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A novel approach for improved tractography and quantitative analysis of probabilistic fibre tracking curves

Nagulan Ratnarajah [a,*], Andrew Simmons [b,c], Oleg Davydov [d], Ali Hojjatoleslami [a]

[a] Medical Image Computing, School of Biosciences, University of Kent, UK
[b] Neuroimaging Department, Institute of Psychiatry, King's College London, UK
[c] NIHR Biomedical Research Centre for Mental Health at the South London and Maudsley NHS Foundation Trust and Institute of Psychiatry, King's College London, UK
[d] Department of Mathematics and Statistics, University of Strathclyde, UK

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ABSTRACT

This paper presents a novel approach for improved diffusion tensor fibre tractography, aiming to tackle a number of the limitations of current fibre tracking algorithms, and describes a quantitative analysis tool for probabilistic tracking algorithms. We consider the sampled random paths generated by a probabilistic tractography algorithm from a seed point as a set of curves, and develop a statistical framework for analysing the curve-set geometrically that finds the average curve and dispersion measures of the curve-set statistically. This study is motivated firstly by the goal of developing a robust fibre tracking algorithm, combining the power of both deterministic and probabilistic tracking methods using average curves. These typical curves produce strong connections to every anatomically distinct fibre tract from a seed point and also convey important information about the underlying probability distribution. These single well-defined trajectories overcome a number of the limitations of deterministic and probabilistic approaches. A new clustering algorithm for branching curves is employed to separate fibres into branches before applying the averaging methods. Secondly, a quantitative analysis tool for probabilistic tracking methods is introduced using statistical measures of curve-sets. Results on phantom and *in vivo* data confirm the efficiency and effectiveness of the proposed approach for the tracking algorithm and the quantitative analysis of the probabilistic methods.

1. Introduction

Fibre tractography using diffusion MR images is a promising method for reconstructing the pathways of white matter fasciculi in the human brain. This method allows one to study the anatomical connectivity of the brain and is an essential diagnostic tool for a number of neurological diseases. A variety of algorithms have been proposed aiming to generate fibre-tract trajectories. Generally these algorithms can be categorised into two main types, deterministic and probabilistic. Deterministic approaches (Basser et al., 2000; Mori et al., 1999; Lazar et al., 2003a) are based on the assumption that the principal eigenvector (PEV) of the diffusion tensor is parallel to the underlying dominant fibre direction in each image voxel. They propagate a single pathway bi-directionally from a seed point by moving in a direction that is parallel to the PEV. These approaches are capable of creating anatomically reliable reconstructions of major white matter tracts. However, they do not correctly deal with branching of white matter tracts as such algorithms produce only one path per seed point and there is no measure describing the uncertainty of the reconstructed trajectories.

Probabilistic tractography algorithms (Friman et al., 2006; Hagmann et al., 2003; Jones, 2008; Lazar and Alexander, 2005) have been developed to overcome the shortcomings of deterministic methods. The aim of probabilistic tracking methods is to provide a natural approach for modelling uncertainty and generate multiple curves originating from a seed point. Probabilistic methods have also been developed to attempt to resolve fibre crossings at the intravoxel level under looser constraints, for example in terms of stopping criteria, allowing them to pass through low-anisotropy areas and to penetrate deeper into gray matter (Behrens et al., 2003), and these methods allow branching of white matter tracts. Generally, probabilistic tracking methods have three stages. In the first stage, they model the uncertainty at each voxel using a probability density function (PDF) of fibre orientations. In the second stage, the tracking algorithm repeats a streamline propagation process many times (typically between 100 and 10,000 per seed point) from a seed point with the propagation direction randomly sampled from the PDF of fibre orientations. The connection probability from a seed point to a random voxel within the dataset is defined as the frequency with which streamlines pass through

* Corresponding author.
E-mail address: rn54@kent.ac.uk (N. Ratnarajah).

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