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Diffusion Tensor Imaging Tractography in Decision Making of Extra Temporal Resective Epilepsy Surgery

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Abstract:
The main purpose of this paper is to assess the utility of diffusion tensor imaging tractography (DTIT) in decision making in patients considered for extra temporal resective epilepsy surgery. A supervised learning technique is used for the automatic registration and segmentation of white matter tractographies which is extracted from the brain DT-MRI. The supporting structure provides direct registration between the fibers without requiring any intensity based registration algorithms. For the registration purpose Iterative Closest Fiber (ICF) algorithm is used. To improve the precision of the target tract segmentation Probabilistic Boosting Tree (PBT) algorithm is proposed. It acts an important role in predicting postoperative neurological outcomes and assists in surgical decision making and used in pro operative counseling of patients with extra temporal epilepsies.

Key words: *Tractography, epilepsy, resective, registration, segmentation*

1. Introduction

Diffusion tensor imaging is novel imaging techniques that can reveal unique information of white matter structures also detect the abnormalities in the brain. The basic principle of diffusion tensor imaging focuses the micro movement of water molecules inside the brain. Tractography is a 3D modelling technique that is used to produce the visual representation of neural tracts. Epilepsy is a brain disorder. In general population, 0.5 – 1% of peoples are affected by epilepsy.

Epilepsy is caused by seizure and seizure is the symptom of brain problem. They happen because of sudden abnormal electrical activity in brain. Seizure is classified into two types namely, Focal seizure and generalized seizure

The focal seizure affect one part of the brain and the generalized seizure affect both sides of the brain. Temporal lobe epilepsy is also the type of focal epilepsy. The causes of temporal lobe epilepsy are brain injury, abnormal brain development etc, high resolution magnetic resonance imaging (MRI) helps to identify and localize the lesions responsible for focal epilepsy.

Focal epilepsy is a seizure disorder. Functional magnetic resonance imaging can be employed to identify eloquent cortical areas and their relationship to the epileptogenic lesion. Structural magnetic resonance imaging and functional magnetic resonance imaging do not provide any information concerning the relationship of the epileptogenic lesion and eloquent cortical areas to adjacent white matter tracts.

Diffusion tensor imaging (DTI) is a new magnetic resonance technique for investigating white matter microstructures by measuring mobility of white matter molecules with in a voxel and its directionality. DTI tractography (DTIT) is an extension of DTI that provides in-vivo method of quantifying and visualizing the integrity of white matter tracts. DTIT helped to modify the surgical procedure.

DTIT is a non invasive imaging technique that can be used effectively in planning respective of epileptogenic lesions and cortical areas. It acts an important role in predicting postoperative neurological outcomes and assists in surgical decision making and used in preoperative counselling of patients with extra temporal focal epilepsies.

To extract the white matter fibers supervised learning method is used for automatic registration and segmentation of white matter tractographies which extracted from brain DT-MRI. The supporting structure provides direct registration between the fibers without requiring any intensity based registration algorithms. For the registration purpose Iterative closest Fiber (ICF) algorithm is used. To improve the precision of the target tract segmentation Probabilistic Boosting Tree (PBT) algorithm is proposed.

In many cases the epilepsy causes are unknown. Doctors use brain scans and other tracts to diagnose epilepsy. There is no complete cure for epilepsy disorder but medicines can control seizures for most peoples. When medicines are not working surgery or implanted devices may help.

In this paper used for the surgical decision making and pre surgical planning. A review of the related works in these fields is presented next followed by a short description of the current work and the paper outline.

2. Materials

A review of the related works in these fields is presented next following by a short description of the current work

2.1. Diffusion Tensor MRI

Diffusion tensor MRI is a magnetic resonance imaging (MRI) method that produces in vivo images of biological tissues weighted with the local micro structural characteristics of water diffusion, which is capable of showing connections between brain regions. The field of diffusion MRI can be understood in terms of two distinct classes of application diffusion weighted MRI and diffusion tensor MRI. Diffusion MRI is a key technology in the creation of the human connections, which is the structure and organization of the connections throughout the central nervous system. DT MRI was introduced in 1986 by Le Bihan.

