Dynamic Scan Plane Control for Effective MRI-Guided Robotic Intervention

Mahamadou Diakite¹, Steve Roys¹, Yeongjin Kim², Taehoon Shin¹, Mark J Simard³, Jaydev P Desai², and Rao P Gullapalli¹

¹Center for Metabolic Imaging and Therapeutics, Depart. of Diagnostic Radiology and Nuclear Medicine, University of Maryland, School of Medicine, Baltimore, MD, United States, ²Mechanical Engineering, University of Maryland, College Park, MD, United States, ³Neurosurgery, University of Maryland, School of Medicine, Baltimore, MD, United States

Target audience:

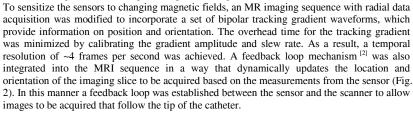
MR scientists and clinicians interested in robot-assisted MR Image-guided neurosurgical interventions.

Purpose

Real-time tracking and navigation is important for effective use of surgical robotic devices with multiple degrees-of-freedom, and especially ones that have multiple end effector functions including cauterization^[1]. The goal of this study is to develop a real-time MRI system for tracking and visualizing the interventional device using a passive magnetic sensor and a closed-loop control algorithm. Its technical feasibility is demonstrated on a phantom.

Methods:

All imaging was performed on a Siemens Tim Trio 3T MRI scanner (Siemens Medical Solutions, Erlangen, Germany). A miniature magnetic field sensor used in this study has two sets of three orthogonal coils (Robin Medical, Inc, Baltimore, USA) that detect magnetic field change and report on the position and orientation of the sensor with a sampling rate of 40 Hz (Fig 1).



The ability to track the sensor and obtain images from the tip of the sensor was tested using a home-built phantom that consisted of a shaped piece of tubing immersed in water (Figure 3a). The tracking sensor was also embedded at the tip of a prototype spring based continuum robot that is actuated by shaped memory alloy (SMA) springs using a tendon-sheath mechanism (Fig. 4.a). Testing was performed to evaluate the ability to track the tip of the robot accurately.

Figure 1: Position tracking sensor

Figure 2: Schematic of the software architecture for real-time tracking

Results:

To characterize the performance of the tracking sensor, we collected 2177 position data points while the sensor was held stationary. The standard deviations were found to be: $\sigma_x = 0.053$ mm, $\sigma_y = 0.066$ mm, and $\sigma_z = 0.028$ mm. The values reported were accurate to within approximately 0.5mm along X- and Y-axes, and 0.18mm along the Z-axis.

Next, simultaneous imaging of the phantom with real-time update of a slice orthogonal to the direction of the sensor's movement was performed. Fig. 3b shows the trajectories of dynamic position of the sensor overlaid on a coronal image of the phantom. The dynamic position data are well correlated with the path through the phantom obtained from the MR images. Fig. 4.b shows the sagittal images of the robot while it is being actuated under MRI guidance. No apparent image artifact has been observed.

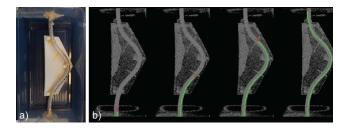


Figure 3: a) Test phantom. b) Real-time tracking of the sensor's positions at different time points.

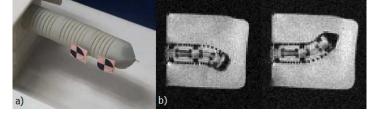


Figure 4: a) Spring-based continuum robot using SMA actuator. b) Sagittal images of the robot while it is actuated in a phantom.

Discussion and Conclusion:

The preliminary results have shown fundamental evidence of real-time monitoring and tracking of a surgical robot under MRI guidance. The feedback algorithm used in the present study had feedback latency of less than 10ms allowing for real-time navigation, and the accuracy of the position reading of the sensor is less than 2mm in any of the orthogonal directions. Since our goal is to track the tip of a robot with multiple degrees of freedom, quantitative evaluation of the tracking ability during complex movement is currently ongoing and the results will be published in our future work. Overall, the experiments demonstrate the feasibility of using passive sensors that can be incorporated into robots with complex dexterity to obtain appropriate image guidance during a surgical procedure.

References: [1] Ho, McMillan, Simard, Gullapalli, Desai. IEEE Trans Robot, 2011, [2] Siemens Image Calculation Environment (ICE) manual (VB17).