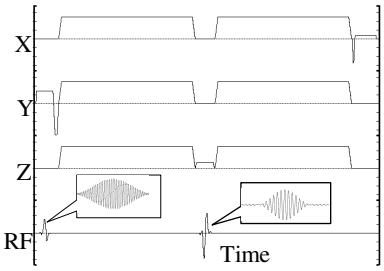

Fig. 1 Pulse sequence of parallel line scan diffusion imaging with 2D acceleration

Results: The pulse sequence for parallel line scan diffusion imaging with 2D acceleration was implemented on a 3T GE Signa EXCITE 14.0 scanner, and an 8-channel product head coil was used. 2D acceleration was performed along the sagittal (z) and coronal (y) directions. One quarter of the brain volume was scanned with 31 slices along the sagittal direction (slice thickness = 3mm, FOV = 28.8x14.4x9.3cm^3, matrix size = 96x48x31 for isotropic resolution, TE=50ms, TR_{eff}=89*24 =2136ms = 89ms/column * 24 columns/sweep). The high and low diffusion b-factors were set to 750 s/mm^2 and 5 s/mm^2, respectively. Total scan time was about 4 minutes. One slice of the 2D aliased and the reconstructed images are shown in Fig. 4. Orthogonal slices through the reconstructed brain volume are shown in Fig. 5, for the high b-factor setting.

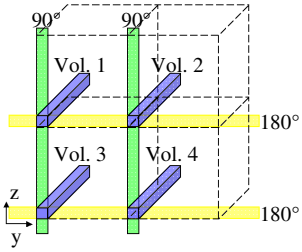

Fig. 2 Double slice excitation along y and z simultaneously

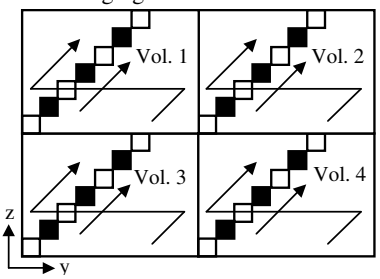

Fig. 3 Diagonal scan scheme

Discussion: Parallel line scan diffusion imaging is not expected to reduce SNR. This can be understood through an analogy with the phase-offset multi-planar (POMP)[2] method, whereby SNR is improved by $\sqrt{n}$ when n slices are excited simultaneously. Similarly, the gain in SNR obtained by exciting n lines simultaneously offsets the usual loss of SNR associated with parallel imaging. Parallel line scan diffusion imaging with a 2D acceleration approach can reduce scan time by a factor of four while maintaining image quality. Due to the absence of phase encoding in the line scan method, susceptibility induced signal loss and geometric image distortions can be avoided while motion robustness is maintained. Compared with the one dimension acceleration approach previously proposed [3], the 2D acceleration method provides additional advantages. One such advantage is the possibility to reduce cross-talk artifact [4] between excitation pulses, by alternating the orientation of the 90° and 180° excitation pulse after each column excitation (chopping). A second advantage is that one more degree of freedom is provided by allowing one to freely choose the overlapping slices, something which can not be done in 2D/3D Fourier imaging.

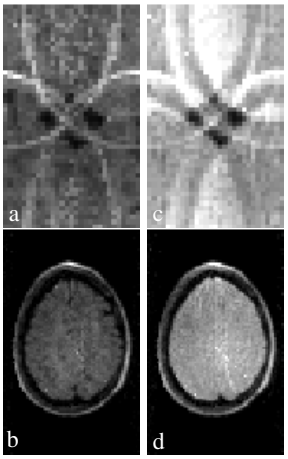

Fig. 4 Recon images (b,d) and aliased images (a,c). Frequency encoding is orthogonal to the image plane. b-factor is 750 s/mm^2 in (b) and 5 s/mm^2 in (d).

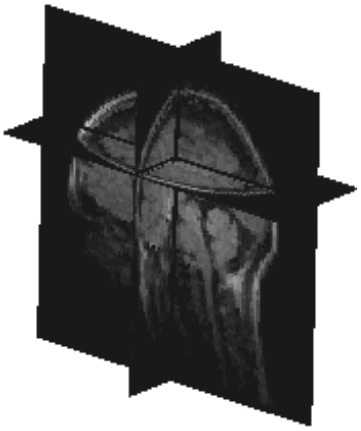

Fig. 5 Orthogonal plane display of 3D reconstruction images

Conclusion: Our proposed parallel line scan diffusion imaging with 2D acceleration technique can reduce scan time by a factor of four, at no cost in SNR. The technique preserves the significant advantages of line scan diffusion imaging, specifically, immunity to the susceptibility-induced signal loses and geometric image distortions that often plague EPI.

[1] Maier. MRM 2001;46:1136 [2] Glover. JMRI 1991;1:457 [3] Chu. ISMRM 2008:761 [4] Ailion *et al.* MRI 1992;10:747

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