Measurement Accuracy of Different Active Tracking Sequences for Interventional MRI

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Introduction: For interventional vascular procedures, precise localization of the catheter is a crucial requirement. This has been typically accomplished in MR using active devices, (i.e. catheters containing small solenoid coils) combined with 1D projection imaging [1, 3]. Three variants, Single Echo [1, 2], Dual Echo [3], and Hadamard Multiplexed [1], (Fig. 1) have been described in the literature, but to our knowledge have not been compared directly. Therefore, the aim of this work is to investigate the spatial accuracy of each method using a custom-built phantom that facilitates precise positioning of the catheter at known physical locations.

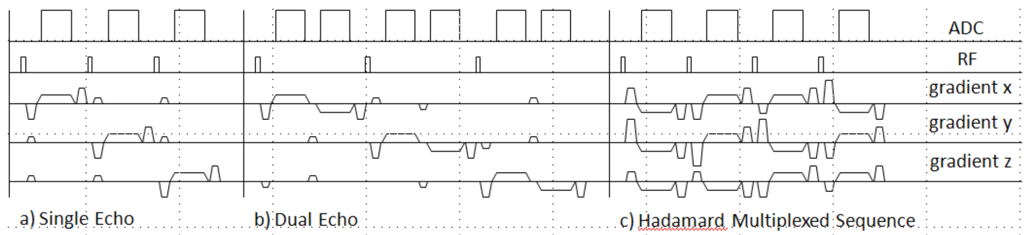

Fig1: Tracking Pulse Sequence Diagrams for (a) Single Echo, (b) Dual Echo, and (c) Hadamard Multiplexed

Materials and Methods: All three tracking sequences were interleaved with a FLASH imaging pulse sequence (track-image-track-image-…) and implemented on a commercial 3T whole body MR scanner (Siemens MAGNETOM Trio, A Tim System, Erlangen, Germany). Each sequence incorporates orthogonal dephasing gradients to suppress signal originating from other catheter components [2,4]. Tracking was set up with the following parameters: FOV: 400mm; 512 data points; TR/TE: 5.4/2.7 ms; BW: 300 Hz/Px; dephasing moment: 2.5 mT/m/ms; flip angle: 5°. The 3D coil position was determined by performing a cross-correlation between the measured projections and a theoretically simulated B_1 model of the micro-coil. Relevant image sequence parameters were TR/TE:5.0/2.5 ms; flip angle: 12°; and 128 phase-encodes. A custom-built electrophysiology catheter (SurgiVision, Inc., Irvine, CA) incorporating four micro-coils (see inset in Fig. 2) was used as the active device in experiments.

A dedicated phantom was constructed out of LEGO® Duplo bricks (Bilund, Denmark) (Fig. 2) which was water-flooded during the experiment. Holes were drilled into the bricks to accommodate the catheter and to reduce the formation of air bubbles inside the bricks. A small, acrylic clamp was also constructed to plug the catheter into a brick, thereby facilitating an easy and accurate movement of the catheter between several defined positions.

Two experiments were conducted. The first was performed for 14 known positions along the head-to-foot (H/F) direction with an increment of 10 mm for each run, where each run consisted of 10 tracking and image measurements. In the second, the shim gradient was increased manually in the Z-direction to produce an artificial field inhomogeneity of 1mT/m. 9 positions were acquired with an increment of 20 mm in the H/Fdirection. The dimensions of the phantom and catheter were measured by a Vernier caliper and a fixed-point in scanner coordinates was set using the laser system of the scanner and then confirmed with a high resolution, 3D FLASH sequence. The measurement uncertainty of this coordinate system was estimated to be ±1 mm. Results were plotted with a Bland-Altman approach [5] comparing each sequence to caliper data with caliper as ground truth. Finally an ANOVA test was conducted to statistically investigate the difference between the mean errors of the three techniques.

