Fully Automated DTI Postprocessing Embedded in Scanner Control Software: Deghosting, Denoising, Smoothing, and Registration to a Standard Atlas

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Introduction: Diffusion Tensor Imaging (DTI) is being widely used for investigating tissue microstructural organization. The DTI data consists of large number of images, particularly when the number of diffusion encoding directions is large. Diffusion-weighted images (DWI) are typically acquired with fast sequences such as echo planar imaging (EPI). EPI images generally exhibit low signal-to-noise ratio (SNR) and are susceptible to ghosting and geometric distortions. Elimination or minimization of these artifacts and generating the DTI metrics requires significant image processing and generally involves significant manual intervention. This is prone to errors and prevents batch processing. The main objective of our studies is to develop an automated pipeline for efficient batch processing of large DTI data.

Materials and Methods: MRI scans were performed on a 7T Bruker Biospec horizontal bore scanner (USR70/30, Bruker, Karlsruhe, Germany). Twenty, one mm thick contiguous coronal brain images were acquired from Sprague-Dawley rats with dual echo RARE sequence. DWI (128 X 128 matrix) were acquired with a four-shot spin-echo EPI sequence. DWI were acquired using a rotationally-invariant icosahedral encoding scheme with 21 alternating polarity encoding directions (1). In addition nine images without diffusion weighting (b0 images) were acquired. The fully automatic data processing was implemented in IDL (ITT, Boulder, CO) and was embedded in a ParaVision (scanner operating system; Bruker, Karlsruhe, Germany) macro. The macro opened a GUI for the scan selection from ParaVision's scan control window. The user selection of the anatomical and the DWI files was the only manual intervention in the whole pipeline. ParaVision commands ('pvcmd') extracted automatically all scan parameters such as matrix size, slice number, resolution, echo time, number of diffusion encodings, and number of repetitions. Extrameningeal tissues were stripped by an in house developed algorithm that detected the negative gradient from brain to bone, starting from the center of the image. In the next step ghosted images were identified by comparing their SNR values with the average SNR of all images. Ghosted images were eliminated and replaced by unghosted selected from the remaining repetitions. Eddy current correction was performed with a module of the FSL package (2). Hahn et al. have reported that low SNR DTI data follow Rician statistics and therefore produce a biased mean, variance, and skewness of the data. To avoid such contamination of data, a nonlinear spatial filter was applied to the averaged data. The stripped b0 images of the DTI data set were registered to the stripped anatomical images using Automatic Image Registration (3). The resulting transformation matrices were used to register the complete DTI data to the anatomical data, which was registered to a standard rat brain MRI atlas (4). The transformation matrices found for the anatomical data set were subsequently used for the DTI data set. The results were saved in Analyze format. The complete processing time for the data was about 100 minutes.

Results:

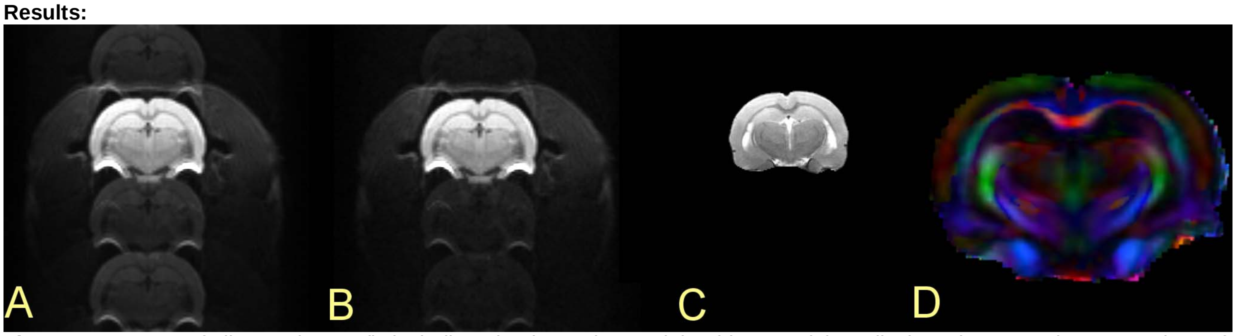

Figure 1: Average of slice 11 (20 total), including nine b0 and 42 weighted images (A). B displays the same data set as in A after deghosting. C displays the corresponding slice of the anatomical RARE data set after automatical stripping. D displays a color coded FA map of a corresponding slice after Eddy Current correction with FSL, Rician noise filtering, and registration to a standard atlas.

Figure 1 displays the result of the presented batch job. A displays an axial image contaminated with strong ghosting. B displays the same data set after fully automatic elimination of ghosted images. Ghosting is clearly suppressed though not completely eliminated. C displays the corresponding fully automatically stripped RARE image. C displays the corresponding color coded RGB - FA map of the corresponding slice. The colors represent following orientations: red = right - left, blue = rostral - caudal, green = ventral - dorsal.

Discussion: In this study, we have implemented a pipeline that is fully integrated with the scanner operating system for automatically processing DWI data in a batch mode. The preprocessing steps included stripping, deghosting and registration of images for reducing eddy current-induced image artifacts. While in the present study this pipeline is implemented on an animal scanner, it can easily be implemented on human scanners. An important feature of this pipeline is that it incorporates many of the publicly available software packages such as FSL, for easy implementation without developing new software. The images were automatically stripped using the in-house developed stripping technique, based on Snake algorithm to facilitate registration of the DTI results to a standard atlas. The last step simplifies the evaluation of data, because standardized masks can be used for the regional analysis of DTI metrics.

References:

1: Madi et al, Magn Reson Med 53: 118-125 (2005)
2: Smith et al, Neuroimage 23: S208-19 (2004)
3: Woods et al, J Comput Assist Tomogr 22:139-165 (1998)
4: Schwarz et al, Neuroimage 32: 538-50 (2006).