Fiber Selection from Diffusion Tensor Data based on Boolean Operators

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Abstract. Diffusion tensor imaging (DTI) allows investigating white matter structures in vivo which is of particular interest for neurosurgery. A promising approach for the reconstruction of neural pathways are streamline techniques, which are commonly referred to as fiber tracking. However, the resulting visualization of fibers within the whole brain may be complex and difficult to interpret. For this reason, a novel strategy for selecting specific tract systems based on user-defined regions of interest (ROIs) and Boolean operators is presented in this work. The approach provides ultimate flexibility and is an excellent tool for fiber tract selection and planning in neurosurgery.

1 Introduction

Diffusion tensor imaging (DTI) is a magnetic resonance acquisition technique which provides valuable information about the location of white matter tracts within the human brain in vivo. DTI allows quantifying diffusion of water which is anisotropic in tissue with a high degree of directional organization such as in the white matter of the brain. In this way, information about the location of neuronal fibers is provided which is of great interest for neurosurgery.

The reconstruction of white matter tracts from DTI data is commonly solved by tracking algorithms [1, 2] which use streamline techniques known from flow visualization. This tracking strategy provides an intuitive understanding of the spatial relation between fibers and space occupying lesions and is therefore a valuable supplement for neurosurgical planning [3, 4].

Streamlines are traced starting from seed points located in areas of anisotropic diffusion. The resulting fibers represent the white matter tracts within the whole brain, rather than individual tract systems. For this reason, strategies for selecting specific tract systems have been presented. Automated approaches based on clustering [5] do not require any user interaction, but are of limited value for medical application since the fiber selection and clustering is purely based on geometric criteria. For this reason, a more practical approach employs regions of interest (ROIs) defined by the user. In a basic approach [6] the user is allowed to define multiple box-shaped ROIs, and all fibers crossing the ROIs are displayed. A more advanced approach is based on Boolean selection strategies [7, 8], which are however restricted to two ROIs only.

For planning in neurosurgery, these approaches are not sufficient and more sophisticated selection methods are required. For this reason, an approach based on an arbitrary number of user-defined ROIs with associated Boolean operators is presented in this work, which provides ultimate flexibility and user-interaction.

2 Material and Methods

2.1 Image Data

The DTI datasets used in this work were acquired on a Siemens MR Magnetom Sonata Maestro Class 1.5 Tesla scanner. The specifications of the gradient system were a field strength of up to 40 mT/m (effective 69 mT/m) and a slew rate of up to 200 T/m/s (effective 346 T/m/s) for clinical application. The field of view was 240 mm, resulting in a voxel size of $1.875 \times 1.875 \times 1.9\,\text{mm}^3$. For each of the six diffusion weighted datasets (gradient directions (±1,1,0), (±1,0,1) and (0,1,±1)) and the reference dataset, sixty slices with no intersection gap and an acquisition matrix of 128×128 pixels were measured. Additionally, a MRI_{T1} sequence (256×256×160 voxels) was acquired in each patient which was used for surgical planning.

2.2 Fiber Tracking

Fiber tracking algorithms based on streamline propagation have several steps in common such as seed point selection, fiber propagation and termination strategies [9]. Starting from predefined seed points, streamline integration is used to propagate the fiber until a termination criterion is reached. For this purpose, a threshold based on fractional anisotropy (FA) [1, 2] is commonly applied to stop fiber propagation if the anisotropy of diffusion decreases.

In this work, fiber tracts were computed using fourth order Runge-Kutta integration and trilinear tensor interpolation. A constant tracking step size of 0.5 mm was employed. FA was used as termination threshold for fiber propagation, and a length threshold of a minimum of 100 tracking steps was used in order to exclude short fibers from the tracking result.

2.3 Definition of Regions of Interest

In order to extract individual fiber tracts, the user needs to define regions of interest (ROIs) that are used in the fiber selection process. The ROIs can have arbitrary shape and are defined using a voxel-based segmentation tool. The DTI dataset that is measured without diffusion gradient is used as anatomical scan and loaded into the segmentation tool. The ROI is drawn manually on axial, sagittal or coronal sections based on anatomical knowledge. In this way, also non-trivial ROI shapes can be defined, e.g. in the vicinity of a tumor. Finally, the ROI is imported into the fiber tracking tool for further processing.

2.4 Boolean Operators associated to Regions of Interest

Boolean logic has many applications in electronics, computer hardware and software, and is the basis of all modern digital electronics. Boolean operators are used in order to define conditions on sets in order to retrieve the qualifying elements. The basic Boolean operators are logical OR and logical AND, which perform the union and intersection of sets, and logical NOT which is a unary operator and forms the complement.

In order to further control the fiber selection process, each ROI has an associated Boolean operator that defines a rule for fiber tract selection for this ROI. Basically, the following three options exist:

- *AND*: A ROI with associated Boolean operator AND requires any fibers that are retained to cross this ROI. Multiple AND ROIs result in a fiber bundle that crosses all AND ROIs.
- *OR*: A ROI with associated Boolean operator OR requires any fibers that are retained to either cross this ROI or any other OR ROI. If only one OR ROI is defined, the effect is the same as if the OR ROI was an AND ROI.
- *NOT*: In some cases, it is desirable to exclude certain fibers from the extracted fiber tract, e.g. fibers that connect to the other hemisphere. For this purpose, a NOT ROI may be defined, which excludes any fibers that cross the ROI.

