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Acceleration of High Angular and Spatial Resolution Diffusion Imaging

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Abstract

Diffusion magnetic resonance imaging (dMRI) is a unique in vivo imaging modality that has the capability to reveal the white matter tissue micro-architecture of the brain. It has propelled our understanding of the structure of the brain, which in turn has helped to understand the functioning of the brain by elucidating the different anatomical connectivity pathways. However, the current diffusion imaging protocols are limited in their ability to generate high resolution images that are crucial in tracing the underlying anatomical connections. In this thesis, a new imaging scheme is developed that can enable the acquisition of high angular and spatial resolution diffusion imaging.

High resolution imaging in MRI always comes with the cost of longer scan times and reduced signal-to-noise ratio (SNR). In order to maximize the SNR, we proposed to use multi-shot variable density spiral k-space sampling trajectories for the imaging. In order to reduce the scan time, we proposed to under-sample the combined k-q space of diffusion imaging using an incoherent under-sampling scheme. The recently proposed signal recovery technique known as compressed sensing was employed to recover the images from the under-sampled measurements. By using a sparse complex Gaussian mixture model to depict diffusion process, the image reconstruction was posed as a sparse recovery problem. Since the complex signal modeling (as opposed to limiting to the real part of the signal) enabled to accurately account for the noise statistics of the k-space data, the proposed joint recovery scheme were able to generate high spatial and angular resolution images from highly under-sampled measurements with high accuracy comparable to that of the fully sampled measurements.

With the use of non-Cartesian sampling trajectories, the reconstruction of the images becomes difficult because of the inability to use fast Fourier transforms (FFTs). Conventional gridding reconstructions are unsuitable for the highly under-sampled measurements that we employed. Model based iterative sparse reconstruction schemes are employed in such situations, which are afflicted by long reconstruction times. Combined with the fact that multi-shot acquisitions require motion compensation to reconstruct artifact-free images, the reconstruction time is further lengthened with the accommodation of a motion-compensation scheme. In order to reduce the reconstruction time, we proposed an alternate pipeline for reconstruction. The new scheme involved exploiting the redundancy and smoothness of the sensitivity functions used in the motion-compensated reconstruction. By representing the sensitivity functions in terms of a few basis function derived from a principal component analysis (PCA) bases, the number of non-uniform Fourier transforms to be performed is reduced. The evaluation of non-uniform Fourier transforms were then avoided by exploiting the Toeplitz structure of the product of forward and backward Fourier transforms. Finally, using a fast augmented Lagrangian optimization algorithm, the sparse recovery of diffusion data was accelerated to enable its use in a practical setting.