Interactive Real Time Inductively Coupled Catheter Coil Tracking Using a Transmit Array System

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INTRODUCTION: MRI is an alternative modality to X-ray in guidance of some vascular procedures since it provides better soft tissue contrast without any ionizing radiation. A favorite approach is to use active catheters - intravascular devices with embedded RF coils connected to MR scanners - to perform procedures. For active catheters, important real-time interactive control features have been introduced by Guttman *et. al*, such as adaptive projection modes [1]. Device handling of active catheters is difficult and cable connections to MR scanner impose RF safety problems. Quick *et. al.* designed inductively coupled radio frequency (ICRF) coils that require no connection to MR scanner, which reduce the difficulties of active catheters aforementioned; although visualization of ICRF catheters is good only under low flip angles in forward B1 polarization scheme [2]. Celik *et. al.* proposed reverse polarized scheme both in RF transmit and data acquisition chains to tackle the problem of visualization of ICRF catheters for high flip angle cases [3]. However, there is no real-time interactive control software specifically developed for polarization modes to enable better real-time tracking of ICRF coils. In this study, using a transmit array system, we developed and implemented a real-time interactive control on B1 polarization to track ICRF coil. Our interactive system also enables user to set and change the direction of linear polarization, so that ICRF coil can be uncoupled as well as switching between forward and reverse polarization in real-time.

THEORY: Anatomic spins are only sensitive to the forward polarization of B1. On the other hand, the polarization of ICRF coil is linear, thus the ICRF coil can also couple to reverse polarized component of B1 and creates a linearly polarized induced field, strong in the vicinity of the catheter. Since linearly polarized field can be decomposed into forward and reverse polarized components, half strength of the induced field causes spins to be excited and there will be MR signal in the vicinity of the ICRF coil. Therefore, using reverse and forward polarization modes, one can either switch between images with catheter signal only or an image that includes both catheter and anatomical signal. Moreover, setting B1 field linearly polarized, desired part of ICRF coil can be uncoupled by setting the direction of linear polarization of B1 field parallel to the catheter.

Figure 1: Snapshot of client software (Interactive RF Polarization Control – IRPC), which controls the RF attributes of selected channels

METHODS: In order to change the B1 polarization, we used two RF channels of the 8-channel transmit array system on a 3T scanner (MAGNETOM Trio a Tim System, Siemens Healthcare, Erlangen, Germany), connected to the two ports of the body coil. Changing the phase and amplitude of each of the RF channel, the B1 polarization inside the magnet's bore can be altered. Each RF channel is controlled by a corresponding computer, called MPCU. Each MPCU's operating system is VWORKS, a real-time software platform. Since each MPCU is running sequence instructions applied on them, changing the phase and amplitude values of two RF channels in real-time can be achieved by additional software that can connect and send commands to the sequence code running on MPCUs during scan. Using C socket programming compatible with VWORKS platform, a server code is implemented and inserted into a work-in-progress tip tracking pulse sequence (BEAT_IRTTT, Siemens Corporate Research, USA) [4,5]. The task of this server is to accept the connection request by the external client software, which we call *Interactive RF Polarization Control* (IRPC) (Figure 1). The server embedded in sequence manipulates the RF phase and amplitude values according to the received data from IRPC. The server code is designed in such a way that each MPCU will bind to its own IP address and change its RF attributes upon request by IRPC in real-time. On the other hand, IRPC (the client software) runs on an external computer that has network connections to the MPCUs. The GUI part of the client software is designed using GUIDE tool of MATLAB (The MathWorks Inc., Natick, MA). Networking part of the client software is implemented on C platform. The client software sends connection requests to the desired MPCUs and allows user to change RF phase and amplitude values of each MPCUs via sliders. Interactively changing phase and amplitude values of channels, user sets reverse polarization when real-time acquired images have catheter signal only. Once reverse-polarization mode is achieved, changing to linear and forward polarization is done by checking the forward and linear *check-boxes*, respectively. Furthermore, once linear polarization is set, the software enables user to uncouple ICRF by letting user sweep the bottom slider, which changes the amplitudes of RF channels in that the direction of linear polarization is changed accordingly.

EXPERIMENTS AND RESULTS: An ICRF coil (10 cm in length) was implemented (tuned to 123 MHz) in a 2.5 mm diameter catheter (Figure 2) and tested in 2 g/liter copper sulfate solution. Fast GRE mode is selected for the modified sequence. Among all the real-time acquired images, below are the selected three coronal images of the catheter phantom for the following acquisition chains: reverse-polarized, forward polarized and linearly polarized with uncoupled case (Figure 3). The sequence parameters for the conducted experiment were as follows: Fast GRE, FOV: 290x160 mm^2, bandwith: 500 Hz/Px, phase resolution 50%, flip angle: 12 degrees, 5 images/sec.

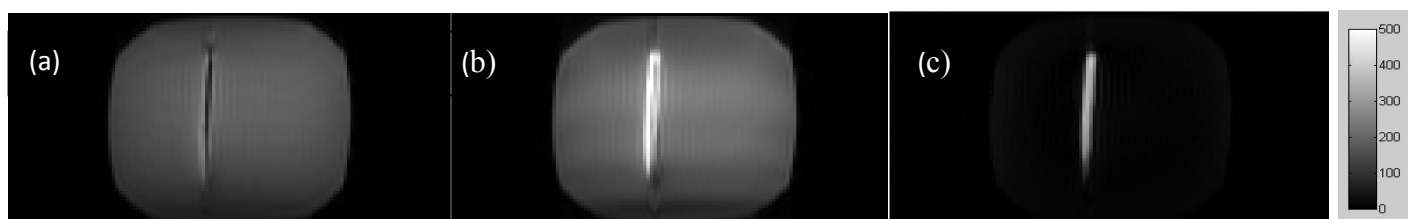Figure 2: Inductively Coupled Catheter Coil (tuned to 123 MHz)

Figure 3: Selected three coronal images of the catheter phantom. a) Linear polarization mode with uncoupled case, b) forward polarization mode, c) reverse polarization mode. All three images are shown within the same gray-scale range

CONCLUSION: ICRF catheters are easier to be handled as they have no cable connections to the MR scanner. Therefore, it is important to have real-time interactive control mechanism to track them, and we have shown the possibility of real-time interactive ICRF catheter tracking, based on B1 polarization on the transmit array system. In our interactive control scheme, the user has to sweep the amplitude and phase sliders of each channel until real-time acquired images have strong catheter signals with most possible suppressed anatomic signal at the same time. Nevertheless, our system enables user to switch between the reverse, forward and linear polarization modes very fast (synchronized with image acquisition rate), once reverse polarization is obtained. Moreover, with linear polarization direction sweep, we have achieved interactive real-time uncoupling of ICRF catheter.

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