By combining ROIs with different associated Boolean operators, utmost flexibility for tract selection is provided. In Fig. 1, the user interface for fiber tracking is shown, the associated Boolean operator can be toggled for each ROI. The approach has been integrated into the software framework MedAlyVis (Medical Analysis and Visualization).

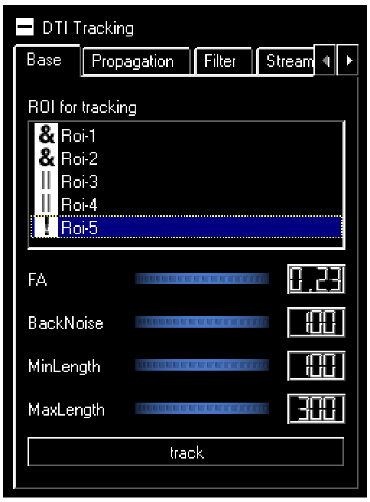


Fig. 1. Fiber tracking tool. The Boolean operator can be toggled for each ROI. Available options: AND, OR, NOT.

3 Results

In Fig. 2, different combinations of ROIs with associated Boolean operators are shown for a brain tumor patient. If no ROI is defined, the fibers resulting from fiber tracking within the whole brain are displayed (upper left). Combination of two AND ROIs allows extracting the pyramidal tract (upper right). A combination of an AND ROI and two OR ROIs allows displaying the fraction of fibers that expand from the AND ROI to either of the OR ROIs (lower left), and a NOT ROI is used in order to exclude undesirable fibers that belong to a different tract system (lower right).

The performance of the tract selection method depends on the number of voxels within the dataset, the number of fibers, the size of the ROIs and the individual position of the ROIs. For a whole brain tracking comprising 300.000 fibers, the fiber tracking and fiber tract selection using up to four ROIs with different associated Boolean operators took between 20 and 50 seconds on a PC equipped with a Intel Core i7 CPU (3.0 GHz) and 3 GB RAM.

4 Discussion

Fiber selection techniques are of major importance in order to make fiber tracking results accessible for surgery planning and intra-operative visualization. The presented approach overcomes the limitations of automated clustering strategies [5], manual selection techniques [6], and Boolean selection strategies [7, 8] that were presented previously.

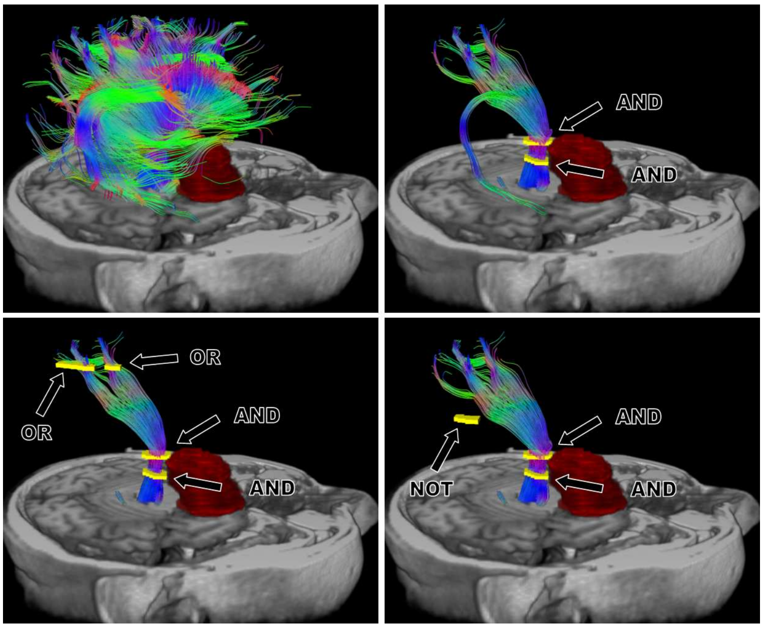
Compared to the timings reported in [6], the approach is slower since a tracking of the whole brain is always performed in the first instance. Options to speed up the approach would be to compute the fibers within the whole brain only once, and to use an octree in order to speed up the fiber selection [6].

Nevertheless, the possibility of dedicated tract extraction for surgery planning was greatly appreciated by the neurosurgeons, and the computing times were still considered as acceptable. Especially the option to exclude perturbing fibers using NOT ROIs proved to be very desirable.

5 Conclusion

In this work, a novel strategy for selecting specific tract systems based on user-defined ROIs and Boolean operators is presented, which is applicable to an arbitrary number of ROIs. The approach overcomes the limitations of current techniques and offers ultimate flexibility for tract extraction. Overall, the presented technique makes it possible to extract fiber tracts in a very patient-specific way, which is desirable for surgical planning and intra-operative visualization in neurosurgery.

Fig. 2. Fiber tracts extracted by using a combination of ROIs with different associated Boolean operators. Upper Right: Fiber tracking result without ROIs. Upper Right: Usage of AND ROIs. Lower Left: Effect of using OR ROIs. Lower Right: Undesirable fibers are excluded using a NOT ROI.



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