Advances in Data Analysis of Diffusion Tensor Imaging

Cheng Guan Koay

Under the supervision of

Prof. M. Elizabeth Meyerand

Prof. Andrew L. Alexander

and

Prof. Susan N. Coppersmith

At the University of Wisconsin - Madison

This dissertation describes briefly the Diffusion Tensor Magnetic Resonance Imaging (DT-MRI or DTI) theory and experiments which have been developed to study water diffusion in the brain. Primarily, the techniques of data analysis in DTI are reviewed and extended upon in this work. My research contributions in DTI data analysis are

- The investigation of anomalous estimates in tensor-derived quantities in DTI,
- The development of full Newton methods for least squares methods:(1) the constrained linear method (CLLS), (2) the nonlinear method (NLS) and (3) the constrained nonlinear method (CNLS), and
- The development of multiple b-values method for estimating the non-diffusion weighted image in DTI image registration.

The anomalous estimates arise from the situation when the diffusion tensor is not positive definite. This investigation leads to the use of the Cholesky decomposition for automatic constraint satisfaction. A

specific mapping was constructed based on the knowledge of the Cholesky composition rather than its decomposition. This mapping takes points from the unconstrained space to points of the constrained space so that it will always produce admissible tensor estimates (i.e. tensor estimates that are positive definite). The search of good tensor estimates from the diffusion weighted signals can be formulated as a least squares problem. The linear least squares method (LLS) is the most common method used by researchers and clinicians. The second most commonly used method is NLS. It is not unusual to see the use of Levenberg-Marquardt method for solving NLS. We have developed in this work the full Newton methods not only for NLS but also for CNLS and CLLS. The robustness of full Newton-type method is well-known but its implementation is potentially more complex. Fortunately, this is not the case in DTI estimation problem. In addition to the work mentioned above, we have developed multiple b-values method for estimating the reference (non-diffusion weighted) signals. This development is very important for robust DTI image registration. Finally, this dissertation is meant to demonstrate recent advances in data analysis of diffusion tensor imaging and by no means represents a comprehensive study of any particular clinical problem.