Real-time Interactive MRI Using a Passive Magnetic Field Sensor

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Introduction: The ability of a conventional high-field MR scanner to function as a dynamic, flexible real-time interventional imaging tool is appealing as closed-bore systems become more open and accessible. Currently available fast imaging techniques can acquire images with a rapid frame rate, but real-time modification of the image plane requires an active or passive navigational sensor. We have developed a system to enable real-time interactive MRI on closed-bore scanner using a passive magnetic field sensor (PMFS).

Methods: A real-time 2D multi-slice gradient echo pulse sequence was developed on a 3T MR scanner (Tim Trio, Siemens Medical Solutions, Malvern, PA). Real-time control was performed via TCP/IP connection from the pulse sequence to a server program running on the Ethernet network of the MR scanner. The server is a multi-threaded Java program which allows interactive control of the slice position and orientation from a GUI and/or other networked entities via standard network protocols. To enable real-time passive tracking of position within the MR scanner, a PMFS (Endoscout, Robin Medical Inc., Baltimore, MD) was integrated into the system. A gradient echo pulse sequence was modified to include special tracking gradients that enable the identification of the absolute position and orientation of the PMFS. To test the accuracy of the position and orientation given by the PMFS, a motion simulator which provided in-plane translation and rotation was constructed (Figure 1).

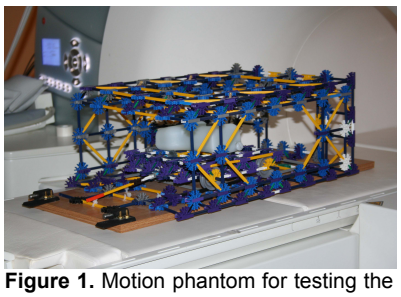

Figure 1. Motion phantom for testing the PMFS.

Results and Discussion: Using a rapid scan with tracking gradients, dynamic images of a phantom were obtained along with real-time measurements of position and orientation from the passive sensor. 2D rigid body registration was performed to estimate motion parameters from the image data and compared to the output of the PMFS as shown in Figure 2. The real-time pulse sequence allowed dynamic positioining of the slice plane and orientation in less than 384 ms using an 128x96 acquisition with TR of 4 ms. Improvements in temporal resolution can be obtained with reduced matrix size and the use of parallel imaging (which may not be optimal for all spatial orientations). To improve overall temporal resolution tracking was performed on a single gradient axis at each TR. Thus a full tracking update required 3 TRs, but represented a time penalty of only 10% versus 30% for position tracking at each TR. Accuracy of the Robin Medical Endoscout for tracking was compared to the image-based registration of a moving object and was found to be to be linear (R^2>0.98) and accurate (position error = 0.83 mm ± 0.70 mm; rotation error = 1.80° ± 1.35°). Figure 3 shows the images from a phantom with and without correction of motion parameters obtained from the PMFS demonstrating that real-time position updated MR images may be attained.

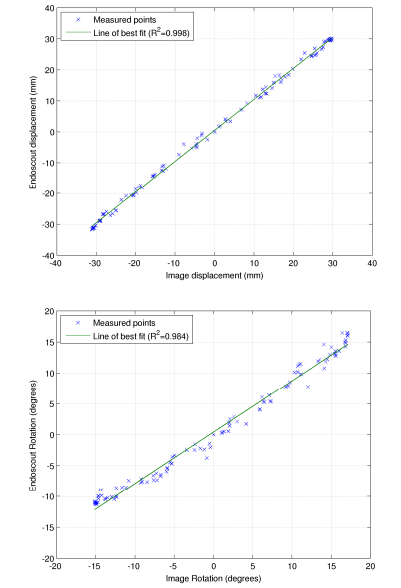

Figure 2. Plots of position (top) and rotation (bottom) obtained from the PMFS (ordinate) and images (abscissa).

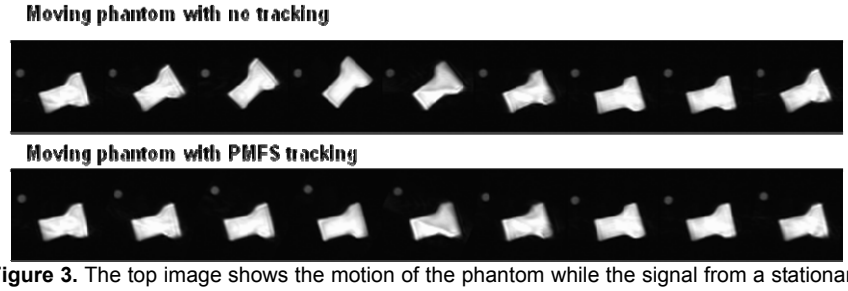

Figure 3. The top image shows the motion of the phantom while the signal from a stationary circular object appears at the same location in the image when no tracking is applied. The bottom image is motion-corrected using parameters obtained from the PMFS.

Conclusion: Real-time Interactive MRI can be performed with passive tracking in closed bore MR systems. Such technology will ease the performance of stereotactic manual or robotic interventions under real-time MRI.