It measures the diffusion of water molecules in biological tissues. Though water appears move around freely, individual water molecules are constantly in motion, colliding with each other and encountering other cellular structures from time to time at high speeds. These high speed collisions cause the water molecules to diffusion.

More extended DTI scans derive neural tract directional information from the data using 3D or multidimensional vector algorithms based on six or more gradient directions, sufficient to compute the diffusion tensor. The diffusion model is a rather simple model of the diffusion process, assuming homogeneity and linearity of the diffusion within each image voxel. Moreover, the principal direction of the diffusion tensor can be used to infer the white matter connectivity of the brain. DT-MRI is the first non invasive in vivo imaging modality with the potential to generate fiber-tract trajectories in soft fibrous tissues, such as nerves, muscles, ligaments, tendons, etc. Recently more advanced models of the diffusion process have been proposed that aim to an overcome the weakness of the diffusion tensor modals. The most important difficulty is motion sensitivity, which can cause severe ghosting artifacts or complete signal loss. The problem is more serious when scans must be obtained in disoriented and confused stroke victims, whose head movements are excessive.

The introduction of DT-MRI has provided one novel and multifaceted diagnostic tool for very basic clinical needs and for advanced, specialized diagnosis and treatment planning. In particular, the fibre tracking in the brain is the fresh approach to diagnosis the brain. It is very important in medical applications when a brain surgeon has to determine how to remove a cancer from a patient's brain and not to damage any important nerves fiber. It is also important to study the nerve system connectivity between different parts of the brain to determine if any brain disease is related to the disconnections of certain nerve fibers.

2.2. Medical Image Registration

Image registration is the process of overlaying two or more images of the same scene taken at the different times, from different viewpoints, and/or by different sensors. It geometrically aligns two images i.e. the reference and sensed images. The present differences between images are introduced due to different imaging conditions. Image registration is a crucial step in all image analysis tasks in which the final information is gained from the combination of various data sources like in image fusion, change detection, and multichannel image restoration. It is the process of systematically placing separate images in a common frame to reference so that the information they contain can be optimally integrated or compared. This is becoming the central tool for image analysis, understanding, and visualizing in both medical and scientific applications.

The medical image registration provides the first comprehensive coverage of this emerging field. This monograph details the theory, technology, and practical implementations in a variety of medical settings. International experts thoroughly explain why image registration is important, describe its applications in a non mathematical way, and include analysis for those who plan to implement algorithms themselves. It is accessible and informative to those new to the field, yet it provides in depth treatment for the expert. With its practical examples, extensive illustrations, and comprehensible approach, medical image registration is a must have guide for medical physicists, clinicians, and researchers.

2.3. Medical Image Segmentation

Segmentation is the process of splitting images into different objects from background. For intensity images four popular approaches are: threshold techniques, edge based methods, region based techniques, and connectivity preserving relaxation methods. Threshold techniques, which make decision based on local pixel information, are effective when the intensity levels of the objects fall squarely outside the range of levels in the background. Because spatial information is ignored, however, blurred region boundaries can create havoc. Edge based methods center around contour detection: their weakness in connecting together broken contour lines make them, too, prone to failure in the presence of blurring.

A region based method usually proceeds as follows: the image is partitioned into connected regions by grouping neighboring pixels of similar intensity levels. Adjacent regions are then merged under some criterion involving perhaps homogeneity or sharpness of region boundaries. Over stringent criteria create fragmentation; lenient ones overlook blurred boundaries and over merge. Hybrid techniques using a mix of the methods above are also popular.

