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Accelerated data acquisition for B_0-distortion correction using interlaced q-space sampling in diffusion MRI

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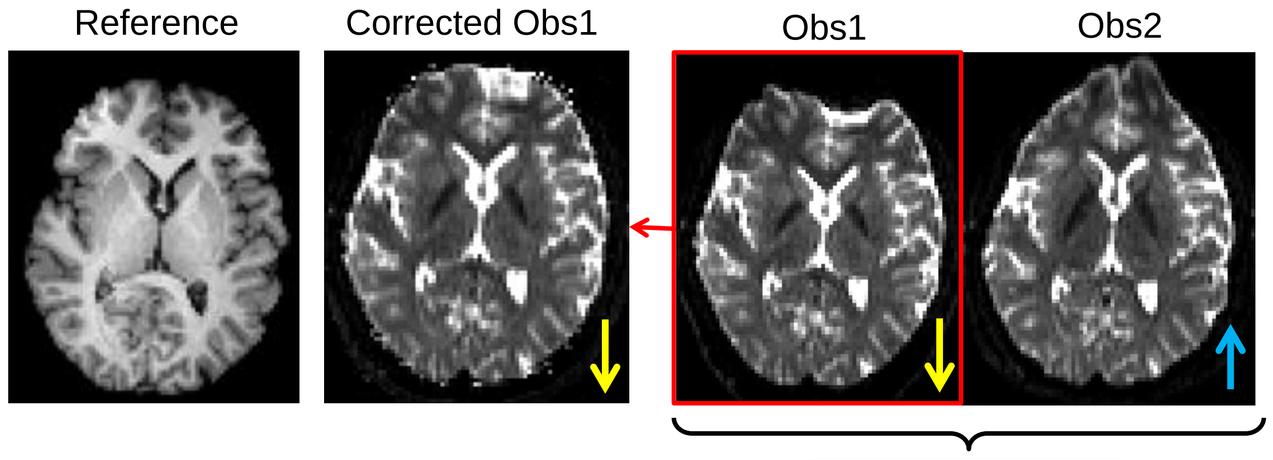
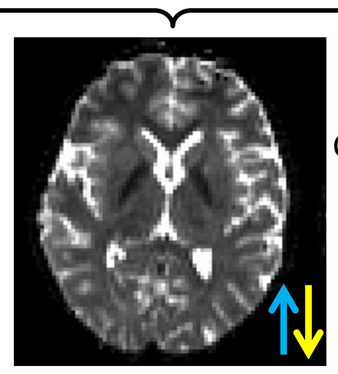
Motivation & Introduction

- Diffusion MRI (EPI scan) + B_0 field inhomogeneity = Geometric Distortion
- Distortion limits accuracy of multi-modal analysis
- Reconstruction from distorted images can be highly ill-posed
- Need "more" observations to reconstruct accurately
- More observations = Longer scan time = Larger cost!

Our approach:

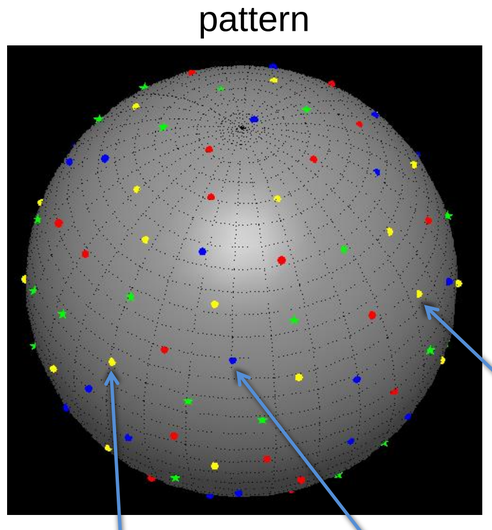
- Exploit known "structure" of diffusion data in q-space
- Reduce number of required observations for accurate reconstruction
- Data is smooth in q-space (on surface of sphere)
- Borrow information from neighboring q-space samples
- Joint reconstruction all diffusion images





