Directional Distribution of Nerve Fibers from Histological Images of the Human Corpus Callosum

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Introduction

Diffusion Magnetic Resonance Imaging (dMRI) is an imaging technique which, from measurements of random molecular motion of water, can map biological tissue at the microstructural level. White matter in the brain is organised in parallel bundles, which gives an internal anisotropic nerve fiber structure. Water molecules diffuses mostly unrestricted along the bundles of nerve fibers, but are restricted in their motion perpendicular to it. This utilises dMRI to infer the neural fiber structure, and hence white matter connectivity of the brain. Current dMRI voxel resolution is approximate $12\,\text{mm}^3$, which can contain several thousand neural fibers.
Currently the models used to produce dMRI images assume the nerve fibers within one voxel has a certain size distribution, but are all co-aligned. If the nerve fibers are not co-aligned, the nerve fiber size distribution, estimated by dMRI, will be greatly affected.
This project is the first attempt to measure the true directional distribution of the nerve fibers. We present an automatic method for determining the neural fibers directional distribution from light microscope (LM) images.

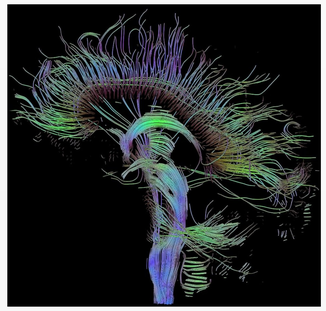

FIG.1: White matter connectivity.[3]

Method

Matched Filtering

First the input LM image is filtered by a match filter. The filtering takes place in decreasing scale-space. At each scale the image is filtered with four kernels, one circle and four independently rotated ellipses.

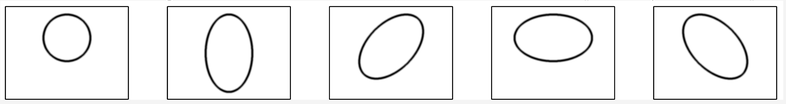

FIG.2: Match filter kernels.

Thresholding + Local Maxima

The filtering creates one new image of correlation indexes per scale filtered. These correlation images are thresholded and local maxima is determined. These local maxima of correlation are used to initialise the sampling algorithm.

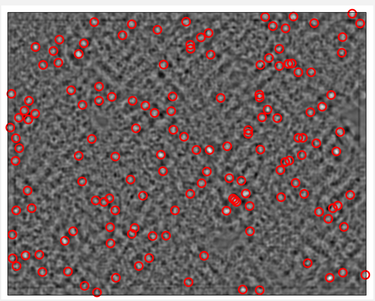

FIG.3: Result of matched filtering with circle (r =20 px). Local maxima is marked with red circle.

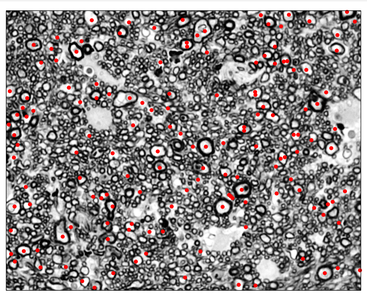

FIG.4: The filtered image with the ellipse candidates marked as a red dot.

Radial Sampling

The neighborhood around each ellipse candidate is sampled in 32 different directions, along the radial vector. The first point that has a zero first order derivative and a positive second order derivative, is the sampling point.

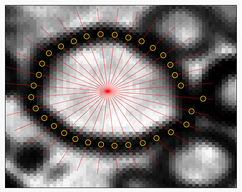

FIG.5: Candidate Sampling example.

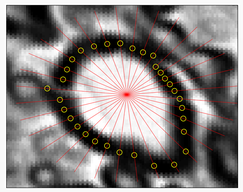

FIG.6: Candidate Sampling example.

Pruning (simple)

First some fast and simple rules are used to prune the amount of candidates.

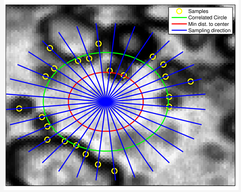

FIG.7: Too few sample points.

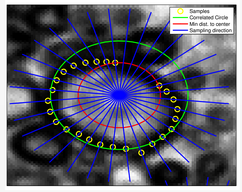

FIG.8: Samples too close to the center.

Robust Fitting

The remaining candidates are robustly fitted by use of the RANSAC algorithm. At each fit the mean error is calculated which is afterwards used to prune even further.

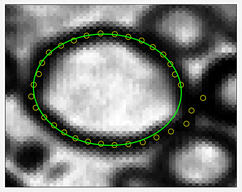

FIG.9: Fittet ellipse example 1.