3. Method

The block diagram in Fig. 1 presents the main steps of the proposed method for supervised automatic registration and segmentation of white matter tractographies. The input images used in this proposed system is temporal lobe epilepsy disease images. Around hundred images are collected and stored in data base. All of these images are collected from the hospital for study purpose with the images of patient affected by temporal lobe epilepsy disease. Fig. 2 represents the captured input image. When the captured image is comes under the preprocessing section to removing the unwanted noise present in the image and the important needs of image preprocessing,

- Improvement of image quality
- Noise reduction
- Contrast enhancement
- Elimination of artifacts.

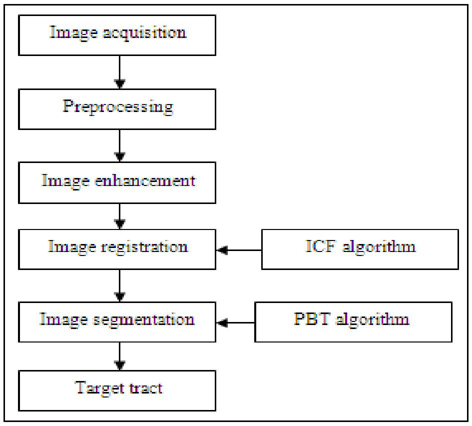

Figure 1: main steps of the proposed method

Figure 2: Captured Input Image

Image enhancement is used to improve the image quality and contrast value. This is also used to reduce the lowest gray values to black and highest to white. Image enhancement technique can be divided into two broad categories such as Spatial domain methods, which operate directly on the pixels. Frequency domain methods, which operate on the Fourier transform of an image.

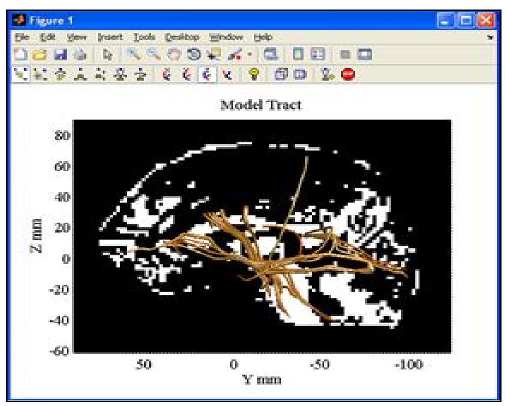

Figure 3: represents the model fiber tract in the brain and the white surface represents the white matter region

3.1. Iterative closest Fibre (ICF) Algorithm

Iterative Closest Fiber (ICF) algorithm is used to reconstruct 2D or 3D surfaces from different scans. Here ICF algorithm is applied for the registration purpose. It is the process of aligning two or more images in the same scene. When the application of DTIT technique each fibers are projected into a high dimensional feature space. This kind of fiber sets registration having some alignment problem which is resolved by this ICF algorithm. It is also related to iterative closest curve algorithm. ICF algorithm is used to extract the 3D head model and 2D curves from 2D face images. Let M_i, $i = 1 \ldots n$ and T_j, $j = 1 \ldots m$ be the model and target set of fibers, respectively which is obtained by any tractography algorithm. For the target set, the complete white matter tractography of the target brain will be considered. The model set will be either the complete tractography or its subsets. The goal is to match between model and target fibers by finding for each model fibers M_i, the corresponding target fibers T_j. The ICF algorithm has following steps such as,

- Preprocessing
- ICF Loop

3.1.1. Preprocessing:

This preprocessing steps contain following steps namely

- *Short fibers removal* – in this work the fibers is shorter than 35mm can considered as an artifact fibers and are removed from the model and target sets. This step reduces the data set size and provides very significant efficiency gain.
- *Model set down sampling* – it usually reduce the data rate and size of the data. It depends on the size and position of an image. The affine registration of two full brain tractographies requires the estimation of 12 transformation parametres. As the complete fiber set of brain may include more than 100000 fibers. It is clear that only a small subset of matched model target fibers is needed to fit an affine transformation.

