

Computing Corpus Callosum as Biomarker for Degenerative Disorders

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Abstract

The developed framework can automatically extract a plane with minimal corpus callosum area while simultaneously segmenting it. The method used, introduced by Ishaq, treats the corpus callosum area as a function of the plane extraction parameters and it uses deformable registration to generate a displacement field that can be used for the calculation of the corpus callosum area. Our registration framework is accelerated using CUDA, which enables researchers to benchmark huge amounts of data (patients) to test the hypothesis of the corpus callosum evolution as a biomarker for multiple degenerative disorders like e.g. Alzheimer disease and multiple sclerosis (MS).

Background

Multiple Sclerosis is an inflammatory disorder of the brain and spinal cord and it has been known to cause atrophy and deformation in the corpus callosum. Longitudinal studies try to quantify these changes by using medical image analysis techniques for measuring and analyzing the size and shape of the corpus callosum. These medical techniques mostly analyze and track changes in the corpus callosum by measuring the cross-sectional area by selecting a 2-D measuring plane, typically the midsagittal plane. If this identification is done incorrectly, the measurement of the corpus callosum area will also be faulty. Therefore, an automation of finding a plane with minimal corpus callosum area is implemented to ensure that the measurement of the cross-sectional area is done correctly with high accuracy.

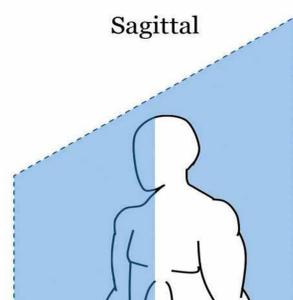


Figure 1. Sagittal plane

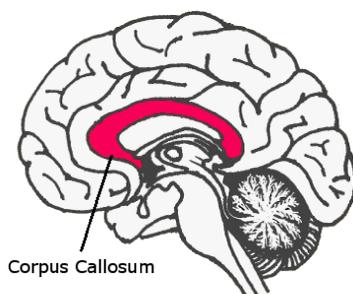


Figure 2. Corpus callosum

Method

Ishaq proposed a novel and clinically meaningful criterion for defining an ideal measurement plane for the corpus callosum area measurement. It differs from symmetry and feature-based methods because it is based on finding the plane that optimizes specific physical properties of the corpus callosum itself. The method is therefore clinically meaningful and specifically tailored for the task at hand, that is, the measurement of change in the corpus callosum area and its correlation with disease progression.

The corpus callosum is segmented in the extracted plane by a deformable registration with a 2-D template. The corpus callosum area is then calculated from the integral of the determinant of the Jacobian of the displacement field. This area is a function of the plane extraction parameters. Optimization of this function results in the plane with minimum corpus callosum area.

Used steps to calculate the corpus callosum area

- Extract** a 2-D slice from an MRI volume. This entails resampling a plane in the volume, which can be done efficiently using CUDA textures. The orientation and position of this plane are parameterized over two rotations round the X- and Y-axes respectively, and one translation along the Z-axis.
- Segment** the corpus callosum cross-section in the slice extracted in step 1 (see our image registration algorithm in Figure 4).
- Calculate** the area of the corpus callosum is by integrating the determinant of the Jacobian of the displacement field over all the points on the template which lie inside the corpus callosum.

Implementation

The employed method of finding a plane with minimal corpus callosum area depends heavily on deformable image registration. As the image registration process must be performed multiple times, it is important that the registration is performed as quickly, and correctly, as possible. The use of a GPU greatly improves computation time, so this framework is built out of algorithms and data structures that exploit its parallel computation capabilities and hardware. The implemented framework is algorithmically inspired by the work of various research groups and combines the advantageous approaches into one method.

Registration specifics

An image registration process needs four components: a transformation model, a similarity measure, a regularization term, and an optimization technique. The implemented framework uses a non-rigid transformation model called a free-form deformation model, the sum of squared differences as a similarity measure, a diffusion regularization term, and gradient descent as the optimization technique.

Calculating cost function gradient with CUDA

The B-spline interpolation and the gradient calculation are the two most time-consuming stages within the overall registration process. Therefore, these two stages have been accelerated with CUDA. Two GPU methods have been implemented for calculating the cost function gradient: a naïve and an optimized version, based on the work of Shackelford.

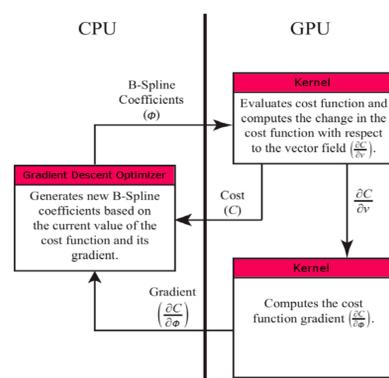


Figure 3. While the calculation of the cost function gradient is performed by the GPU, the optimization remains on the CPU.

