A Comparison of MR-tracking Methods in the Presence of Severe Metallic Artifacts and Physiological Motion

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Introduction: In MR-guided interventional procedures, the position and orientation of a catheter or needle can be precisely tracked using MR-based tracking methods with microcoils [1]. The presence of metal, such as needles used in radiation bracytherapy treatment of cervical and prostate tumors, affects tracking quality by causing both static magnetic field (B_0) and radiofrequency field (B_1) inhomogeneities due to the strong paramagnetic and conductive properties of the metal needles. In addition, the long (~15 cm) metallic needles act as RF "antennas" which couple to the tracking coils as well as the body coil, distorting the tracking signals. Zero-phase-reference and Hadamard multiplexing schemes can be used to correct the B_0 inhomogeneities [1]. Recently, the theory of phase-field dithering (PFD) was described to improve the tracking quality in low SNR conditions, possibly correcting for B_1 effects as well. PFD applies multiple orthogonal magnetic-field gradients in arbitrary directions and selects the highest-quality tracking signal based on certain algorithms [2]. The aim of this work is to investigate the tracking accuracy and robustness of different MR-tracking schemes and the effect of PFD in an environment where metallic artifacts and physiological (e.g. respiratory, peristaltic) motion are present.

Methods: *Tracking device design*: Two 5-mm long solenoid microcoils were built on a carbon fiber rod of 9-mm diameter and 20-cm length. Carbon fiber is diamagnetic, free from susceptibility artifacts, and has far lower conductivity than metal, which makes it suitable for placement of tracking coils. It also has the stiffness required to perforate tissue, so it can be incorporated into MR-compatible needles. This tracking device was built for use as an actively tracked interstitial catheter for MR-guided bracytherapy. The microcoils were connected to a custom 8-channel interface for the Siemens 3T Verio, allowing simultaneous tracking of up to eight microcoils.

Experiments: The experimental setup consisted of a Syed-Neblett template (routinely used in gynecologic bracytherapy) holding the tracking catheter and tungsten-alloy needles (Fig. 1), simulating the tracking environment in an interstitial therapeutic procedure [3]. Five needles were inserted around the carbon fiber catheter at positions ~10 mm away. The template was attached to a custom-built positioning platform used to generate motion of the entire assembly. The platform enabled a 1D oscillation of the catheter and the surrounding metal needles with variable control of maximum displacement (5-40 mm) and frequency (0-10 Hz). The needles and the catheter were inserted into a mineral oil phantom. Zero-phase-reference and Hadamard multiplexing MRI-tracking schemes were implemented. PFD was integrated into both schemes, with the capability of adding 0-3(0 signifies none) orthogonal dephasing gradients along assigned directions. Tracking parameters: $\alpha = 5°$; resolution = $0.6 \times 0.6 \times 0.6$ mm3; frame rate (fps) = 40 Hz. Tracking in the presence of metal with several motional frequencies was tested by using different MR tracking methods. The experiments were also repeated with the metallic needles removed. The coil positions at rest w/o and with the needles were also measured using a high resolution 3D FLASH sequence (uncertainty: ± 1 mm) as a "gold-standard" for the tracking methods.

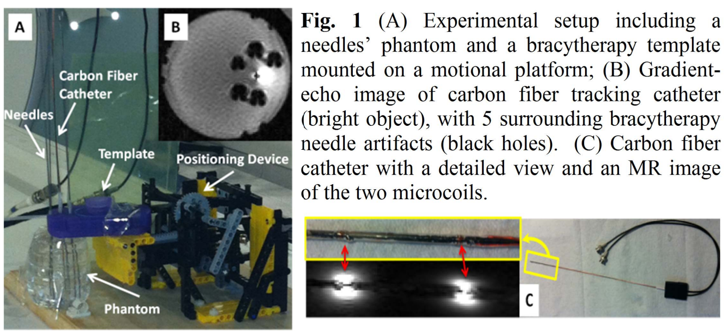

Fig. 1 (A) Experimental setup including a needles' phantom and a bracytherapy template mounted on a motional platform; (B) Gradient-echo image of carbon fiber tracking catheter (bright object), with 5 surrounding bracytherapy needle artifacts (black holes). (C) Carbon fiber catheter with a detailed view and an MR image of the two microcoils.

