In-vivo Applications of Optical Real-time Motion Correction Using a Monovision System

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INTRODUCTION – Correction of motion artifacts is one of the unsolved but highly relevant topics in MRI. Due to the limitations of imaging-based methods that require additional navigator readouts [1], real-time optical motion correction systems have been proposed to perform rigid head motion correction [2,3]. Recently, an in-bore optical motion correction system has been proposed that uses a single camera and a planar marker to detect and correct for rigid head motion in real time [4]. In this study, we demonstrate the in-vivo applications of this system.

MATERIALS and METHODS – (a) System Description: The real-time optical motion correction system used is shown in Figure 1. A single camera was used for real-time motion correction, which was attached to an 8 channel head coil (Fig. 1 a). This camera took the images of a planar marker which was attached to the patient's head (Fig. 1 b) and sent these images to a laptop where they were processed. The processing steps on the laptop comprised detection of the grid points on the planar marker (Fig. 1 b) and determination of marker pose relative to the MR scanner. The estimated marker pose was sent to the scanner in real time using the real-time scanner control protocol rtHAWK [5]. According to the new geometry information coming from the laptop, the gradients and RF frequency were updated so that the scan plane followed the patient motion. **(b) Experiments**: Two healthy volunteers were scanned on a 1.5T GE Signa scanner using an 8 channel head coil. Two sequences were used: 1) GRE with cartesian line-by-line readout, TR/TE=200/7ms, flip angle=20°, 256x256 resolution, FOV=24cm, slice thickness=5mm, 5 slices. 2) Spin echo with spiral readout, TR/TE=2500/90ms, 256x256 resolution, FOV=24cm, 24 interleaves, slice thickness=5mm, 7 slices. For both sequences, the volunteer was asked to perform two types of voluntary motion: 1) Head rotation around SI axis 2) Nodding motion around RL axis. For each case, the volunteer performed a single motion in the middle of the scan and continuous motion throughout the whole scan. Experiments were carried out with the motion correction system turned on and off.

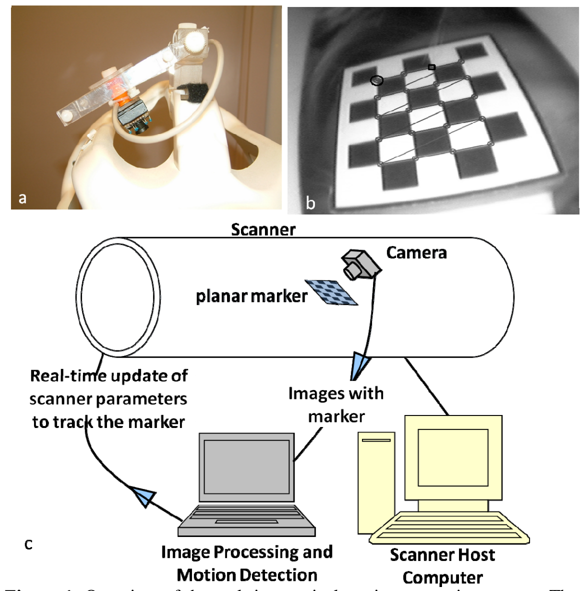

Figure 1. Overview of the real-time optical motion correction system. The images are acquired using a single camera that is mounted on the coil (a). The camera takes images of a planar marker that is mounted on the patient's head (b). These images are processed on a laptop computer and the pose of the marker is estimated. This information is fed back to the scanner in real-time. The gradient waveforms and RF frequency are updated so that the scanner effectively follows the movements of the patient.