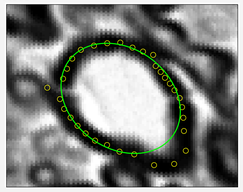

FIG.10: Fittet ellipse example 2.

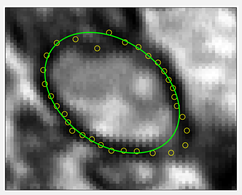

FIG.11: Fittet ellipse example 3.

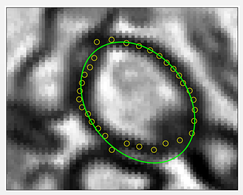

FIG.12: Fittet ellipse example 4.

Pruning (Goodness of Fit)

If the mean distance between the fitted ellipse and the sampling points is too large, the candidate is dropped.

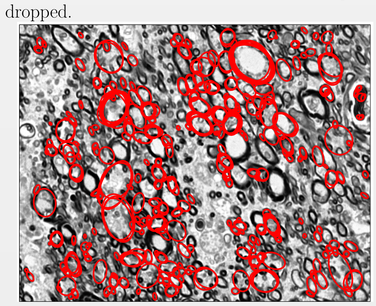

FIG.13: Dropped ellipses example 1.

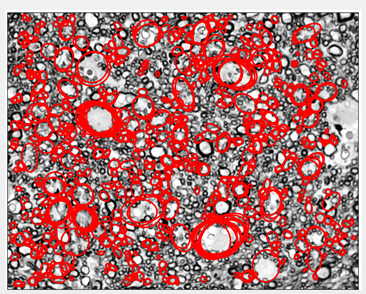

FIG.14: Dropped ellipses example 2.

Results

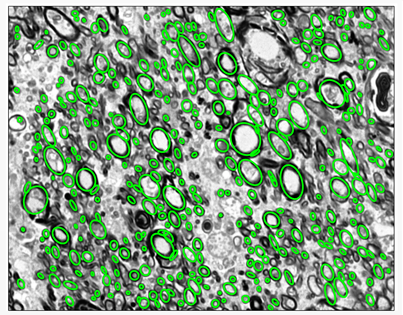

FIG.15: LM1 ellipse fit.

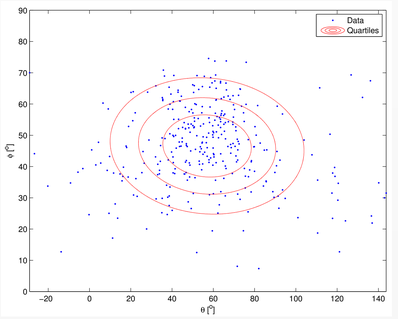

FIG.16: LM1 Directional Distribution.

It is seen from FIG. 12 that the nerve fibers in FIG. 11. has directional tendency to point in a horizontal angle of 57° away from the x-axis, and a vertical angle of 43° away from the z-axis (0° is straight out of the image).

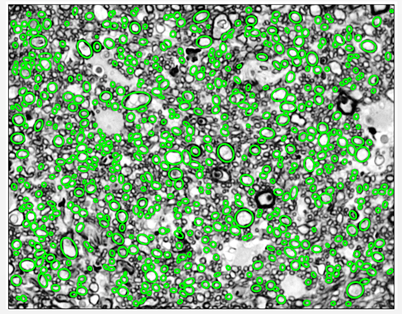

FIG.17: LM2 Ellipse Fit.

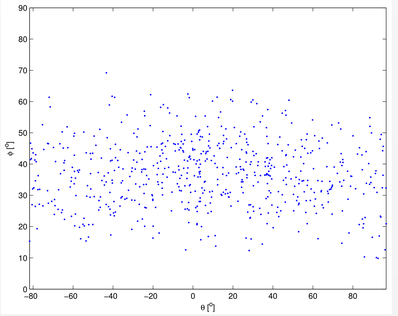

FIG.18: LM2 Directional Distribution.

The nerve fibers in FIG. 13 has no horizontal tendency and they point nearly straight out of the image.

Conclusions & Outlook

- Most ellipses are correctly fitted, and almost no false positives appear.
- Directional distribution is inferred from the fitted ellipses.
- Next step is to map entire corpus callosum and compare with MR images.

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References

[1] R. Halir and J. Flusser. Numerically stable direct least squares fitting of ellipses. *WSCG'98. The Sixth International Conference in Central Europe on Computer Graphics and Visualization'98*, 1(vol.1):125–32, 1998. ISBN 8070823593.

[2] Kim Ik-Sung. An algorithm for finding the distance between two ellipses. *Commun. Korean Math. Soc.*, NO.3:559–567, 2006.

[3] Wikipedia. DMRI. `http://en.wikipedia.org/wiki/Diffusion_MRI`, May 2010.