Advanced Polarization Imaging Techniques for Microstructural Validation of Diffusion MRI

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Background

Magnetic resonance imaging (MRI) is a non-invasive method to image organs, tissue, or skeletal systems deep within the body. A primary challenge with MRI is that a large amount of mathematical modeling is required to generate the resulting images. As a result, there is a strong need for robust validation techniques for MRI imaging. In particular, diffusion MRI is gaining popularity as an imaging technique in which physiological mechanisms are determined by the mobility of water molecules. This has strong implications for imaging grey matter and white matter in the brain.

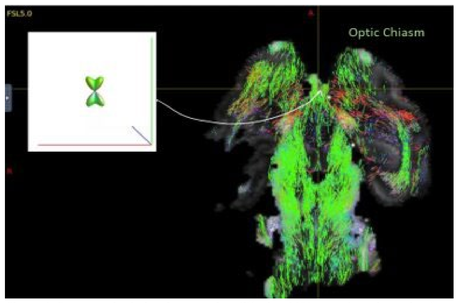


Figure 1: Ferret optic chaism image using diffusion MRI to probe orientation features.

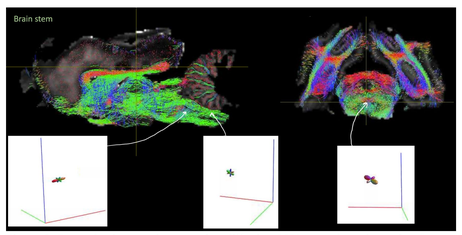


Figure 2: Ferret brain stem image using diffusion MRI to probe orientation features.

Motivation

Polarization imaging is an optical technique that probes microstructural features and shows promise for diffusion MRI validation. A polarimeter will use monochromatic light that passes through polarizing plates, creating a polarized beam that rotates as it passes through a given sample (Fig. 2-3). By doing this it can measure polarizing effects such as depolarization, retardance, and diattenuation, which are linked to tissue microstructure and orientation.

Objective

Our overreaching goal is to develop robust validation techniques for diffusion MRI scans using polarization imaging.

Methods

- Five ferret brains were imaged using diffusion MRI given similarity to human physiology.
- For each brain, three regions with different microscale features were imaged using a custom Nikon polarimeter.
- Polarimetric data is then processed to output the Mueller matrices through MATLAB.
- Quantification is then conducted by using the Mueller Matrices to identify depolarization, diattenuation and retardance (Fig. 3-4).

a) b)

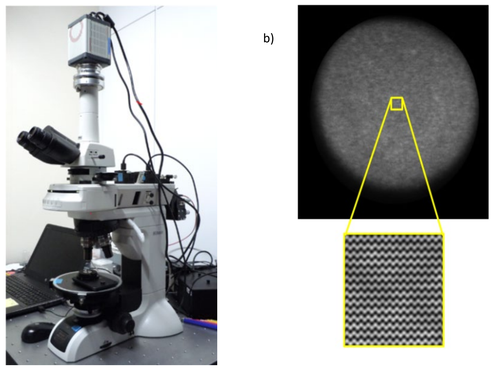


Figure 2: a) The following is a Mueller Matrix Imaging Polarimeter microscope system that helps visualize polarization information b) Image of Fourier domain imaging polarimeter with polarizer set to 30-degrees.

a) b)

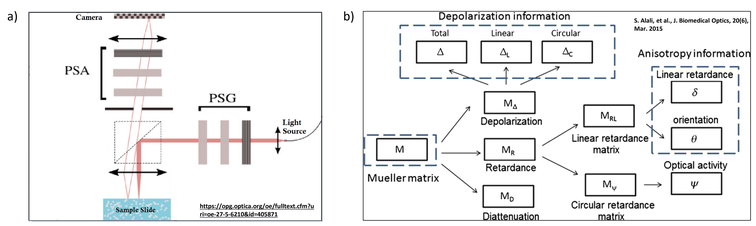


Figure 3: a) Path of light through backscattering polarimeters, which consists of a polarization state generator (PSG) and a polarization state analyzer (PSA). b) Flowchart illustrating Mueller Matrix decomposition to acquire depolarization, diattenuation and retardance.

