Towards MRI-Guided Vascular Intervention with an Electromagnetic Tracking System and 3D Navigation Software

D. F. Kacher[1], S. P. DiMaio[2], E. Samset[3], B. Fetics[4], E. Nevo[4], F. A. Jolesz[1]

[1]Radiology, Brigham and Women's Hospital, Boston, MA, United States, [2]Radiology, Brigham and Women's Hospital, Boston, M, United States, [3]Radiology, Brigham and Women's Hospital, Boston, MA, United Arab Emirates, [4]Robin Medical, Baltimore, MD, United States

MRI-guidance has increasing potential to augment or replace conventional X-ray fluoroscopy in cardiac, peripheral-, and neuro- vascular interventions [1]. Catheter tracking with MRI, using frequency encoding, to localize the NMR signal near small RF coils has been proven feasible [2]. Recently, an electromagnetic (EM) tracking system that utilizes the scanner's gradients has emerged [3]. Coupling such tracking systems with near real-time imaging [4] and 3D visualization of previously acquired data sets [5] yields a powerful tool for the interventionalist. EM tracking has long been used in the cath lab setting for catheter tracking. The advantage of EM tracking over MRI tracking, is with a second transmitter, it is foreseeable to seemlessly track the sensor inside and outside the bore.

Methods:

Tracking System. The EndoScout system (Robin Medical Inc, Baltimore MD USA) employs a set of three orthogonal micro-coils to determine the position and orientation of a sensor. The system is calibrated during installation by mapping the gradient coil currents (Gx, Gy and Gz) to the induced gradient fields (Bx, By and Bz), as detected by the sensor. The micro-coil signals are amplified and digitized with dedicated hardware. The induced voltage in the micro-coils can uniquely localize the sensor with any pulse sequence, without the need to toggle modes between tracking and imaging. Tracking data is acquired in the same frame of reference as the MR scans, obviating a need for registration. Moreover, coil dimensions can be minimized since they do not require an imbedded NMR signal source. The mean dynamic errors reported for this system in open air are 0.25mm (σ = 0.29 mm) and 0.07 mm (σ = 0.35) for motion in the XY and XZ planes, respectively [6].

Experimental Setup: A 15 mm ID section of silicon tubing was positioned inside the head coil in a Signa SP 0.5T open MRI scanner (GE Healthcare Milwaukee, WI). SPGR images of the entire volume were acquired, loaded into our in-house software, 3D Slicer [6], and segmented. A 9.4mm cubic sensor containing three 7.4mm diameter orthogonal coils [Fig 1] was advanced through the water-filled tubing. SPGR images centered at the sensor location were acquired every 5 seconds, using the "realtime" feature of the GE workstation in communication with the scanner (precursor of I-drive), and superimposed on the rendering of the tubing within the 3D Slicer visualization interface [Fig 2]. Scan planes were either orthogonal or parallel to the axis of the sensor. A visual icon representing the sensor can be turned on to indicate the position and orientation of the sensor.

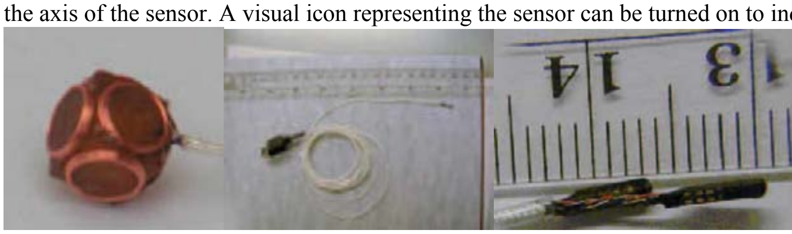

Figure 1: (left) 9.4mm FDA approved cubic sensor used in this experiment. (middle) 1.2 mm diameter catheter based sensor and (right) a close-up of the tip (work in progress).

Results and Discussion: Results depicted in Figure 2 show proof of principle for vascular navigation. The graphical 3D roadmap may be substituted or accompanied by the original higher resolution grey scale image data or segmented structures that cannot be acquired in real-time (e.g., coronary arteries and veins). Moreover, functional data (e.g., strain maps, conduction delay data) can conceivably be superimposed for navigation. The near real-time images would show the effects of the intervention and demonstrate when the pre-procedural data is invalidated due to internal or bulk movement or changes due to the intervention, signalling the need for update. Catheter tip localization is a lingering problem for passive tracking. With frame rates now exceeding 10 fps with the application of parallel imaging methods, the interventionalist cannot visually parse multiple slices of data to locate the catheter tip. Alternative software schemes have been proposed to localize signal sources at the cost of time [7]. Although it is impractical to equip every catheter with sensors, a family of guidewires and catheters with working channels will provide an invaluable tool for vascular intervention. We duly note the 0.5T open scanner is not adequate for vascular interventions due to SNR and temporal resolution limitations. Our future work is planned at 3T. Heating at high field and system accuracy in the presence of dielectric load must be assessed.

Conclusion: Unlike MRI coil tracking, the inexpensive scalability of this EM based system enables tracking of many coils, leaving all MRI system receivers to be used for phased array imaging. The scheme requires no modification to the pulse sequence. Furthermore, the temporal resolution of coil localization combined with imaging is higher than with MRI tracking, since it is not necessary to interrupt the pulse sequence with localization pulses. Most important for the interventionalist, it is feasible to extend this system to track inside and outside the bore.

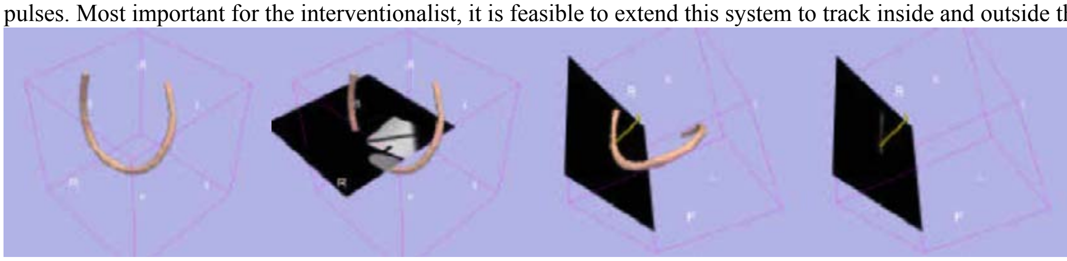

Fig 2: 3D Slicer views as the cube sensor is advanced through water-filled silicon tubing. Near real-time images (5 second acquisition time) are shown superimposed on the previously acquired and segmented 3D road map.

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