Motion Correction in Diffusion-Weighted Imaging using Intermediate Pseudo-Trace-Weighted Images

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Target Audience: Sequence programmers and neuroscientists.

Purpose: Diffusion tensor imaging (DTI) [1] and High Angular Resolution Diffusion Imaging (HARDI) [2] are often affected by subject motion, causing errors in the calculated parameter maps and fibre-tracking analyses. This problem is typically addressed by applying retrospective motion correction to the images [3]. The effects of motion can be further reduced by using a prospective correction technique [4] that modifies the acquisition during the scan to maintain a fixed relationship between the scanning geometry and the brain. In one such method [5], the diffusion-weighted (DW) images are used directly to detect the motion using image registration with a fast, least-squares cost function for the real-time calculations. However, this approach can be sensitive to the variation in image contrast that occurs when the direction and magnitude of the applied diffusion-encoding gradient are altered. A second method of prospective correction uses interleaved, low-b-value navigator images for motion detection [6], requiring an increase in scan time of around 10%. The current study explores a new approach to image registration in DW imaging using intermediate trace-weighted images. This technique is insensitive to image contrast variation between images and does not require the acquisition of additional data.

Methods: ***Motion Correction Technique*:** (1) Data are acquired with a set of diffusion gradient vectors, which are ordered to include subsets of three successive vectors that are mutually orthogonal to within a specified tolerance; (2) the geometric mean is calculated from the images corresponding to each set of three vectors to generate a pseudo-trace-weighted (PsTW) image; (3) image registration is used to identify the spatial transformation that maps each PsTW image to a reference image; (4) the transformation for each PsTW image is then used to register the corresponding diffusion-weighted images; (5) the temporal resolution of the motion detection can be improved by sharing one or two vectors between consecutive three-vector subsets; (6) the required set of diffusion gradient vectors $D=\{\underline{d}_1,\underline{d}_2,\underline{d}_3,...,\underline{d}_n\}$ is determined iteratively using the following expression for each three-vector subset: $\max\left(\left|\underline{d}_i^{\,T}\cdot\underline{d}_{(i+1)}\right|,\left|\underline{d}_i^{\,T}\cdot\underline{d}_{(i+2)}\right|,\left|\underline{d}_{(i+1)}^{\,T}\cdot\underline{d}_{(i+2)}\right|\right)<DEV$ with $\|\underline{d}_i\|=1$,
where *DEV* specifies a tolerance for an allowed deviation from the ideal angle of 90° between vectors.
***Data Acquisition and Processing*:** Data were acquired on a 3T MAGNETOM Prisma system (Siemens Healthcare, Erlangen, Germany) from a healthy subject using 64 diffusion directions with interleaved low-b-value images between each of the DW images; voxel size 2mm x 2mm x 2mm, 49 slices, b=2000s/mm^2, TR 4.8s, TE 67ms. One acquisition was performed with one vector shared between the successive sets of three vectors and a second acquisition was performed with two shared vectors. Motion parameters were determined for the following three methods: (1) image registration based on the interleaved low-b-value images; (2) image registration based on the DW images; (3) image registration using intermediate PsTW images. In all cases, image registration was based on a standard least-squares cost function [7].

Results: Fig. 1 shows data from the acquisition with two shared vectors. Each PsTW image in the bottom row was calculated from three consecutive DW images in the top row. The vector sharing allowed an updated PsTW image to be generated each time a new DW image was acquired. The PsTW images have a low contrast variation compared to that seen in the base DW images, making them useful for image registration purposes. Fig. 2 shows that the PsTW images provided motion parameter estimates that were close to those given by the interleaved low-b-value images, whereas the DW images produced estimates with large deviations from the low-b-value results. The small systematic offsets between the PsTW and low-b-value estimates can be attributed to the different time points for the respective reference images.