Corrected using Obs1 & Obs2

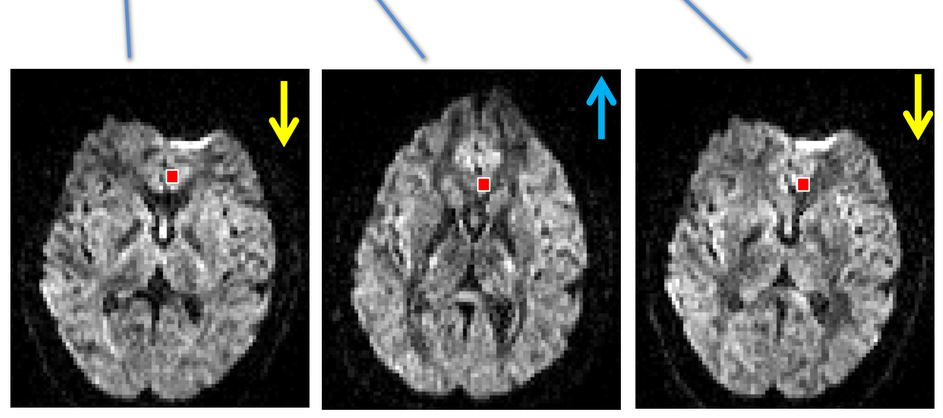
q-space sampling pattern



$$\hat{\mathbf{C}} = \underset{\substack{\mathbf{C}\in\mathbb{R}^{V\times N} \\ \text{s.t. } \mathbf{S}=\mathbf{C}\mathbf{Y}}}{\arg\min} \left(\underbrace{\sum_{q=1}^{Q} \|\mathbf{D}_q\mathbf{s}_q - \mathbf{d}_q\|_{\ell_2}^2}_{\text{Data fidelity}} + \underbrace{\sum_{v=1}^{V} \alpha_v \|\mathbf{L}\mathbf{c}_v\|_{\ell_2}^2}_{\text{spherical smoothness}} + \underbrace{\beta \sum_{q=1}^{Q} \|\mathbf{F}\mathbf{s}_q\|_{\ell_2}^2}_{\text{spatial smoothness}} \right)$$

Deformation operator; Observed data; Laplace-Beltrami operator; Spherical Harmonic coeff.; 1st Order Derivative Operator

