WHITE MATTER MATTERS

By

Kim Son Nguyen

Rachael Lew

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ABSTRACT

Diffusion Tensor Magnetic Resonance Imaging (DT-MRI) has become the standard in the study and measurement of white matter in the brain. This paper consists of an analysis of data sets taken from a DT-MRI of a human brain. It describes the process involved in visualizing the data using hyperstreamlines.

INTRODUCTION

Diffusion Tensor Magnetic Resonance Imaging (DT-MRI) is a technology that measures the diffusion of water in tissue, such as white matter in the brain. It is non-invasive and implemented in vivo. Using the information about the anisotropy, DTI shows the orientation of the white matter fiber bundles. Thus, it can be used to map the white matter anatomy and muscle structure. Applications of diffusion tensor imaging (DTI) include studying the structure of white matter in order to help diagnose and treat neurological disorders. In order to do so, visualizations of the DTI data sets prove necessary to be able to understand the brain anatomy and draw useful conclusions about it. However, visualizing DTI data sets often can be difficult, as a DTI data set contains a 3D grid of diffusion tensors. A diffusion tensor is made up of six tensor components and measures a 3D diffusion process.

BACKGROUND

WHITE MATTER

White matter is comprised of pathways that connect the regions, referred to as grey matter, that contain nerve cells. It consists of axons, or nerve fibers, that are coated with a fatty substance called myelin, which provides insulation and speeds up impulses between neurons. White matter abnormalities due to the loss or destruction of the myelin sheath often indicate the presence of a disease, such as Multiple Sclerosis.

Using brain-scanning technology called diffusion tensor imaging (DTI) enables a closer inspection of white matter in the brain. DTI creates brain-image slices that display the vectors of water that diffuse in tissue. Because water diffuses asymmetrically along axon bundles, white matter appears especially visible due to the resulting irregular pattern. In addition, DTI signals become stronger around areas with heavily myelinated axons. DTI thus proves useful in locating white matter abnormalities where myelin has been destroyed. As a result, it also holds the potential for diagnosing neurological disorders.

HYPERSTREAMLINE VISUALIZATION

Tensor fields can be reduced to a vector field in order to visualize DTI data sets. The vector field is defined by the major eigenvector, which is assumed to identify the direction of linear structures in the areas of linear anisotropy. The most common method for visualization 3D DTI data sets is streamline tracing, which involves three steps. First is the definition of seed points, which are usually user-defined. Regions of interest are specified and samples found from the interior of these regions are used as seed points. The second step is integration, and such numerical integration techniques as Euler and second or fourth-order Runge Kutta are used. Last is to determine the stopping criteria, which involves not calculating the streamline in areas where the vector field is not robustly defined. A threshold is set based on anisotropy indices to identify the areas where the vector field is defined. Hyperstreamlines are used for second-order tensors and extend the streamline technique. They utilize all eigenvalues and eigenvectors. The streamline, defined by the major eigenvector, establishes the axis of a cylinder. The cross-section of the cylinder consists of perpendicular axes determined by the medium and minor eigenvectors and eigenvalues.

TECHNICAL DETAIL AND METHODS

The project analyzes diffusion tensor MRI data sets. The process involves mapping the tractography of the diffusion tensor using the eigenvectors and eigenvalues. The tensor field is reduced to a vector field, allowing the use of hyperstreamlines for the visualization.

To begin, after the DT-MRI data set is read in, the tensor field is reduced to a vector field, and the major, medium, and minor eigenvalues are obtained. For the vector field visualization, fractional anisotropy is used to seed the points along the major eigenvector where anisotropy is very high. The stopping condition is when the fractional anisotropy falls below the threshold. The medium and minor eigenvectors are scaled to serve as dimensions of the hyperstreamline cylinder.

The DT-MRI data set is dissected for two features of interest. The first one is the point where the anisotropy is high, which indicates the dominance of the major eigenvector over the medium and minor eigenvectors. The second significant point is the place where all three eigenvectors and eigenvalues are almost equal. This signifies that the white matter diffusion is not as powerful.