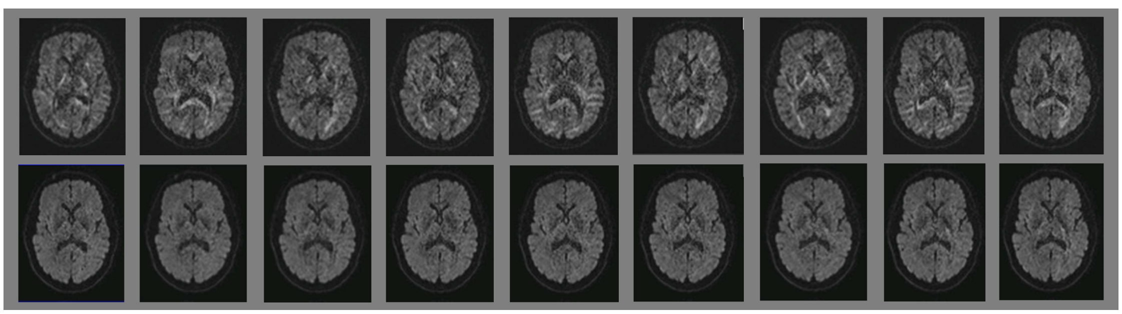

Fig 1: Top row: diffusion-weighted images, shown in order of acquisition. Bottom row: corresponding intermediate pseudo-trace-weighted images

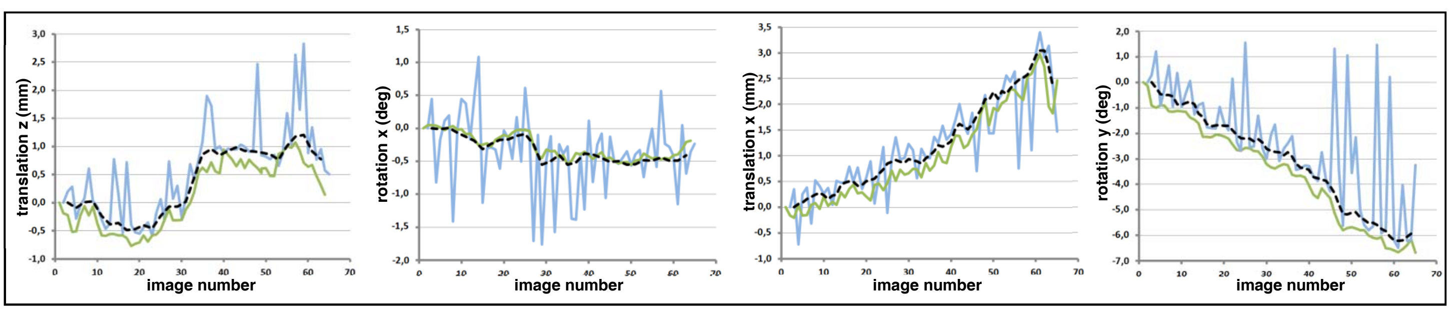

Fig 2: Comparison of motion detection parameters from low-b-value images (▬), DW images (▬) and pseudo-trace-weighted images (▪▪▪▪▪).

Discussion: This preliminary study suggests that motion detection using intermediate PsTW images can provide a robust correction for the typical long-term motion seen during diffusion imaging studies. The method has the advantage that the motion detection is performed using data that is exclusively derived from the diffusion-weighted images and removes the requirement for additional, interleaved, low-b-value images. The technique can be easily adapted to prospective motion correction during the scan because image registration can be performed using a fast algorithm based on a least-squares cost function.

References: [1] Basser et al *Biophys J* 1994:66;259. [2] Tuch *MRM* 2002:48;577. [3] Rhode et al. *MRM* 2004:51;103. [4] Thesen et al. *MRM* 2000:44;457.
[5] Benner et al. *MRM* 2011:66;154. [6] Bhat et al. *ISMRM* 2012;113. [7] Fristen et al. *Hum. Brain Map* 1995:2;165.