↑ Reconstructed correct diffusion Images

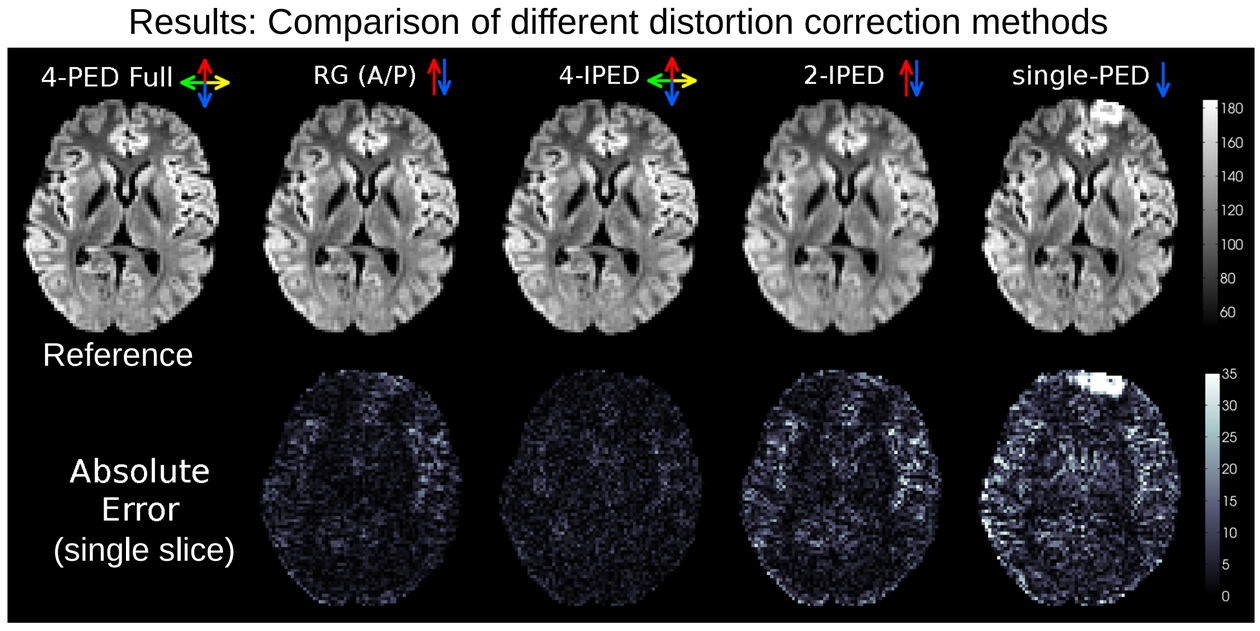


q-space samples with different phase encodings

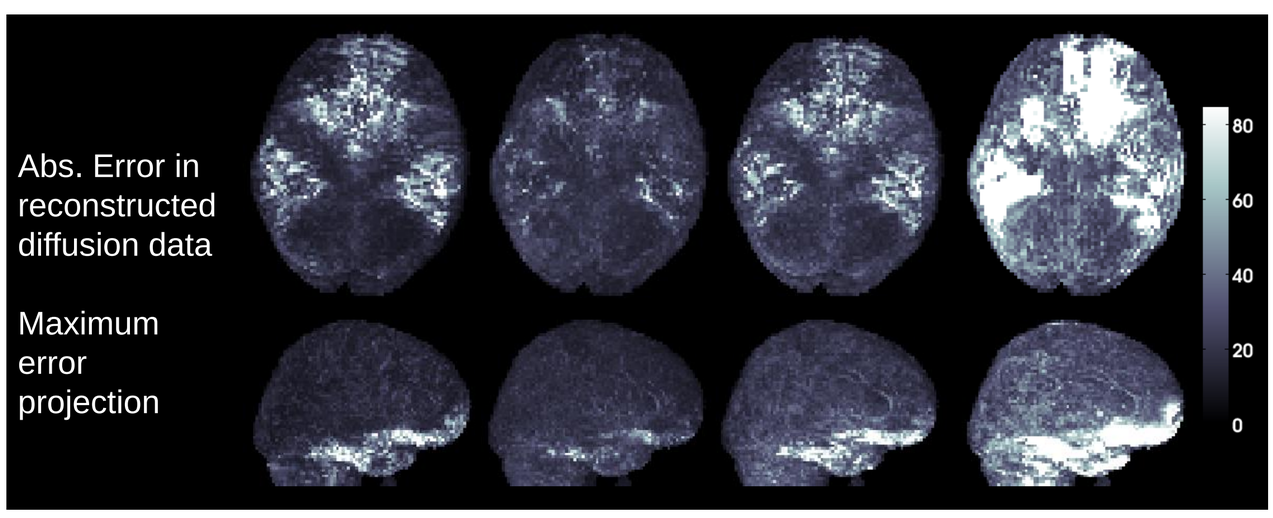
in-vivo Experiment

- Acquire *in-vivo* diffusion data (20 q-space samples) of a human subject with four different observations (Phase encoding directions - PED)
- Use "full" data to reconstruct reference images
- Sub-sample full data to create "single PED", "Reversed Gradient (RG)" and "Interlaced (IPED)" dataset
- Compare performance of different method with reference both qualitatively and quantitatively

Results: Comparison of different distortion correction methods



4x	2x	1x	1x	1x
Scan Time	Scan Time	Scan Time	Scan Time	Scan Time



Conclusion & Future Work

- Proposed method reduces total scan time by a factor of two as compared to "Reversed gradient" method while showing similar/better performance
- Superior performance to single PED (observation) method
- Easy to implement in modern MRI scanners – does not require huge change to pulse sequence

Future work:

- Generalize method to different q-space sampling schemes
- Use correct noise models for low SNR images

References:

- Bhushan et al., *Improved B0-distortion correction in diffusion MRI using interlaced q-space sampling and constrained reconstruction,* Magnetic Resonance in Medicine, Accepted
- Bhushan et al., *Accelerating Data Acquisition for Reversed-Gradient Distortion Correction in Diffusion MRI: A Constrained Reconstruction Approach*, ISMRM, Salt Lake City, 2013, p. 55

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