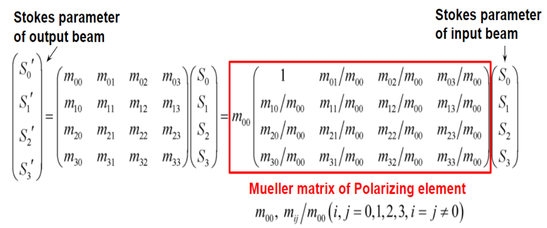
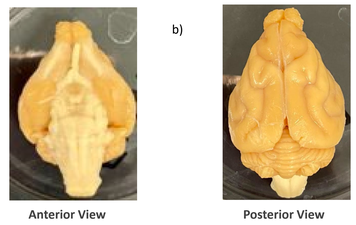


Figure 4: The Mueller Matrix is a techniques used to characterize the wavelength-dependent polarization rotation of optical fibers. This is determined by the relationship between a set of input polarization vectors and corresponding output polarization vector

Ferret Brain FT233

a) b)



c)

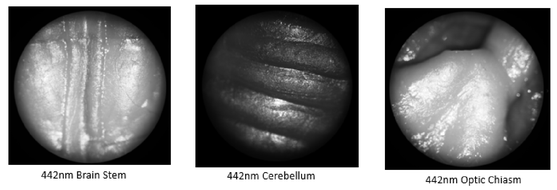


Figure 5: Examples of ferret brain samples (a,b) and imaged regions of interest including brain stem, cerebellum, and optic chaism (c) under 442 nm illumination.

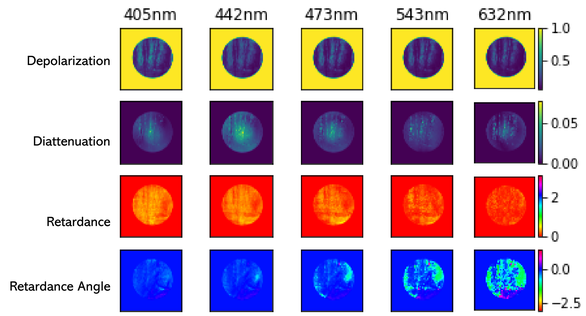


Figure 6: The illustrations are of the selected parameters for the center of FT233 Cerebellum

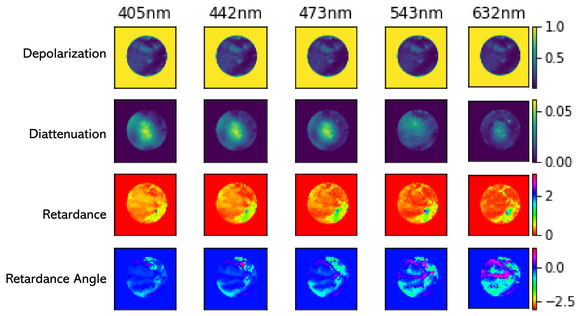


Figure 7: The illustrations are of the selected parameters for the center of FT233 Optic Chiasm

Conclusion

Preliminary results suggest that the polarization parameters extracted from the imaging system correlate with microstructural features (Fig 6-7). There seems to be slight wavelength dependence. Current work is focused on quantifying the values of polarization parameters for the regions of interest.

By analyzing the depolarization, diattenuation, and retardance found in the images we can then certify the images produced by MRI scans, as well as have a deeper understanding of the structural physiology composing the different types of tissue.

Next steps

Next steps are to compare quantitative values between complex Mueller polarimeter to conventional polarized light imaging methods, and to correlate to diffusion MRI data to assess suitability for validation. We also are examining the use of polarization imaging when applied to samples of human brain tissue.

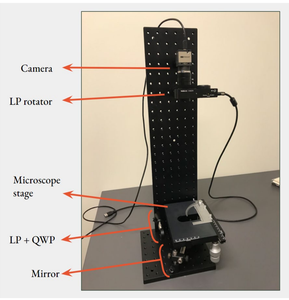


Figure 8: Conventional polarized light imaging system to collect retardance of thin sections. Comparison to the Mueller matrix polarimeter will examine which method is more powerful

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