Real-time Optical Motion Correction for Diffusion Tensor Imaging

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INTRODUCTION – Due to its prolonged acquisition time, motion correction is essential for diffusion tensor imaging (DTI). Retrospective correction using low resolution 2D navigator images has been suggested [1], but this technique cannot correct for through plane motion. On the other hand, aside from non-linear phase errors, patient motion has two effects in the case of DTI acquisition: Pixel misregistration and change in effective diffusion encoding direction (i.e., the b-matrix). In the case of multi-shot DTI, correction for the change of b-matrix between successive interleaves requires non-linear optimization, which can be time consuming [1] and in case of a limited number of encoding directions, rank-deficient. Real-time prospective optical motion correction systems have been proposed as an alternative to navigator based methods [2,3] and they have the advantage of being able to correct for through plane motion. For DTI even more important, the system follows the position of the subject and thus diffusion tensor encoding directions will remain consistent with the orientation relative to the patients. In this study, we demonstrate the application of our real-time optical motion correction system [4] to perform motion correction for DTI.

MATERIALS and METHODS – The real-time optical motion correction system used in this study consisted of a single camera and a planar marker that contains a checkerboard pattern [4] (Fig 1). The camera was mounted on an 8 channel head coil and the checkerboard marker was attached to the patient's head. Each frame obtained from the camera was processed on an external laptop and the relative pose of the planar marker with respect to the camera frame of reference was calculated using planar homography [5]. Since the marker was attached to the patient's head, the relative positional change of the marker was also an indication of the relative positional change of the patient's head. Then, the updated geometry info that must be applied to the scanner's gradient and RF waveforms were calculated, which was transferred to the RF and gradient hardware controller via rtHAWK protocol in real time [6]. Due to the delay between successive gradient and RF waveform updates and signal dropouts that are caused by motion during diffusion encoding gradients, some readouts were repeated if the detected motion was larger than a certain threshold. In order to eliminate random phase errors that change from show to shot, SENSE reconstruction was employed [7].

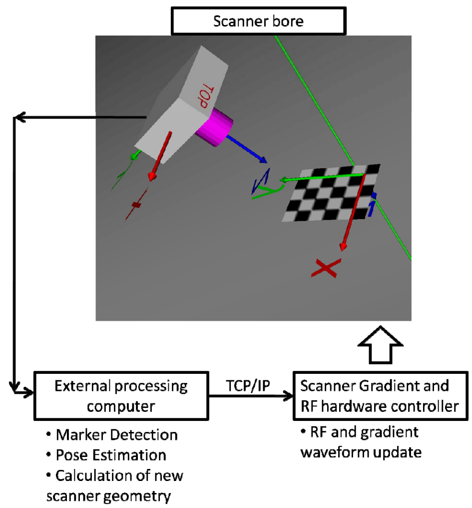

Figure 1. Overview of the real-time optical motion correction system. The images taken by the single camera were processed by a laptop, and the relative change in marker (i.e. subject) pose was determined. Then, the new geometry information was transmitted to the scanner via rtHAWK interface in real-time.

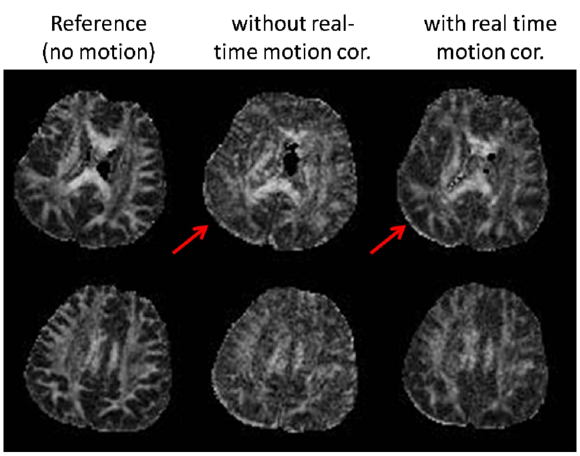

Figure 2. FA maps reconstructed in the case of no subject motion (first column), continuous subject motion (second column) and continuous subject motion with the real-time motion correction system running (third column). The loss in white matter structure in the non-corrected image was significantly recovered using real-time motion correction (red arrow).

