Landmark guided spatial normalization of Diffusion Tensor Images in the presence of large deformations

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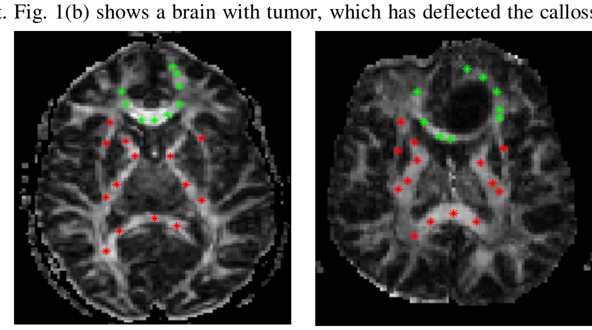
Abstract: We propose a method of correspondence detection in diffusion tensor images by using a unique morphological signature of each voxel which incorporates the anisotropy, diffusivity and orientation information provided by tensors. This proves to be a key step in enhancing existing spatial normalization routines for diffusion tensor images (DTI), by adding the white matter context to the information provided by other scalar measures computed from DTI or other MR modalities. This is especially useful in the case of registering brain tumor images to a healthy template brain, as is required in large population studies.

INTRODUCTION: The need for group based analysis in large scale clinical studies has fueled the need for a tensor-based deformable registration technique applicable to DTI. Existing normalization techniques use image intensity based local information to drive the registration. While these apply well to scalar images with small deformations, they perform sub-optimally in the presence of large deformations, as in the presence of tumor mass effect. Existing DTI registration routines estimates the non-linear elastic warping by minimizing locally optimized scalar (fractional anisotropy) [1] or tensor similarity measures between the template and the subject image followed by the reorientation of the tensors using the rotational component of this registration transformation [2]. We provide a method of correspondence detection which incorporates the white matter context provided by DTI, thereby providing a method of DTI registration as well as enhancing existing spatial normalization techniques applicable to scalar images. This finds widespread application in normalization of data with large deformations, like tumors which displace and destroy white matter fibers, where the context provided by DTI will prove useful in establishing correspondences between the severely deformed anatomy and a healthy template. The method is also useful in having the registration emphasize some regions of the brain over others.

METHODS: We propose an automated correspondence detection framework based on similarity of tensors characterized by a rich and distinctive morphological signature using oriented Gabor filters which provide an anatomical, spatial and orientational context for each tensor [3] and lay the foundation for a warping transformation. We rigidly align the template and subject and identify a set of focal points on the template, based on some criterion such as high fractional anisotropy, which emphasize some parts of the brain. The formulation differs from existing methods in that multiple correspondences are identified for each focal point, depending on the similarity of the morphological signature, thereby creating a fuzzy correspondence for each focal point. With each correspondence, we associate a sparsity parameter which is one, only for the exact correspondence. We model automated correspondence detection as a non-linear constrained optimization problem with bound constraints based on kernelized combination of these focal points for which the morphological signatures have been evaluated. The method will adaptively choose the best correspondence via a warping transformation that seeks to satisfy three criteria : sparsity, which enforces unique correspondence, similarity of attribute vectors and smoothness of the transformation, which will be solved as a constrained non-linear optimization problem in terms of the interpolation parameters and the sparsity parameters as: $\min_{C,W} \lambda(\text{Interpolation Error}) + \mu(\text{Sparsity term}) + \delta(\text{Smoothness term})$

with constraints on the sparsity parameters. While the first term in the objective function balances the error between the exact match and the match obtained from interpolation when the displacement is written as a kernelized combination of the other focal points and its possible correspondences, the sparsity term controls the correspondence detection and the tensor similarity in a sparsity formulation using the sparsity parameters, all of which go to zero on optimization, except the one which is actual correspondence and the smoothness term controls the smoothness of the deformation field produced. We use IPOPT [4], a nonlinear programming solver employing the primal-dual interior point method in conjunction with filter methods that ensure global convergence and inherent high scalability of interior point methods. The solution of the optimization problem will induce sparsity on the candidate matches, thereby identifying exact correspondences for the focal points. In addition, it will also provide the values of the interpolation parameters based on the correspondences so that correspondences at non-focal points can be evaluated, to obtain a dense deformation field. The correspondences so generated can be incorporated into any elastic warping method [1] to obtain complete warping.

RESULTS: The proposed framework has been tested on real human data and in images with tumor which have a large deformation owing to mass effect. Fig. 1(a) shows the template image with some white matter focal points identified in red and green dots. The green dots are picked on fibers which have been affected as a result of tumor growth in Fig 1(b) and the red dots are placed on fibers far away from the mass effect. Fig. 1(b) shows a brain with tumor, which has deflected the callossal tracts and has also caused a thinning in these tracts around the tumor. It can be seen that the correspondences are correctly identified around the tumor, as well as the points on the internal and external capsule chosen far from the mass effect of the tumor. Thus the correspondence detection framework is able to identify point correspondences even in the presence of large mass effect, based on white matter context provided by the morphological signatures.



(a) (b)

Fig. 1: Correspondence detection between (a) atlas without tumor and (b) subject with tumor. Accurate correspondences are obtained n the deflected callossal fibers, as well as in the unaffected fibers of the internal and external capsule

DISCUSSION: We have proposed a method of correspondence detection, which is general and applicable to any modality in which focal points can be described using morphological signatures. This method can be incorporated into a full-fledged DTI registration framework. It can be utilized to emphasize registration in specific areas of the brain over others. This in turn helps the method in handling large deformation changes, as around a tumor with large mass effect. Such images cannot be registered by available intensity based methods, as the deformation of structures is too large. Although the formulation is more computationally intensive than the existing registration algorithms, it is very advantageous due its sheer flexibility in incorporating information from several modalities (in terms of morphological signatures) and its ability in focusing on different parts of the brain and different modalities at different stages of registration.

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