The Johns Hopkins University

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Deformable Image Registration in the Analysis of Multiple Sclerosis

Dissertation Defense by

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Abstract

In medical image analysis, image registration is the task of finding corresponding features in two or more images and using the features to solve for the transformation that best aligns the images. Knowing an alignment allows information, such as labels, landmarks, and functional metrics to be easily transferred between the images. In addition, aligning images from multiple individuals into a common space allows them to be analyzed together as a group.

This dissertation focuses on the development and application of image registration techniques for the analysis of multiple sclerosis (MS), a neurodegenerative disease that damages the myelin sheath of nervous tissue. MS is known to affect the entire central nervous system (CNS), and can result in the loss of sensory and motor control, memory, cognition, and vision. Hence, there is great interest in studying the effects of MS across multiple areas of the CNS. The four primary contributions of this dissertation are on the development of deformable image registration in the three areas of the CNS that are most currently studied for MS -- the spinal cord, the retina, and the brain.

First, for spinal cord magnetic resonance imaging (MRI), an approach is presented that uses deformable registration to provide atlas based priors for automatic topology-preserving segmentation of the spinal cord and cerebrospinal fluid. The method shows high accuracy and robustness when compared to manual raters, and allows spinal cord atrophy to be measured and analyzed on large MS datasets that manual segmentations are not available for. Second, for spinal cord diffusion tensor imaging, a pipeline is presented that uses deformable registration to correct for susceptibility distortions in the images. The pipeline allows for more accurate diffusion metrics to be computed in the spinal cord, which enabled several studies by clinical collaborators to show significant correlations between these imaging metrics and clinical measures of sensorimotor function and disability levels. Third, for optical coherence tomography (OCT) of the retina, a deformable registration technique is presented that constraints the deformation to respect the physical geometry of OCT acquisitions. 3D voxel-based analysis using the proposed registration found significant differences between healthy and MS cohorts in regions of the retina that is consistent with previous findings using 2D thickness analysis and post-mortem histology. Lastly, for brain MRI, a multi-channel registration framework is presented that can use distance transforms and image synthesis to improve registration accuracy. Results showed statistically significant improvements in accuracy when compared between using and not using the multi-channel framework.

Together, these techniques have both improved our ability to analyze MS in the three anatomical structures, and also enabled several types of analysis that were previously unavailable for the study of MS.

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