Accurate catheter tip tracking for MR-Guided EP procedures using realtime active detuning

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Introduction

MR-guided electrophysiological procedures require precise localization of catheters. The catheter position is tracked accurately to guide the catheters to the target regions for diagnostic (voltage mapping) or therapeutic (ablation) studies. These studies use active-tracking catheters in one of two modes: imaging the body of the catheter [1] or tracking the tip of the catheter using microcoils [2]. The microcoil approach is advantageous due to its faster rate of tracking, tracking multiple coils along the body of the catheter, and choice of guidance using prior high-resolution roadmaps or realtime imaging. However, due to size considerations, the designers may choose to forgo tuning and matching capacitors. This leads to coupling of the microcoils with the imaging receiver coil (body or surface coils) resulting in a large sensitivity volume for the microcoils. This coupling is particularly evident in cases of low SNR, poorly shielded cables or unbalanced microcoils. A solution using phase dithering was proposed in [3] using gradients orthogonal to the frequency encode direction. However it requires multiple TRs to achieve accurate tracking. We propose an alternate method for decoupling, an operator controlled enabling or disabling of the imaging coil in realtime, which allows us to track accurately at high frame rates while also facilitating realtime imaging using surface coils.

Methods

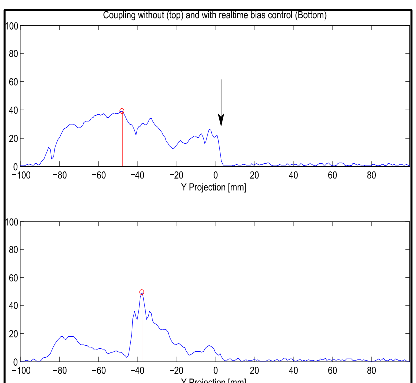
Active detuning using PIN diodes is a well-known technique to isolate transmit and receive coils [4,5]. This was developed to isolate the receive electronics from transmit and to reduce image artifacts due to induction coupling. Active detuning is implemented in almost all commercially available imaging coils. We modified our custom realtime platform (RUFOUS) [7] to incorporate detuning. The realtime pulse-sequence was modified to incorporate a detuning command to communicate the forward bias or reverse bias controls to firmware on a GE 1.5T Signa system. Additional controls were added to the user-interface so that the user can select tracking (forward bias supplied to PIN diodes on surface coil and so turned "off") or realtime imaging (reverse bias "on" state) or both.

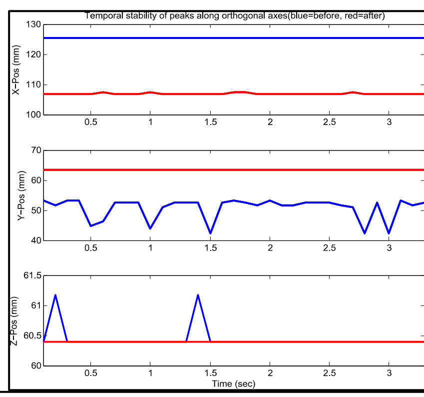
Experiments were done using a single channel 5-inch receive coil (GE Healthcare) and an 8-French MR-guided ablation catheter with microcoils along the tip (Vision™ MR conditional catheters, Imricor Medical Systems, Minnesota, USA). The catheter was placed in a Gd-doped bath and the 5-inch coil was placed close to it. Catheter tracking using projections along orthogonal directions was done[6]. Imaging was then performed using the 5-inch coil. Tracking and imaging were then interleaved with operator controlled and automatic switching.

Results

We looked at the accuracy of tracking and its temporal stability. The catheter position was calculated from projections using simple peak detection. Tracking position without bias-control was off by several centimetres, while with bias-control tracking was accurate to within 2mm [Figure-1]. The temporal stability of the peaks is shown in Figure-2. It shows cases where the position was consistently wrong (X-Projection, Fig-2 Top) and temporally unstable (Y-Projection, Fig-2 middle). With bias-control correction the peak was accurately determined and is temporally very stable within 1mm. More sophisticated peak finding algorithms should give better results for spatial-temporal accuracy.

We then looked at the time for switching, to see if this adversely affects interleaved realtime imaging and tracking. Since the PIN diode based blocking circuits are designed to be fast, it was much faster than our lowest tracking/imaging TR of 25ms. We are currently applying this in our pig experiments and a preliminary result is shown in Figure-3, displaying the catheter coils overlaid on the prior acquired stack of SSFP images.





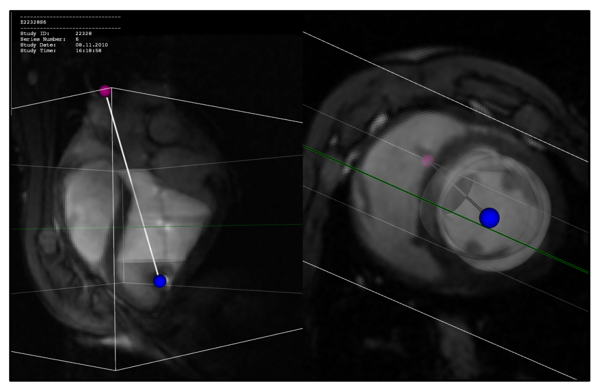


Fig-1 (Left): It shows a projection along Y-direction (up-down) without and with realtime bias control. The peaks are highlighted with a red stem. Without bias control (**Top**), the entire water bath thickness is clearly visible and the arrow points to the edge of it. The catheter position is also incorrect. With bias control (**Bottom**), the sensitivity volume is greatly reduced, position is accurately determined but we can still see local susceptibility variations.
Fig-2 (Middle): Temporal stability of the peaks of orthogonal projections (X,Y and Z). The plots show the variation of the peak position with time. With realtime bias control (red) peaks are much more stable (within 1 mm) than without bias control (blue).
Fig-3 (Right): An image from a pig experiment showing catheter microcoils (blue and red dots) overlaid on SSFP images.

Discussion

We have shown a simple, fast and flexible method (realtime bias control) for decoupling catheter microcoils and the surface coil(s). Our technique does not require the multiple TRs per measurement used in phase dithering approaches; however the local susceptibility variations are still an issue. Phase dithering can also be implemented with realtime bias-control since these approaches are complementary. It also enables us to do interleaved realtime imaging and catheter tracking with a fast switching rate. Our approach can also be used to switch between active and passive tracking in realtime if the coil electronics support it.

References

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