RESULTS

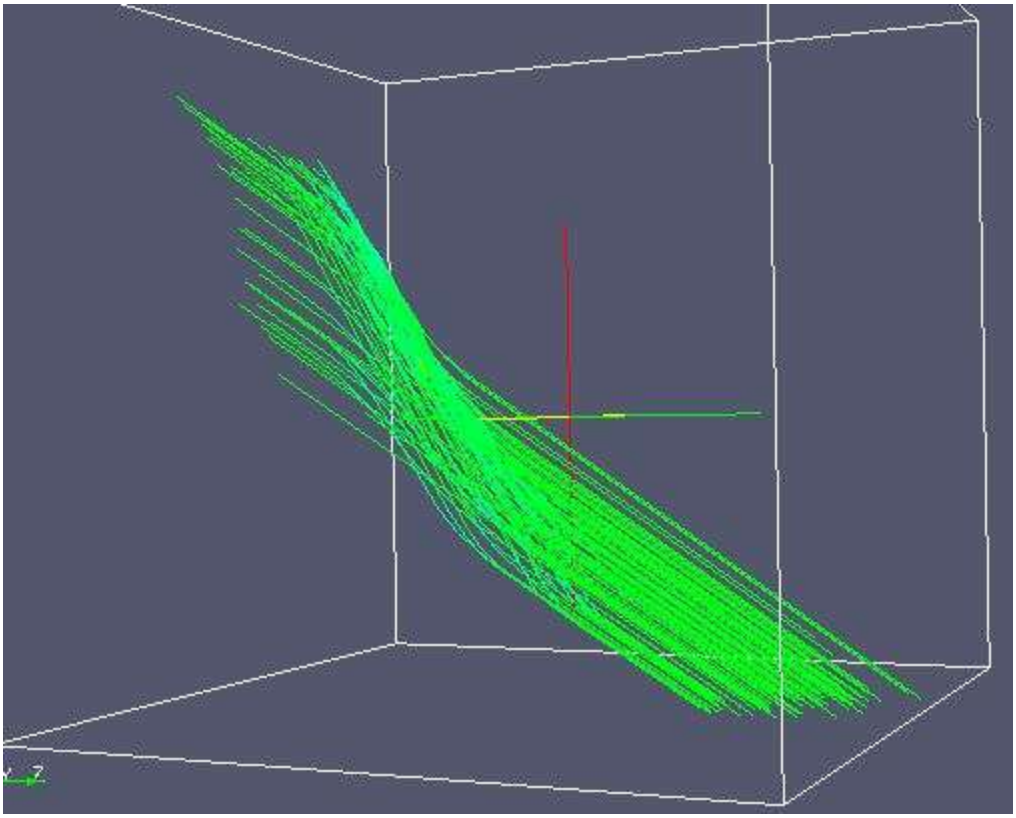

Figure 1 Hyperstreamline

Figure 1 shows the hyperstreamline visualization representing the white matter fiber bundles from analyzing the DT-MRI data set.

CONCLUSION

Despite its supposed simplicity, the algorithm to generate the streamline is slow, although this may be more the fault of the large data set. The process to reduce the tensor to a vector is easy to understand and shows sufficient information of the fiber bundle. However, the stopping criteria are not always clear, especially in isotropic regions or planar diffusion, and the major eigenvector has no meaning in those areas. In some cases, one can overlook important features, and too many seed points can clutter the image.

REFERENCES

Fields, R. Douglas. "White Matter Matters." *Scientific American* Mar. 2008: 54-61. Web. 31 Jan. 2014.

Vilanova, A., S. Zhang, G. Kindlmann, and D. Laidlaw. *An Introduction to Visualization of Diffusion Tensor Imaging and Its Applications*. N.p.: n.p., n.d. PDF.

Kindlmann, Gordon. "Superquadric Tensor Glyphs." Diss. University of Utah, 2004. Abstract. N.p., n.d. Web. 31 Jan. 2014.

"White Matter Tractography Using Diffusion Tensor Deflection." Diss. University of Utah, 2003. Abstract. N.p., n.d. Web. 31 Jan. 2014.