

Prospective Motion Correction for MRI with a Single Retro-Grate Reflector Target and a Single Camera

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Introduction

Even subtle motions may severely degrade MR image quality. Healthy motivated adult subjects are able to maintain their head position to within a few millimetres over 5 to 10 minutes, defining typical settings for structural MR protocols. In clinical settings, i.e. in paediatrics, both imaging time and quality are often significantly constrained. Alternate k-space acquisition strategies or navigator echoes have been proposed to compensate for subject motion^[1,2]. These, however, compromise scan efficiency and/or image quality even in the absence of motion. Recently, correction strategies for rigid body motion have emerged, which rely on external motion data, acquired independently during the MR scanning process^[3]. Optical motion tracking, being a mature technology, presents an interesting option here; however, it is extremely difficult to realise in the tight geometric constraints of the MR scanner. Positioning cameras in the magnet bore has been proposed to ensure a reliable marker visibility^[4,5]. Nonetheless issues with subject preparation and handling prevent the technology from being accepted by a wider range of clinicians and manufacturers. To a greater extent this is due to the use bulky markers and complications in attaching these to the subject while fulfilling stringent tracking accuracy requirements^[6].

Optical motion tracking with a single retro-grate reflector (RGR) target and a single camera has potential of becoming a technology of choice for motion tracking in the constrained space of an MR scanner^[7]. This work aims at adapting the RGR methodology to the geometric constraints given by the magnet and RF coils, integrating the RGR tracking system with an MR scanner and developing easy-to-handle motion correction strategies.

Methods

Prospective motion correction for each k-space line was implemented on a Tim Trio 3T system (Siemens Healthcare, Germany). Prior to each spin system excitation, the gradient rotation matrix and the frequencies and phases of the ADC/RF (de-)modulation carrier signals were updated based on the head position data. The RGR system comprised a GC650 gigabit Ethernet camera (Prosilica, Inc., Burnaby, B.C., Canada) and an illumination system of 8 MC-E LEDs (Cree, Inc., Durham N.C., USA). The camera and flash were operated at 50 fps, transmitting images to a workstation outside the scanner room via a fibre-optic link. Due to the processing time limitations each 5th image was considered for tracking, resulting in the position update rate of 10Hz. Communication with the tracking system was implemented directly on the measurement control unit of the scanner. The camera was positioned behind the scanner to view the subjects face via the mirror (Fig. 1), with a 20mm RGR marker attached to the plastic goggles (Fig. 2). For cross-calibration between the coordinate frames of the RGR camera and the MR scanner, 180° rotations around two orthogonal axes were used^[3]. Since RGR can only detect target tilts of up to 60°, XY and ZY diagonals (in scanner coordinates) were used as axes of rotations.

Human studies were performed in accordance with local IRB regulations. No head fixation pads were used to enable exaggerated motion.

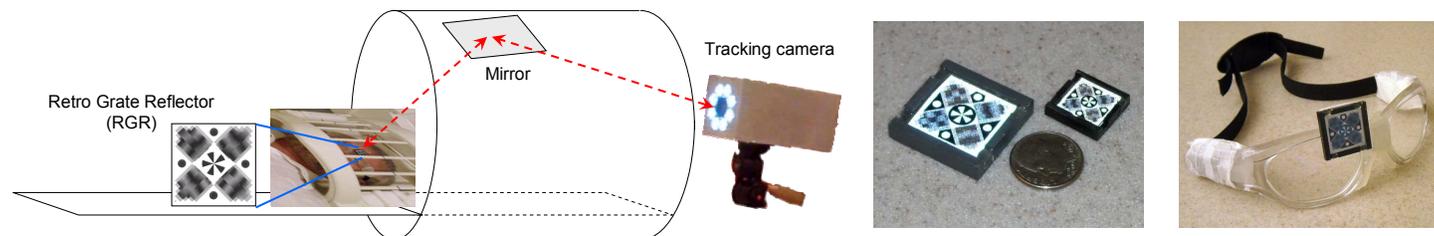


Fig. 1. Setup of the tracking system. Camera enclosure was positioned on a tripod viewing the magnet bore from the far end of the scanner. To account for modern, closed from the top RF coil designs, a mirror was mounted on the inner side of the bore above the head coil, allowing the camera to view subject's face and forehead with a miniature marker fixed to the goggles (Fig. 2).

