Multi-Channel Hybrid-Aided Registration of Multiple Spaces (mCHARM): Diffusion and Structural Image Co-Registration

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Introduction: Diffusion tensor imaging (DTI) has been increasingly used to study white matter structures and connectivity of the human brain. Images in DTI are typically acquired using a single-shot echo planar imaging (EPI) sequence, which offers limited spatial resolution and suffers from image distortion. High-resolution anatomical images (e.g., T1- or T2-weighted images) are often needed to register DTI information onto fine anatomic landmarks, particularly for group analysis. Such co-registration has been challenging not only because of the EPI-related image distortion, but also due to the contrast difference between diffusion and anatomical images. Existing techniques have focused largely on co-registering diffusion images with T2-weighted images [1-4]. In many applications, it is highly desirable to co-register diffusion image to a 3D T1-weighted anatomical image, which can be acquired in a short time with high isotropic spatial resolution. Additionally, 3D T1-weighted images are commonly used as an anatomical reference in fMRI studies. Thus the use of 3D T1-weighted images for co-registration facilitates DTI and fMRI correlations. Herein, we report a novel method to co-reregister diffusion images to T1-weighted images by multi-channel hybrid-aided registration of multiple spaces, which we call mCHARM. This method relies on synthesizing a diffusion multi-channel hybrid (DMCH) image, which mimics the contrast of a T1-weighted image, to aid in the co-registration process. Our results from human volunteers have demonstrated that mCHARM improves the registration accuracy, and produces reliable FA skeleton mask, especially in the U-fibers, for tract-based spatial statistics (TBSS) analysis [5].

Methods: ***Subjects:*** Ten human female volunteers (age = 30.8 ± 10.6 years) were recruited to this study. All subjects underwent anatomical and DTI scans on a 3T GE Signa scanner (GE Health Care, Milwaukee, WI) using an 8-channel head coil. ***Image acquisition*:** T1-weighted anatomical images were acquired using a 3D BRAVO sequence with TR/TE = 13.0/4.0 ms, FA = 25°, FOV = 22.0 cm, matrix size = 512 × 512 × 120, voxel size = 0.43 × 0.43 × 1.5 mm^3, and scan time ~ 3.5 minutes. DTI was performed using a single-shot EPI sequence with TR/TE = 5325/75.2 ms, matrix size = 256 × 256, voxel size = 0.86 × 0.86 mm^2, slice thickness = 5 mm, 27 directions, b = 750 s/mm^2, and scan time ~ 7.5 minutes. Mean diffusivity (MD) and fractional anisotropy (FA) were computed from the DTI image set. ***Synthesis of DMCH Image:*** To synthesize a DMCH image that mimics T1-contrast, the MD image was first converted to its reciprocal (MDinv), which provides a pseudo T1 contrast between CSF and brain parenchyma. Then the MDinv and FA images were thresholded, rescaled (within the range of [0,1]), and linearly combined to produce a DMCH image with contrast similar to that of a T1 image. The DMCH image is mathematically expressed as $DMCH = k * (\alpha * I_{FA} + (1-\alpha) * I_{MDinv})$, where k is a scalar value equal to the intensity at the white matter peak in the T1-weighted histogram, α is a parameter that controls the relative contributions of the MDinv and FA images (initial value $\alpha = 0.5$), and the I_{FA} and I_{MDinv} correspond to the thresholded and normalized image intensities derived from the FA and MDinv images, respectively. An optimal α value was determined using the difference between the gray matter peaks in the DMCH and T1-weighted image as the cost function. The process to produce a DMCH image is illustrated in Fig. 1. ***Group-wise Registration*:** The synthesized DMCH images for each subject were first non-linearly registered to the respective T1-weighted anatomical images using FNIRT in the FSL toolbox. The T1-weighted images were then non-linearly registered to the MNI template brain. The resultant warping files were combined to create a warp from diffusion space to template space. This warp was used to project the DTI based scalar maps (e.g., FA, MD, etc.) into the template space. To evaluate the proposed co-registration method, a comparison was performed to examine the accuracy of the mean FA skeletons overlaid on the MNI 1 mm standard space using three group-wise registration methods: (a) direct inter-subject nonlinear registration and affine registration to standard space [5], (b) subject FA nonlinear registration to standard FA template, and (c) the mCHARM method using T1-weighted images as intermediate transformations to standard space.

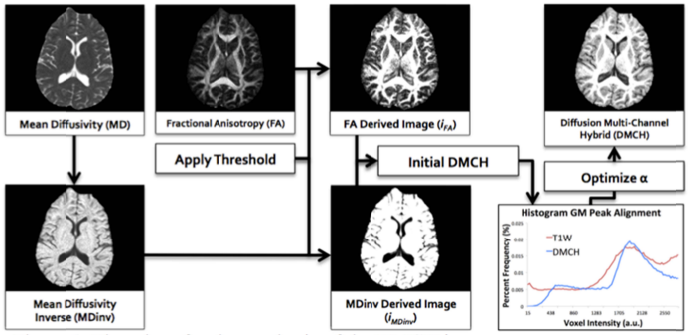

Figure 1. Flowchart for the synthesis of the DMCH image.

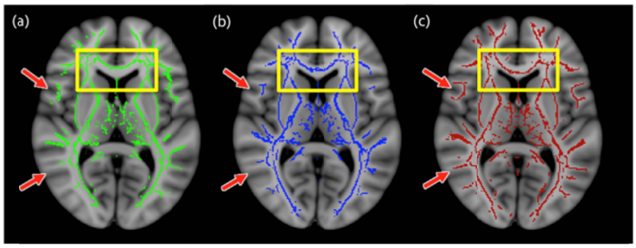

Figure 2. Mean FA skeletons overlaid on the MNI 1mm standard space from the three group-wise registration methods. Yellow boxes indicate skeleton alignment in the anterior corpus callosum, and red arrows indicate alignment of the skeleton in cortical regions, where the proposed mCHARM method (c) showed a clear advantage.

Results: Figure 2 shows the group-wise registration comparison. When the mCHARM method was used (Fig. 2c), a larger and more anatomically accurate FA skeleton mask for TBSS analysis was produced, when compared to the other two conventional TBSS registration techniques (Figs. 2a, b). Specifically, mCHARM removed the spatial mis-registration in the genu areas (yellow boxes in Fig. 2 where the FA skeletons in Figs. 2a and b were shifted away from the genu in the anatomical image) and gave a more extensive FA skeleton mask in the U-fibers that were not shown by other methods (red arrows in Fig. 2).

Conclusions: A novel method, mCHARM, is presented for more accurate and robust co-registration of images from diffusion space to structural space. The matched contrast between the synthesized DMCH acquired and T1-weighted images was responsible for the improved performance of mCHARM over other co-registration techniques. With further refinements, we expect that mCHARM can be used in a number of applications requiring accurate and reliable DTI-anatomy co-registration. The mCHARM concept demonstrated in this study can also be extended and generalized to other applications.

References: [1] Jezzard and Balaban, MRM, 34(1): 65-73; [2] Kybic, Thevenaz et al., IEEE, 19(2): 80-93; [3] Merhof, Soza et al., Med Img Anal, 11(6): 588-603; [4] Wu, Chang et al. Med Img Comp and Comp-Asst Interv, 11: 321-329. [5] Smith, Jenkinson et al., Neuroimage, 31(4): 1487-505.