Accurate Localization of Active Devices during Interventional MR Imaging

J. Barbot[1], T. Wech[2], S. Shea[2], L. Pan[2], K. Kirchberg[1], K. Vij[3], C. H. Lorenz[2], and S. Patil[2]
[1]Center for Applied Medical Imaging, Siemens Corporate Research, Princeton, NJ, United States, [2]Center for Applied Medical Imaging, Siemens Corporate Research, Baltimore, MD, United States, [3]SurgiVision, Inc., Irvine, CA, United States

Objective: For vascular interventions, precise localization of the catheter is paramount for a successful procedure and patient safety. For interventional MR, this has been pursued by embedding micro-coils into the catheter and then measuring the positions of these coils (and thus the catheter) with one dimensional (1D) projections along all three spatial directions (X, Y and Z). In past work, the final position of each coil was determined by finding the maximum in each projection [1]. However, one potential weakness of such a method is that the maximum observed in each projection is offset from the actual coil position by a few millimeters since the measured MR signal originates outside the coil, not within. In addition, the width of the peak signal is often broadened, which leads to further ambiguity in the detected maximum position. To improve the overall position detection, we proposed to calculate a simulated projection signal (model data) for a given solenoid coil and then to cross-correlate this model data with the incoming projection data and thereby improve the localization of the catheter.

Theory: Using Biot-Savart's law, the B_1 field of a 4 turn solenoid coil aligned along the main magnetic field (B_0) was simulated at a spatial resolution of 0.2 mm for projections along three spatial axes (X, Y and Z). Acquired projections were Fourier transformed and then re-sampled to match the simulated projections resolution. Finally, the cross-correlation between the appropriately selected model and the re-sampled projections was performed. The maximum cross-correlation value was determined to be the coil position.

Methods: All the measurements were done on a 3T scanner (Siemens MAGNETOM Trio, A Tim System, Erlangen, Germany). A custom-built electrophysiology catheter (SurgiVision, Inc., Irvine, CA) with four micro-coils was used to perform the experiments. The tracking sequence (three, 1D projections) was integrated into an interactive real-time sequence such that the tracking sequence was interleaved between image acquisitions. The tracking sequence parameters were: spatial resolution=0.78 mm; Bandwidth/pixel=300 Hz; TR/TE=5.4/2.7 ms; orthogonal dephasing gradient moment=2.5 mT/m/ms.
A dedicated phantom was constructed out of LEGO® Duplo bricks (Bilund, Denmark) which was water-flooded during the experiment. Holes were drilled into the bricks to accommodate the catheter and to reduce the formation of air bubbles inside the construction. A small, acrylic clamp was also constructed to plug the catheter into a LEGO brick, thereby facilitating an easy and accurate movement of the catheter between several defined positions. Data were acquired at 13 equally-spaced positions (10 measurements at each location) along the head-to-foot direction (Z projection) from –124 mm to +114 mm. The dimensions of the phantom and catheter were measured by a Vernier caliper and a fixed-point in scanner coordinates was set using the laser system of the scanner and then confirmed with a high resolution, 3D FLASH sequence. Results were plotted with a Bland-Altman approach [2] and a Student's t-test was performed to determine if significant differences ($p<0.05$) existed between the two methods.

Results: Figure 1 shows the simulated coil and its corresponding projections along X, Y and Z. It can be seen that the maximum signal lies outside of the actual coil position, whereas the dip within the projection corresponds to the center of the coil. Figure 2 illustrates the value of the cross-correlation method, as one can observe the shift in calculated micro-coil position from the maximum peak to the center of the model templates in acquired data. The data from the phantom experiments (Fig. 3) confirmed the superiority of the cross-correlation method as accuracy was sub-millimeter for all points, while accuracy for the maximum method was within 2 mm. These results were found to be significantly different ($p \ll 0.01$) by the Student's t-test.

Conclusion: An improved method to determine catheter position was proposed and was shown to perform better than the existing maximum method during phantom experiments. Sub-millimeter accuracy was achieved for this cross-correlation method and shows much promise for use in cardiovascular interventional procedures.

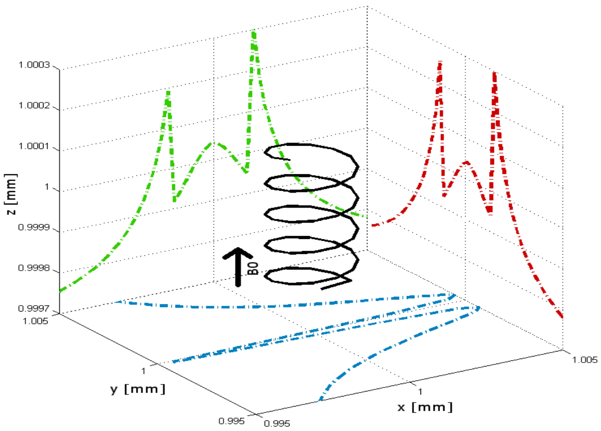

Figure 1 *Coil geometry and its theoretical sensitivity profile projections along the 3 dimensions.*

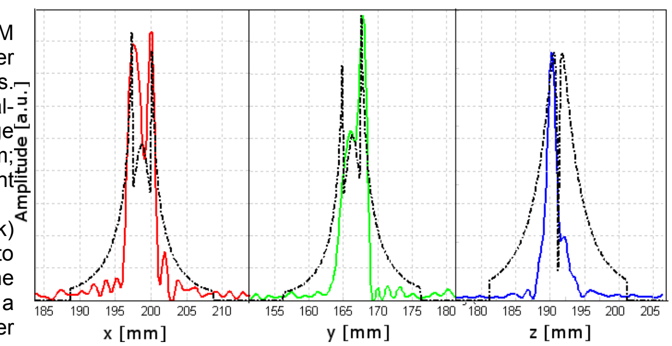

Figure 2 *Signals in the spatial domain along the 3 dimensions (X, Y, and Z) and the corresponding theoretical model position (black, dotted lines) which gave the greatest cross-correlation value.*

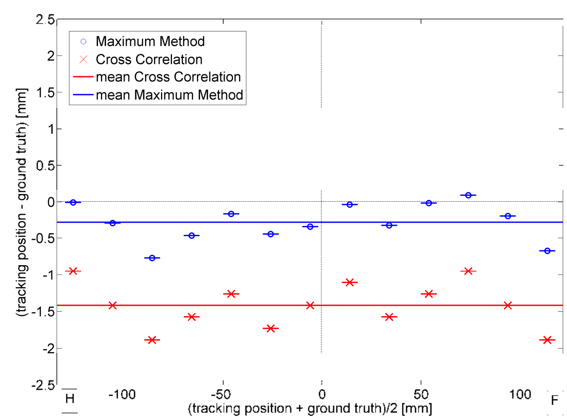

Figure 3 *Bland-Altman plot of the data from the maximum and cross-correlation methods. 0 corresponds to scanner isocenter. The average result from cross-correlation was more accurate than the maximum by greater than 1 mm.*

References:
[1] Dumoulin CL et al. MRM 29(3):411-15, 1993.
[2] Bland JM et al. Lancet 1(8476):307-10, 1986.