- In order to keep the best matching option of the target set for each model fiber down sampling will only be performed to the model set and not to the target.
- *Feature space representation* – Used for a fixed length representation of fibers. In order to obtain a fixed length representation, to re-sample each fibers at *p* equally spaced points. A 3*p* elements feature vectors *f* is assigned to each fiber by appending the sequence of its 3D coordinates
- $f = [x_1,y_1,z_1, \ldots, x_n,y_n,z_n]$
- *d)Locality sensitive hashing* – ICF algorithm is the search for the closest target fibers as it computes 3*p* dimensional nearest neighbor query for each model fibers. L*p* norm is chosen for fiber distance measurement, the approximate nearest neighbor can be computed efficiently with the LSH framework.

3.1.2. ICF LOOP

For each model fiber M_i are queried for the matching target fibers T_j

$j = \arg\min_n (||M_i - T_n||L_2)$

Full length and incomplete fibers will be present in the distance computation. Full length fibers required for good matching.

Next an affine transform is fitted on the set of matched fibers using Random Sample Consensus (RANSAC) scheme in order to provide good robustness to outliers. The main steps of the implemented RANSAC scheme are as follows.

- Let G be the set of the N_G matched model-target fibers pairs, M'_i and T'_j such that, $\| M'_i - T'_i \|_{L2} \leq Th_d$, $i = 1 \ldots N_G$
- Draw at random N_r fiber pairs $M'_i - T'_i$ from G.
- Compute the residual mean squared fitting error e_k for the recovered transform A_k on the whole set G.
- Repeat from point 2 for N_{it} iteration.
- Return the transformation A_m such that $m = \arg\min_l(e_l)$

The ICF loop described above is repeated until convergence of the mean square error measured between the matched model and target fibers. A set of matched target fibers is returned together with the overall affine transform between the initial model fibers (before any transformation) and the final matched target fibers.

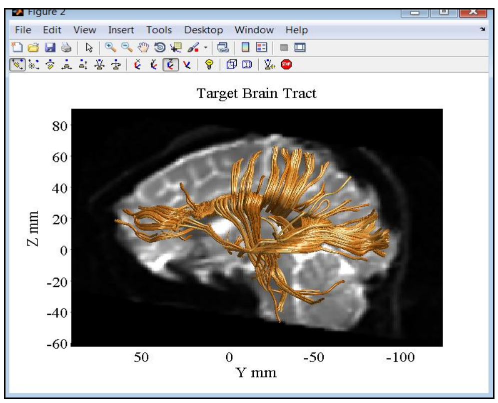

Figure 4: represents the target fiber tract

3.2. Probabilistic Boosting Tree (PBT) Algorithm

To obtain an accurate segmentation of the target a segmentation refinement step is applied. For this Probabilistic Boosting Tree (PBT) algorithm is proposed. This is used to improve the precision of target tract detection.

Precision and recall values are computed by,

Precision = TP / (TP+FP)

Recall = TP / (TP+FN)

Where TP is the true positive count, corresponding to the number of ground truth OR fibers correctly classified. FP and FN stands for the false positive and false negative respectively.

- Nearest Neighbor tract growing: target growing is a region growing process which is used in image processing application. It is used to find a good balance between precision. The method is to increase the number of recovered fibers is to query the LSH tables for the nearest neighbors of each target fiber that was returned by the hierarchical registration-matching. A maximal distance threshold, Th_g , is defined to control the allowed distance between the returned neighbors and the querying target fiber

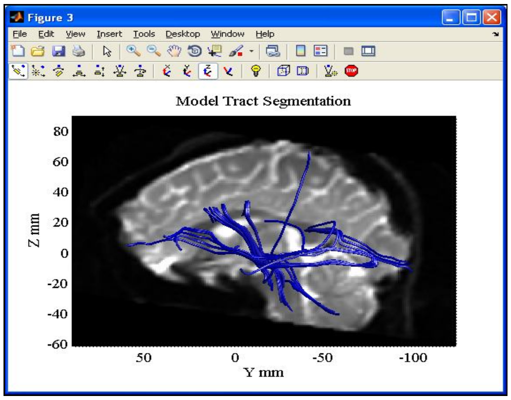

Figure 5: indicates the model tract segmentation

The resulting tract growing process is analogous to a region growing process used in image processing.