Image registration algorithm

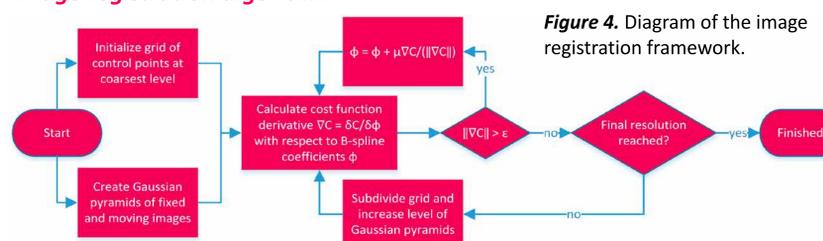


Figure 4. Diagram of the image registration framework.

Evaluation of registration framework

The quality of the registration directly affects the accuracy of the area measurement. Several experiments have been conducted in order to evaluate the deformable registration that was implemented. Synthetic data has been used to demonstrate the effectiveness and performance of the registration framework, but our framework has also been evaluated with medical data.

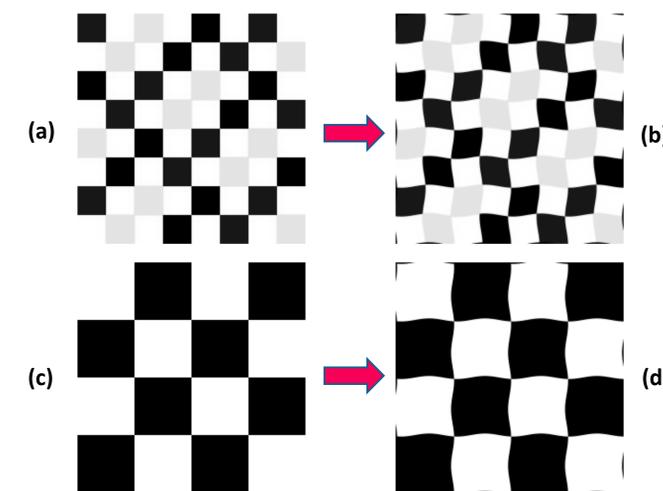


Figure 5. (a) and (c) are registered onto images (b) and (d) respectively. Images (b) and (d) were transformed using a known control point configuration to allow proper benchmarking.

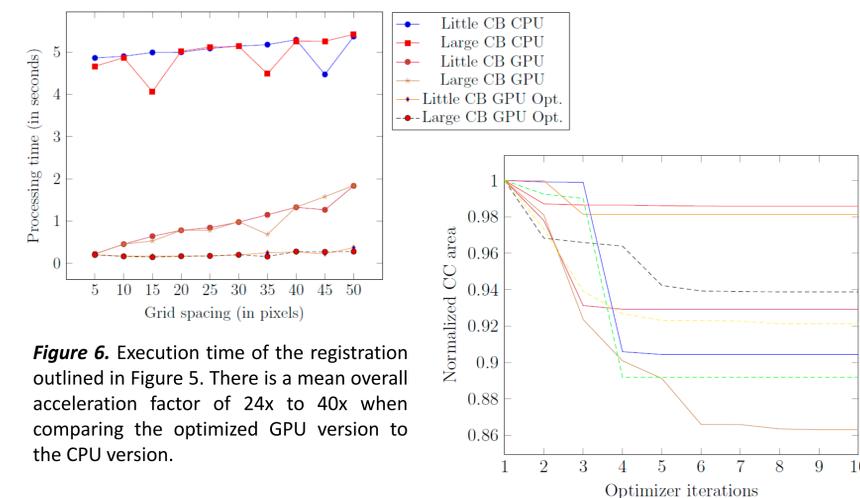


Figure 6. Execution time of the registration outlined in Figure 5. There is a mean overall acceleration factor of 24x to 40x when comparing the optimized GPU version to the CPU version.

Figure 7. Graph of normalized corpus callosum areas of 8 MRI volumes.

Experimental results

Figure 7 shows a graph of normalized corpus callosum areas for 8 MRI volumes in function of the optimizer iterations. Seven of these MRI volumes came from the OASIS project and the other one came from icoMetrix. The results for each volume have been normalized (i.e. starting at '1') with the rotation parameters and the translation parameter set to zero. The results show a distinct decrease and convergence of the corpus callosum area for all examined volumes.

References

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