False Positive Detection using Filtered Tractography

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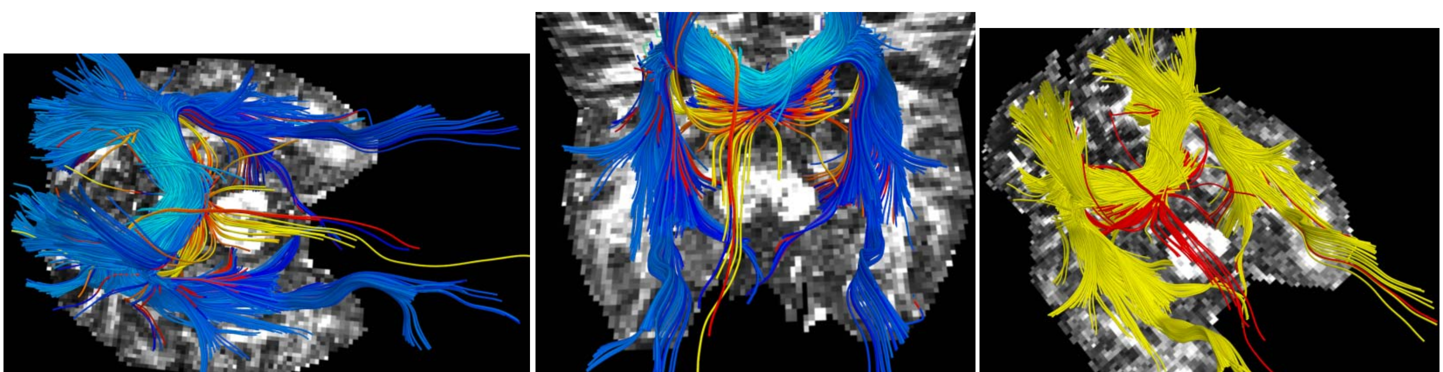
Introduction: Diffusion-weighted MR imaging allows for non-invasive investigation of the neural architecture of the brain. In the past decade, several algorithms have been proposed to trace the fiber bundles using a variety of fiber model representations. The simplest and the most widely used model is the diffusion tensor model, with tracts generated by following the principal diffusion direction of the tensor. Other complex multi-tensor and non-parametric models have also been proposed. However, most of these methods estimate the model independently at each voxel, and tractography is done as a post-processing step. In their recent work [Malcolm et. al. 2009], the authors proposed an unscented Kalman filter based tractography algorithm. In this method, the model parameters (one or multi-tensor) are simultaneously estimated in a recursive fashion as we follow the fiber path. Thus, the inherent correlation in diffusion is taken into account in the model estimation step while tracing the fiber bundles. In this work, we show how false positive detection (fibers that don't exist anatomically, but are nevertheless traced by tractography algorithms) can be done naturally within this filtering framework.

Method: A lot of fiber tracking algorithms exist, however there has been very little work on false positive detection. Specifically, [Clayden et. al. 2009] have proposed a probabilistic model of shape variability between individuals to detect erroneous tracts. Other related work is by [Koay et. al. 2008, Anderson 2008], where they compute the cone of uncertainty at each voxel to know the goodness of fit. We should note that a separate algorithm is required to compute the fiber directional uncertainty in all of these methods. The unscented Kalman filter (UKF) based tractography algorithm not only provides an estimate of the parameters, but also computes a measure of confidence in the estimation in the form of a covariance matrix P (see Malcolm et. al. 2009 for details). This covariance matrix is computed at each step along the fiber tract and can be directly used to compute measures of confidence in the estimation. While there are several measures such as, norm, log-Euclidean norm, determinant, trace, etc. that could be computed from the covariance matrix, in this work, we use the Frobenius norm. We show that this simple measure is sufficient to detect false positives. The norm encapsulates within a scalar measure, the overall uncertainty in the estimation. Thus, higher norm implies more uncertainty and less confidence.

Results: In this work, we show results on the UKF based single tensor tractography. Seeding was done in the splenium of the corpus callosum and a moving average of the norm of the covariance matrix was computed at each step along the path. The interval to compute the moving average was arbitrarily set to 5. The results did not vary significantly by changing this parameter. Figure 1a shows the tracts color-coded with the norm of the covariance matrix. Confidence in estimation decreases from blue-to-yellow. This method could be used to prune part or entire fiber tracts that have low confidence. Thus, fibers along which the norm exceeds a certain user defined threshold, could be entirely removed or partly removed. In the accompanying Figure 1c, red fibers were the false positives detected by choosing a certain threshold of the norm. Another effective use of this confidence measure is in computing statistics of features like FA within a fiber bundle. Thus, regions of the fibers with low confidence can be given lower weight than other regions. We believe that this method of detecting false positives can provide an important tool to neuroscientists in population studies. Further, the proposed method of false detection can easily be extended to filtered multi-tensor tractography.



(a) (b) (c)

Figure 1. (a), (b) Fibers of the corpus callosum color coded with the norm of the covariance matrix. Blue indicates high confidence while yellow indicates low confidence. (c) Red fibers are the false positives detected by choosing all fibers along which the norm of covariance exceeded a threshold.

References: J Malcolm, M Shenton, Y. Rathi, "Neural Fiber tractography using the unscented Kalman filter", IPMI 2009., J. Clayden, et. al, "Shape modeling for tract selection", MICCAI 2009., C Koay et. al., "The elliptical cone of uncertainty and its normalised measures in diffusion tensor imaging", IEEE TMI 2008., H Jeong, A Anderson, "Characterizing fiber directional uncertainty in diffusion tensor MRI", MRM 2008.