- Tree Based Supervised Classification: In order to remove the potential outliers binary supervised classifier is used. The binary tree analyzes the fibers in away that is similar to manual tract segmentation. In this paper binary probabilistic boosting tree classifier algorithm is considered. The tree is trained to boost the several weak classifiers using the standard Ada Boost Algorithm. It is easier to train many good classifiers on simplex data subsets than a single classifier for the entire complex shaped data set.

3.3. Training the PBT

Classification trees perform pattern classification through an ordered sequence of questions or queries. Each question is represented as a node in a direction graph. In the case of PBT the splitting query is a classifier, which is learned for the portion of the training set that has reached this node. It has two classifiers such as strong classifier H(x) and weak classifier h(x). Strong classifier is learned as a combination of several simplex classifiers using Ada Boosting algorithm.

To apply the boosting approach first types of weak classifiers h(x) is selected it has a simple threshold value. The threshold value and the threshold feature are used to minimize the classification errors on the learning set of samples. After a preset number of rounds, the boosting algorithm must combine these weak rules into a single strong classifier, as defined in

$H(x) = \sum \alpha_t h_t(x)$

Where α_t are the weights that set the influence of the rules $h_t(x)$ on the classifier H(x). For a given sample x, the right (+1) and left (-1) probabilities are then given by

$q(+1|x) = \exp\{2H(x)\} / 1+ \exp\{2H(x)\}$

$q(-1|x) = \exp\{-2H(x)\} / 1+ \exp\{-2H(x)\}$

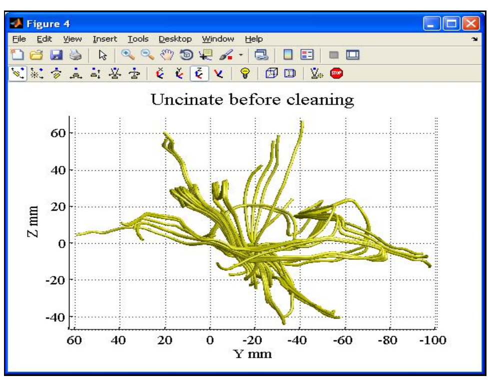

Figure 6: Denotes the segmentation under cleaning process

This process is used to remove the unwanted noice present in the segmented image.

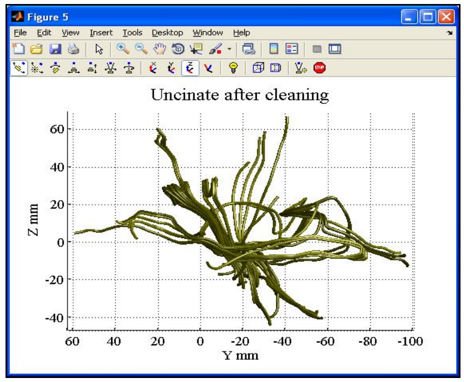

Figure 7: image without noise

3.4. Classification Using PBT

Once the tree is trained, there are two possible methods of classification,

- Crisp classification: in this method each sample/location is placed into one class or another. The class membership values can be either 1 when that class is the best fit or 0 for other classes.
- Maximum posteriory probability: the model that minimizes the probability of model/data is called as maximum a posteriory probability model. It requires basic learning towards simpler models.

