Phase-Field Dithering for Active Catheter Tracking

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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.

One potential clinical application that poses severe technical challenges to the development of robust MR tracking is the manipulation of electrophysiology (EP) catheters in the heart. Some of these challenges arise from the construction of the catheter. For example, EP tracking catheters by necessity have a complicated construction with no room for a substantial lumen. Consequently, the MR signals detected by integrated MR tracking coils 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 detection 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.

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 strategy to increase the robustness of active MR tracking in low SNR conditions. This new method employs dephasing magnetic field gradient pulses that are applied in a direction that is orthogonal to the frequency-encoding gradient pulses used during MR tracking. The operator is allowed to select the strength of the dephasing gradient and a cycle length over which the orthogonal dephasing gradient pulse is rotated. This approach has been tested for several different multiplexing schemes including Hadamard and zero-phase reference approaches.

Materials and Methods

Figure 1 shows a simplified diagram of the MR tracking pulse sequence. The excitation rf pulse is non-selective (or weakly spatially selective). The MR signal is detected in the presence of an applied frequency-encoding magnetic field gradient. In prior implementations of this pulse sequence, the dephasing gradient pulse is applied in the opposite direction from the frequency-encoding pulse. This pulse shifts the MR echo within the data acquisition window and is analogous to dephasing gradient pulses used in conventional MR imaging. Unlike conventional imaging, however, there is no phase-encoding gradient pulse.

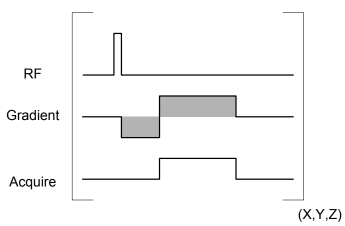

Figure 1.

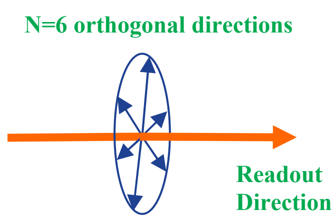

Figure 2.

With the phase-field dithering approach, the dephasing gradient pulse is given two vector components. The first is the conventional dephasing component used previously. The second component is an orthogonal component whose amplitude is selected by the user. Since there are an infinite number of directions in which to apply this orthogonal gradient pulse, an arbitrary choice is made. A user selected cycle length is then used to determine the number of orthogonal directions to apply the gradient. Figure 2 illustrates how a cycle length of N=6 is used to apply six orthogonal dephasing gradients. The orthogonal gradient is rotated $2\pi/N$ for sequential tracking point acquisition.

The MR tracking coordinates that are collected are modulated over the cycle length. The orthogonal dephasing gradient can either improve or hurt the MR tracking signal in an unpredictable fashion. Consequently, MR tracking data acquired over the entire cycle length is combined to extract out the best tracking information. We have implemented several algorithms to do this including: maximum point, averaging, and maximum vector methods. Improvement in tracking robustness has been observed in both phantoms and in the left atria of living porcine models.

Results and Discussion

The application of an orthogonal dephasing gradient in MR tracking has two effects on the detected MR signal. First, it serves to dephase signals over large regions, which in turn reduces the size of MR signals that are coupled into the tracking coil (thereby eliminating rolling baselines). Second, it changes the distribution of MR signal phase in the region around the MR tracking coil. Since there is no *a-priori* knowledge about the phase distribution over the field-of-view, the dephasing gradient can hurt, help or have no effect on the detected signal. For example, for a small solenoid coil arbitrarily aligned with respect to B0, a dephasing gradient pulse applied in a selected direction may reduce phase dispersion for data acquired in the presence of an X magnetic field gradient (hence increasing SNR), while dephasing signals for the Y acquisition (and hence decreasing SNR). Over the course of a cycle, however, there is a likelihood that some of the dephasing gradient pulses will be aligned to help increase the MR signal by compensating for local phase variations. Thus, when data acquired over the cycle is combined (e.g. with a maximum point algorithm) the net signal is likely to have an improved peak that will permit more robust MR tracking.

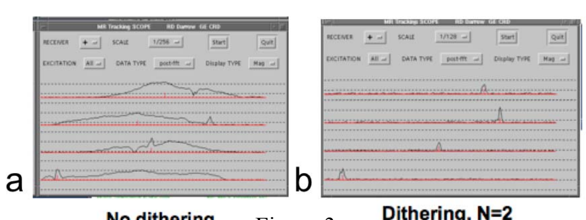

Figure 3.

Figure 3 shows the effect of phase-field dithering on one coil of a lumenless MR EP catheter in a pig. Figure 3a shows the four tracking signals in a Hadamard multiplexing scheme with severe rolling baselines due to coupling with the body coil. The quality of these signals was too poor to allow any device tracking. Figure 3b shows that with just N=2 phase-field dithering robust tracking signals are obtained.

One consequence of selecting a cycle length greater than one is that the tracking rate is reduced by a factor of N for a given tracking TR. In practice, however, this tradeoff has proven to be acceptable because without the use of phase-field dithering the only effective strategy to increase SNR is to increase the tracking TR to allow more time for relaxation of longitudinal spin magnetization (also resulting in a reduced tracking rate). Phase-field dithering has proven to be a valuable strategy for increasing MR tracking robustness under low SNR conditions and permits active MR tracking of devices having sub-optimal MR performance.

References

1) Dumoulin CL, Souza SP, Darrow R.D Magn Reson Med 9:411-15 (1993).