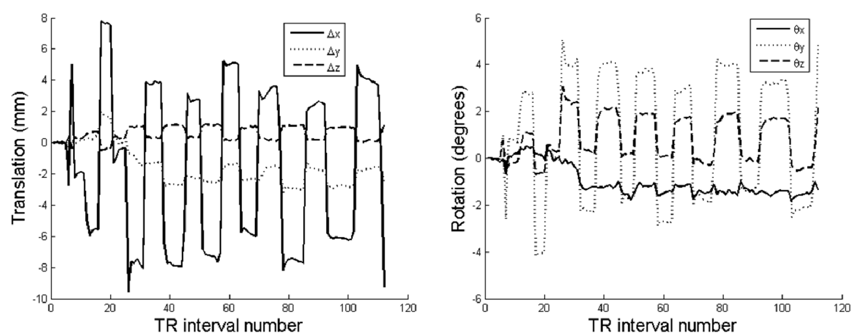

Figure 3. Relative change in the orientation and position of the subject as detected by the real-time system.

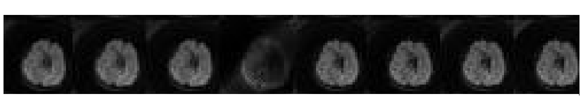

Figure 4. 8 low resolution (32x32) navigator images corresponding to the 8 interleaves of the high resolution (128x128) diffusion weighted image. The navigator corresponding to the 4th interleaf reveals irreversible signal dropouts due to subject motion while the diffusion weighting gradients were applied. The real-time motion correction system proposed here rescans those interleaves that are corrupted by subject motion.

In-vivo experiments were carried out on a 1.5T GE Signa scanner. A spiral in & out readout was used. The spiral in part was used to obtain a low resolution navigator image for phase correction and the spiral out part made up one interleaf of the final high resolution image. Imaging parameters were : TR/TE=3000/55ms, FOV=24cm, 32x32 navigator resolution, 128x128 final image resolution, variable density spiral out readout with a pitch factor α=3.0, 8 interleaves, 7 slices, slice thickness=5mm, b=800 s/mm^2, 7 directions, NEX=2. During the scan, the subject was asked to perform random head rotations. This experiment was repeated with the real-time motion correction system turned off and on. An additional dataset was obtained to be used as a reference where the subject was asked to stay still.

RESULTS – Figure 2 shows the FA maps corresponding to two different slices and Figure 3 shows the motion detected by the real-time system. The FA maps obtained when real-time motion correction was turned off contained motion artifacts and loss of structure, which were recovered by the application of motion correction (Fig 2, red arrow).

DISCUSSION – In this study, we demonstrated the application of rigid head motion correction using a real-time optical monovision system for DTI. The preliminary results show that the proposed system is effective in removing motion related artifacts. It must be noted that, due to the motion sensitivity of diffusion encoding gradients, subject motion can also cause significant signal dropouts in some interleaves, which is usually irreversible (Fig 4). One advantage of our system is that if the detected motion is larger than a certain threshold (1° rotation or 1mm translation), the interleaves that are affected by such signal dropouts are reacquired.

References [1] Aksoy et al, MRM, 59:1138-1150, 2008. [2] Dold et al., Acad. Radiol; 13:1093-1103, 2006 [3] Zaitsev et al., NeuroImage, 31:1038-1050, 2006. [4] Aksoy et al, ISMRM, 2008 [5] Higgins et al, Nature, 293:133–135, 1981 [6] Santos et al, Conf Proc IEEE Eng Med Biol Soc., 2:1048-51,2004 [7] Liu et al, MRM, 54:1412-1422, 2005 **Acknowledgements** This work was supported in part by the NIH (2R01EB002711, 1R01EB008706,1R21EB006860), the Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation and Oak Foundation.