Catheter Tracking with Phase Information

K. J. Anderson[1], A. J. Dick[2], G. A. Wright[1]
[1]Medical Biophysics, University of Toronto, Toronto, Ontario, Canada, [2]Cardiology, University of Toronto, Toronto, Ontario, Canada

Introduction:

Many invasive cardiovascular procedures such as traversing total chronic occlusions and myocardial stem cell delivery would benefit from using MR guidance by exploiting MRI's excellent soft tissue contrast (eg. plaque/vessel wall and infarcted tissue imaging). Active catheter tracking has been a subject of research for more than a decade; most studies have focused on projecting the magnitude sensitivity pattern of small micro coils onto three orthogonal axes. The location of the micro coil can then be determined by identifying the peaks of the three projections [1, 2]. There is, however, a weakness with this approach in that the peak of the projections will not necessarily correspond to the location of the center of the micro coil. The magnitude sensitivity profile of the coil also changes with different coil orientations. This makes peak finding and curve fitting difficult. The method is also inheritably susceptible to noise; high-resolution projections are needed; and it is not possible to obtain orientation information from projections alone. In this study, we explore the possibility of using phase patterns in the MR signal around a small circular micro coil to determine its position and orientation to address these various limitations.

Theory and Methods:

The magnetic field sensitivity of a small circular micro coil was modeled using the theory of reciprocity and by numerically solving Maxwell's equations. The simulated field sensitivity around the circular micro coil in the axial plane (perpendicular to the static field pointing along z) traveling through the center of the coil was found to have lines of constant phase extending in the radial direction from its edges (figure 1a). This phase pattern is independent of coil pitch about the x axis (magnet coordinate system) and was found to rotate with coil rotation about the z axis (θ). The phase pattern is also independent of axial slice so if the signal is integrated over the z-direction (magnet coordinate system), the same phase pattern will result. The phase pattern around the micro coil in an oblique slice through the center of the coil and normal to the coil plane was found to have two areas of constant phase (figure 1b). The areas of constant phase were found to have a value of $\pi/2+\theta$ above the coil and a value of $-\pi/2+\theta$ to the sides of the coil. The discontinuity between the two areas extends in the radial direction from the coil edges. The pattern was found to rotate by an angle ϕ with coil rotation by the same angle about the direction normal to the oblique plane. Figures 1a and 1b depict how the phase patterns around a circular micro coil can be used to determine the position and orientation of the coil. First, an axial projection image (no slice selection gradient) of the coil's sensitivity pattern is created (figure 1a). The position of the coil in the axial plane can be determined by noting that lines of constant phase extend in the radial direction from the coil's edges and the roll angle θ of the coil can be determined by noting the angle at which the phase pattern is rotated with respect to a reference axial phase pattern. An oblique slice is then prescribed through the center of the coil and perpendicular to the plane in which the coil lies (figure 1b). The coil can then be located in a third orthogonal direction by noting that the discontinuities in the oblique phase pattern extend radially from the coil's edges. The pitch angle ϕ can be determined by calculating the angle at which oblique phase pattern is rotated with respect to a reference phase pattern. The phase in the two regions can then be sampled to verify the calculation of θ. θ and ϕ form two Euler angles and the coil's normal can be determined. To test this theory, a small micro coil with radius 4mm was built and embedded in an agar phantom; phase patterns were obtained using a 1.5T GE Signa CV/I scanner with a SPGR pulse sequence (FOV=8cm, TE=10ms, TR=33ms, 256x256, flip angle=30). A second image was obtained for each plane at a delay of 5 ms so that the susceptibility map could be determined and corrected for. The phase patterns obtained from the micro coil can be seen in figures 2a and 2b.

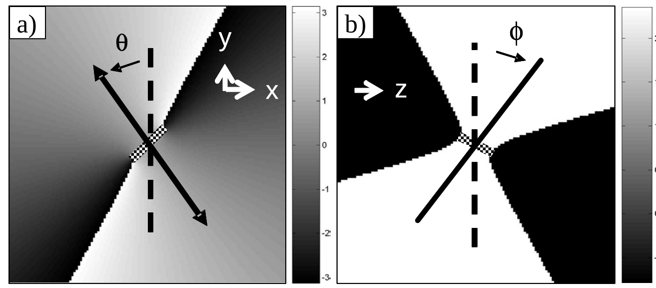

Figure 1. Simulated axial (a) and oblique (b) phase images around a micro coil of radius 5.5 mm (FOV 8cm).

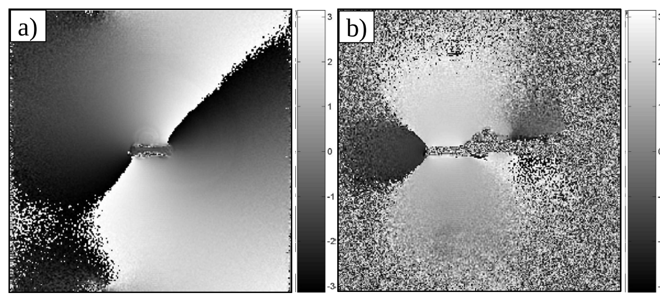

Figure 2. Actual axial (a) and oblique (b) phase images around a micro coil with radius 5.5mm (FOV 8cm).

Results, Discussion and Conclusion:

In the axial phase pattern obtained without slice selection (figure 2a) radial lines of constant phase extending from the coil's edges can clearly be seen and the phase pattern does resemble the simulations. The phase pattern in the oblique slice does consist of two regions of constant phase and the phase values in these regions do agree with theory (figure 2b).The blocking network was found to introduce unwanted phase patterns. An adequately shielded blocking network must be built that does not introduce unexpected phase patterns if reasonable phase patterns are to be obtained in most coil orientations.

There are several advantages to using the phase sensitivity instead of the magnitude sensitivity for locating small micro coils. Unlike the magnitude sensitivity, phase patterns are unique to a coil's position and orientation and information about both can be obtained by using the method described above. There is also potential for a more accurate and robust localization algorithm since phase patterns are more spatially varying than magnitude projections and yield clear position and orientation information over a circular area of at least 4 coil diameters. Because global two-dimensional correlations can be used to identify the phase patterns, low-resolution scans may be sufficient for locating the coil. As a result, localization using phase may prove particularly useful in real-time applications. For example, if the coil were to be located within a 2cm volume, a single spiral acquisition at suficient resolution (2cm FOV, 1.05 mm resolution, 31.25 kHz bandwidth, 1024 readout) could be performed on a 1.5T GE Signa CV/I system in 16 ms. Even with extra acquisitions to correct for inhomogeneities, catheter position and orientation could be determined in under 100ms.

The method presented has significant potential for being able to determine the position and orientation of a catheter tip robustly and accurately.

References:

[1]Dumoulin C.L. et al. MRM 29:411-415, 1993. [2]Elgort, D.R. et al. JMRI 18:621-626., 2003.