Fig. 2. Photographs of the 20mm and 12mm RGR targets together with a dime coin (left) and the 20mm target fixed to MR-compatible goggles used for head tracking in volunteer experiments (right).

Results and Discussion

The camera and LED array enclosed into an aluminium RF screen functioned in the scanner room without producing RF interferences. RMS position noise was 10μm RGR X and Y directions and 400μm in Z (along the camera line-of-sight), Euler angle RMS noise was <0.007° on all axes. Tracking accuracy was not affected by the MR imaging, verifying the mirror fixation to be sufficiently rigid. To reduce noise the RGR Z axis was filtered using a 5th order Butterworth filter with $w=0.63$ [rad/sec].

3D gradient echo images acquired with an adaptive motion correction sequence are presented in Fig. 3. For stationary imaging no apparent quality loss is associated with enabling the motion correction (compare Fig. 3a and 3b). During the acquisition of images 3c and 3d the volunteer performed series of continuous head rotations around X and Z axes of the scanner with the amplitude of 5° to 8°. The recorded motion parameters were verified to be comparable in the respective experiments. Prospective correction (Fig. 3d) effectively suppressed motion artefacts. Nevertheless, a loss of image quality is observed, most likely due to: (1) low update rate of the tracking information; (2) high latency of the motion data processing, further increased for the depth direction in camera coordinates through the low-pass filtering; and (3) possibly insufficient rigidity of marker fixation relative to the brain. These issues will be addressed systematically in future studies.

Reported here is the successful implementation of a prospective real time motion correction with RGR tracking. RGR technology with tracking through a mirror has been shown to be compatible with the space constraints of an MR scanner and suitable for head motion correction.

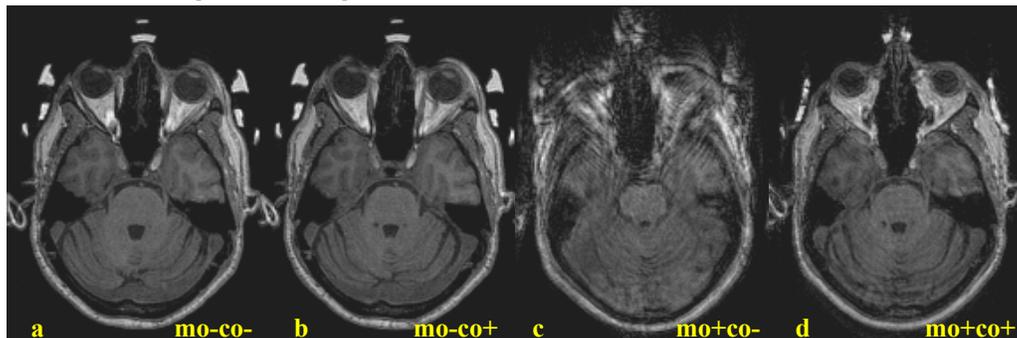


Fig. 3. 3D T1-weighted gradient echo images acquired with and without motion correction: (a) no intended motion, correction deactivated; (b) correction activated without motion; (c) with motion, no correction; (d) corrected images acquired in presence of motion comparable to that of (c). Measurement parameters: resolution 1.25³mm³, TE/TR = 2.1/10 ms, flip angle 15°, with H-F frequency, A-P phase and L-R partition encoding directions. Bright structures close to nose and eyes of the subject are soft pads of the goggles.

References: [1] Pipe JG. MRM 1999; 42:963-969. [2] Welch EB. MRM 2002; 47:32-41. [3] Zaitsev M. Neuroimage 2006; 31:1038-50. [4] Qin L. ISMRM 2008; #1467. [5] Aksoi M. ISMRM2009; #4599. [6] Maclaren JR. MRM 2009. [7] Armstrong B, ISMRM 2009; #4641.

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