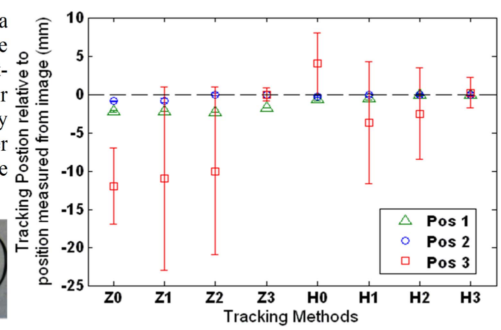

Fig. 2 Tracking results in the absence of motion for 3 different spatial positions by zero-phase-reference (Z0-Z3) and Hadamard (H0-H3) with PFD cycle lengths of 0,1,2 and 3 relative to the imaging-based "gold-standard".

Results and Discussion: For a static catheter in the presence of the metallic environment, a comparison of tracking results are presented for 3 different positions using two tracking schemes with different PFD cycle lengths (Fig. 2). For positions 1 and 2, the difference between tracking positions and the "gold standard", are all within the system error. For position 3, Hadamard produced more accurate and robust results than the zero-phase-reference scheme. Within each scheme, PFD dramatically improved the accuracy and reliability of tracking results. The improved tracking robustness with PFD is shown in Fig. 3.

For high-resolution ($0.6 \times 0.6 \times 0.6$ mm^3) and high-speed (40 fps) positional tracking in the presence of metal with a translational motional frequency of up to 8 Hz, both the zero-phase reference and Hadamard schemes produced a continuous oscillation pattern (Fig. 4). With a sufficient SNR (>9), the two methods yielded similar results in this motional test. The Hadamard scheme was more robust at lower SNR, as compared to the zero-phase-reference, resulting in fewer erroneous positions within the motional curve. This may result from the more efficient use of tracking signals in Hadamard. Increased PFD cycle length does result in a reduction of tracking speed, which sets a practical limitation on the number of cycles possible when following rapid motion.

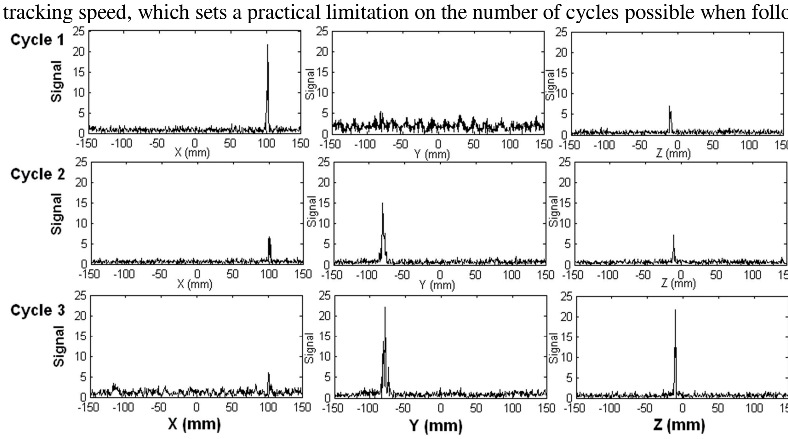

Fig. 3 Tracking signals acquired using the zero-phase reference scheme with PFD cycle length of 3 along three spatial directions (X, Y, Z). The maximum vector method was applied to select the data set with the strongest and sharpest peak; in this case cycle 1 (X) and cycle 3 (Y and Z).

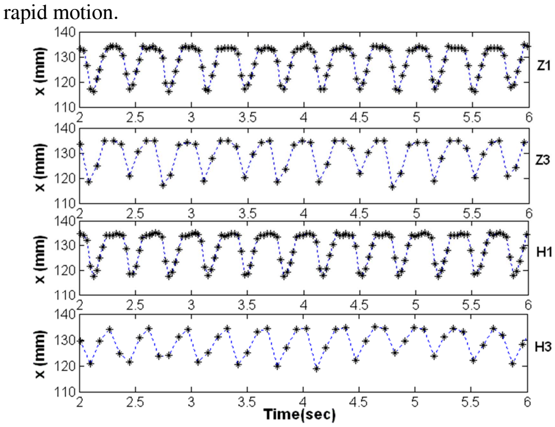

Fig. 4 MR-tracking recording of 18 mm amplitude, 3-Hz oscillatory motion of assembly, Zero-phase-reference (Z) and Hadamard (H) schemes with PFD cycle lengths 1 and 3 are shown.

References: [1] Dumoulin et al. Magn Reson Med 1993; 29:411-15; [2] Dumoulin et al. Magn Reson Med 2010;63:1398-1403; [3] Kapur et al. Magn Reson Imaging 2012; 30: 1279-1290 **Acknowledgements**: AHA 10SDG261039, NIH U41-RR019703, NIH R21-CA158987-01A1