RESULTS – Figure 2 shows the results of the experiments for the GRE and SE sequences. As detected by the tracker, the head rotation and nodding was in the range of ±3° and ±4° respectively. The GRE image obtained in the case of single rotation around SI axis showed a double midline (falx cerebri) as shown by the red arrow (Fig. 2 b). This artifact was removed when the real-time motion correction system was turned on (Fig. 2 c). In the case of continuous motion, significant artifacts in the frontal lobe were observed (Fig. 2 d, red arrow). This was expected since the axis of rotation would be passing through the occipital lobe of the brain, which would result in largest displacements in the frontal lobe. When the real-time system was turned on, those artifacts were removed (Fig. 2 e). Similar results were also observed for the T2-weighted spiral images, where the structure loss caused by continuous patient motion (Fig. 2 g) were removed when the real-time motion correction system was turned on (Fig. 2 h). Figures 2 i,j show the results for continuous nodding motion, which is especially challenging to correct for due to the through plane component. However, the real-time system was successful in recovering the brain structure also in this case.

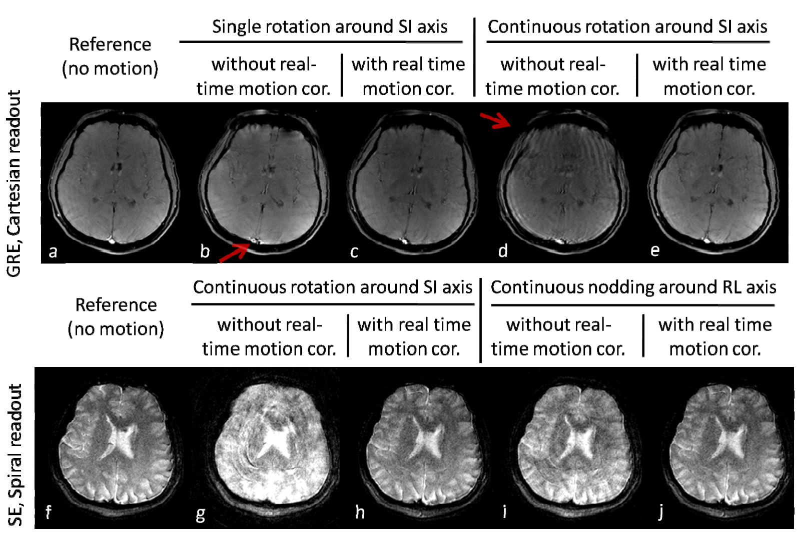

Figure 2. Results of in-vivo experiments using a GRE sequence with cartesian readout and a SE sequence with spiral readout. In all cases, the structure loss caused by patient motion (b,d,g,i) is recovered if the real-time optical motion correction system is turned on (c,e,h,j). The main advantage of this system is that it can correct for through-plane motion which occurs for nodding motion (i,j).

DISCUSSION – In this study, in-vivo applications of an in-bore real-time optical motion correction system that uses a single camera and a planar marker was demonstrated. The experiments were carried out with different k-space trajectories and different types of motion. For all types of motion, the real-time system successfully removed the artifacts resulting from subject motion. An important advantage of using external optical tracking systems for motion correction is that, they have the ability to correct for all 6 degrees of motion. This is especially important if through plane motion is present, which might occur in the case of nodding (Fig 2 i). In general, for MR-image based systems, either a 2D navigator is employed which cannot correct for through plane motion or a 3D navigator is used which has a long readout time and puts restrictions on the imaging sequence. Thus, the ability to correct for through plane motion without occupying the scanner for obtaining navigator information is an important advantage of our system. Currently, the frequency by which the scanner geometry can be updated is 400 ms^{-1}. This frequency depends on the time required for 1) marker detection, 2) marker estimation, 3) transmission of the new geometry info to the scanner over the network and 4) gradient waveform and RF frequency update on the scanner. Most of the delay on our system was caused by transmission over the network. This delay requires some lines (or interleaves) to be reacquired, but helped to stabilize the tracking. By means of faster network protocols, much of the aforementioned latency can be eliminated. However, even with the fastest image processing and network transmission, long TE sequences will still be vulnerable to very fast motion that might occur between the excitation and readout.

References [1] Bammer et al, MRM, 57: 90-102, 2007. [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] Santos et al, Conf Proc IEEE Eng Med Biol Soc., 2:1048-51,2004 **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.