Active MR tracking using micro coils for both transmit and receive

B. Daniels[1,2], Y. Li[1], R. Giaquinto[1], W. Loew[1], R. Pratt[1], and C. Dumoulin[1]
[1]Imaging Research Center, Cincinnati Children's Hospital Medical Center, Cincinnati, Ohio, United States, [2]Bioengineering, University of Cincinnati, Cincinnati, Ohio, United States

Introduction Active MR tracking of devices employs small receive coils with restricted spatial sensitivity [1]. When the Signal-to-Noise Ratio (SNR) of the detected MR signals is high, the accuracy and precision of tracking are well suited to a wide variety of applications. Non-idealities of the tracking device and the MR tracking environment, however, can restrict MR tracking rate and robustness.

Some of the challenges to signal quality in MR tracking arise from the construction of the device. For example, some or all of the MR signals detected by MR tracking coils in catheters arise from regions outside of each solenoid coil. This results in less efficient detection (i.e. lower SNR) and a complicated phase sensitivity profile. The sensitivity profile of a small solenoid coil is further complicated by: a) the orientation of the coil within the static magnetic field of the MR system, b) magnetic susceptibility differences between the catheter and its surroundings, and c) the orientation of the coil with respect to the applied magnetic field gradients that are used in MR tracking pulse sequences. Unfortunately, no *a-priori* knowledge of the orientation of the coil can be used if a fully robust device tracking system is desired [2].

Robust MR tracking under low SNR conditions is also made difficult by coupling of unwanted MR signals into the MR tracking coil. This coupling is usually inconsequential in high SNR cases, but can result in large rolling baseline artifacts that make identification of the small tracking peaks difficult.

We have developed a system which reduces these errors by using the tracking coils for both transmitting <u>and</u> receiving the RF signal. With this approach, only spins near the tracking coils are excited, and the potential for coupling of MR signals from other locations is greatly reduced. In addition, phase cancelation of the MR signal caused by the dipole sensitivity profile of the small coil is virtually eliminated since the same coil now performs both excitation and reception. These improvements in line shape allow for a more accurate determination of the location of each tracking coil.

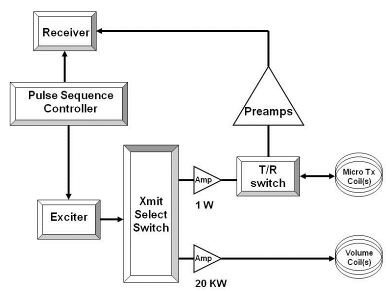

Figure 1: *System diagram*

Figure 2: *5 French catheter with three integrated tracking coils.*

Methods The systems diagram for the micro T/R circuit is shown in Figure 1. In this system the pulse sequence hardware controls a custom-built RF switch which allows the user to select either the micro coil(s) or body coil for excitation. A passive T/R switch employing a ¼ λ filter is used to protect the micro coil's preamplifier.

A 90 cm 5 French catheter (Figure 2, Cordis Corp.) containing three tracking coils was suspended in a solution of copper sulfate ($CuSO_4$). The coils were connected to the preamplifiers via the passive T/R switch. Tracking was performed using a gradient-echo based pulse sequence for MR tracking [1] at a rate of 22 frames per second. Tracking peaks were recorded for body coil transmit/micro coil receive and micro coil transmit/micro coil receive. Micro coil excitation was performed with less than 1W.

The magnetic field profile of a solenoid coil model scaled to the same size as the catheter tracking coil used in the experiments was modeled with electromagnetic simulation software (MWS, CST of America, Inc., Framingham, MA). We also calculated the corresponding B1 field from the simulated field assuming the tracking coil is aligned with respect to B0 field and gradients as shown in Figure 4A. This calculated B1 field was then used to predict the received MR signals.

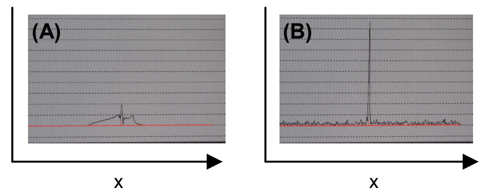

Figure 3: *MR tracking signals from micro coils acquired with an X magnetic field gradient. (A) Body coil transmit, (B) Micro coil transmit and receive.*

Results and Discussion The experimental and simulation results agreed well and are presented in Figures 3 & 4. These figures highlight the difference between body coil transmit and micro coil transmit.

Exciting with the body coil results in a complex peak with a complicated phase sensitivity profile in at least one direction for an arbitrarily oriented micro coil. This complex peak can be attributed to two phenomena: A) the coupling of unwanted MR signals into the MR tracking coil causing large rolling baseline artifacts, and B) the complex phase sensitivity profile of a small dipole detecting uniformly excited spins in its immediate neighborhood. Micro coil transmit overcomes both of these problems by: A) exciting spins only in the vicinity of the micro coil and thus eliminating signals that could be coupled to the micro coil from other locations, and B) employing the same phase sensitivity profile for spin excitation and reception. The net result is that with micro coil tracking the shape of the MR tracking signal is much closer to ideal as evidenced in Figure 3B (e.g. approximately Gaussian). This makes peak detection more robust with a commensurate improvement in tracking accuracy. An additional benefit is the minimization of RF-induced catheter heating [3].

The experimental results were well-predicted with the electromagnetic simulation. As shown in Figures 4B and 4C, we estimated the received MR signals using the B1 field inside and around the tracking coil. When a body coil is used for transmitting, the spins are uniformly excited, but the sensitivity profile of the small solenoid coil results in a received signal with complex peaks (arising from phase cancelation) that may increase difficulty in position determination. When the tracking coil is used for both transmitting and receiving, as expected, the received MR signal is closer to ideal because the phase of the excitation field matches that of the receive field.

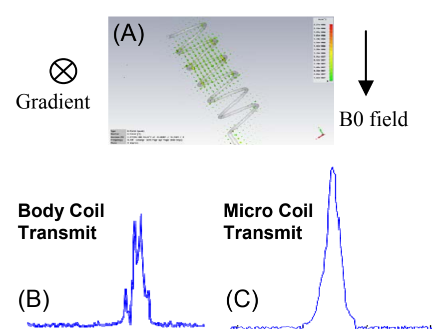

Figure 4: *Simulation results. (A) the solenoid model, (B) predicted MR signal using body coil excitation, and (C) predicted MR signal from micro coil excitation.*

Conclusions Using micro coils for both excitation and reception during MR tracking provides significant improvements in the MR signal line shape and hence the accuracy of tracking. This improvement increases the peak height (and thus SNR) and can, in principle, permit tracking of even smaller coils.

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References

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