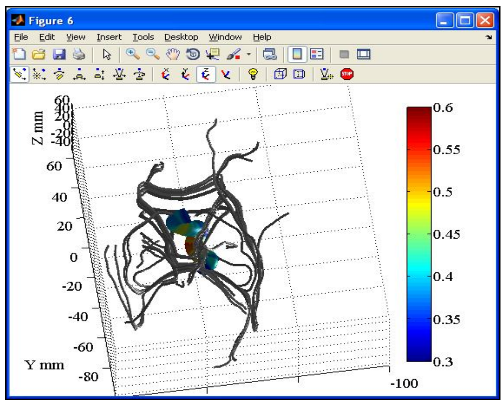

Figure 8: Denotes the target fibers of the brain which is close to temporal region

It provides the reliable information about the fiber tract for decision making purpose.

4. Discussion

The objective of epilepsy surgery is to make the patient seizure free without producing any disabling neurological deficit. To achieve this objective, the surgical intervention should balance complete resection of the epileptogenic zone on the side and preservation of neurological function on the other. The least favorable outcome of epilepsy surgery is a patient who continues to have seizure after surgery.

The DTIT is the only technique that can visualize the white matter tracts in vivo. The data processing for DTIT is performed offline without additional involvement of the patient or prolongation of the scanning time. The integration between structural MRI, FMRI and DTIT can none invasively define the relationship between the epileptogenic lesion, adjacent areas of cortical function and white matter tracts.

The proposed system contains several algorithmic elements. A main component is the ICF algorithm. The ICF alone can be used for affine registration between DTI images when tractography is available. The PBT requires its test set to be aligned with the training set space. This registration could be performed by aligning corresponding scalar DTI images and applying the recovered transformation to transform the PBT input fibers. The resulting classifier will be much more compact and require less training time.

This prompted us to examine the frequency with which the information provided by DTIT assisted us in selecting patients for extra temporal resective epilepsy surgery, in planning the surgical procedure and in predicting post surgery outcome. In order to achieve these objectives, we stratified patients preoperatively into different grades of risk for anticipated neurological complications as judged by the distance of the tracts from the resection zones and functional cortical areas throughout their extent in the gray and white matter. A safe distance of 5 mm from the tumor or resection margin to the pyramidal tract to prevent postoperative epilepsy. However, brain shift that occurs following craniotomy and partial resection of the lesion compromises the results of preoperative tractography. It has been proposed that the maximum shift of the tract that can occur as a result of removal of a large brain lesion might reach 8mm. Based on these data, a distance of less than one centimeter between the white matter tract and the resection zone as indicative of a high risk of postoperative neurological deficit.

The DTIT is only one of the tools in the multimodality pre surgical evaluation protocol and needs to be used in conjunction with the rest of the clinical EEG imaging data. Delineation of the distance between the epileptogenic lesion and the tractographic tract can be compromised if the margin of the lesion. The technique of fMRI driven DTI fiber tracking is more accurate in defining the appropriate seed areas for the DTI fiber tracking. Visualization of the identified tracts wherein the DTIT data can be integrated with an intraoperative neuro navigational system would have further enhanced the neurosurgeon's ability to modify surgical strategy and minimize neurological deficits. This is especially important when one is dealing with extensive resections, where a substantial shift of white matter tract can occur as the neurosurgeon proceeds with resection. The usefulness of DTIT can be made by analyzing the relationship of the tractographic tracts to the resection margin and postoperative neurological deficits.

5. Conclusion

The main purpose of this paper is to assess the utility of diffusion tensor imaging tractography (DTIT) in decision making in patients considered for extra temporal; respective epilepsy surgery. Here fully automated framework for tractography registration and white matter fiber tracts segmentation. Tract segmentation capability was demonstrated qualitatively for some white matter fiber tracts variable complexity on real brain. A supervised segmentation refinement step was proposed to enable high specificity (precision) of the target tract segmentation. The proposed system contains several algorithmic elements. The ICF algorithm can be used for registration between DTI images when tractography is available. The PBT requires its test set to be aligned with the training set space. This registration could be performed transformation to transform the PBT input fibers. Although the proposed method can be used with any tractography algorithm for fiber generation, the expected performance clearly depend on the quality of the available tractography.

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