Results: Except for a single measurement, all positions for all methods were within 1 mm of the gold standard for the first experiment (Fig. 3). This compares favorably to previous studies that cited an accuracy in the range of +/-2-4 mm [6,7]. The standard ANOVA test showed a difference between the three tracking methods whereas a follow up test (Tukey's range test) only showed a significant difference ($P<0.01$) between the Single and Dual Echo positions. For the second experiment (field inhomogeneity), the positions for the Single Echo sequence followed the off-resonance conditions and therefore showed increasing difference as a function of distance from the isocenter compared to the gold standard (Fig. 4). The Dual Echo positions showed an increasing standard deviation with off-resonance that was much higher than Single Echo and Hadamard. In contrast, the Hadamard Multiplexed results showed good conformity with the true position and appear robust against off-resonance shifts, as predicted by Dumolin et al. [1].

Discussion and Conclusion:

The results clearly point out the advantage of the Hadamard Multiplexed sequence in cases of strong off-resonance effects. In addition, the Hadamard sequence also represents the most stable and accurate technique, but with the drawback of increased acquisition time due to a fourth projection and larger gradient demands from double-oblique orientations. Considering that the average position for all three methods was within 1.2 mm of the true position (roughly the estimated accuracy of determining true position), the Single Echo technique may offer sufficient accuracy for time-critical applications, especially at 1.5T where off-resonance effects are less of an issue than at 3T.

The poorer performance for the Dual Echo sequence in off-resonant conditions was due to the appearance of two peaks in the product of the two echo signals. In these instances, the tracking position is "randomly" located at one peak which explains the comparatively large error bars in Fig. 4. One could average the position from each echo to achieve similar results to Hadamard multiplexing, but at a loss of the theoretical background signal suppression that occurs with the product of the two echoes.

References : [1] Dumoulin CL et al. MRM. 29:411-15 (1993); [2] Homagk AK et al. MRM. 63:517-23 (2010); [3] Müller S et al. ISMRM 3358 (2006); [4] Unal O, et al. MRM. 40:356-62 (1998); [5] Bland JM et al. *Lancet* 1:307-10.(1986); [6] Leung DA et al. AJR, 164:1265-70 (1995) ; [7] Hillenbrand CM et al. MRM 51:668-75 (2004)

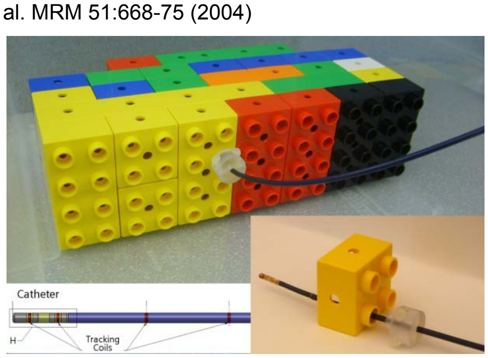

Fig 1: LEGO Duplo phantom and SurgiVision catheter

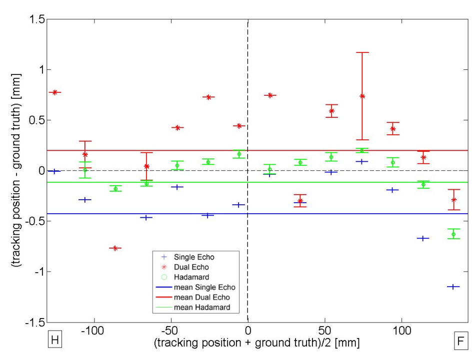

Fig. 3:Bland-Altman-Plot for first experiment in H/F direction with 0 equal to isocenter

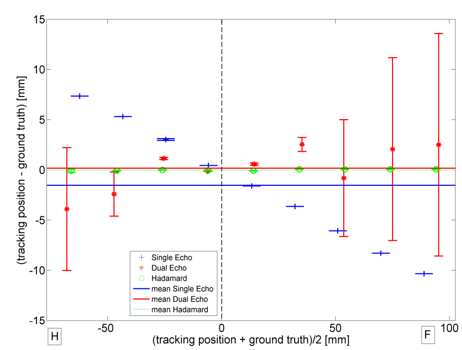

Fig. 4: Bland-Altman-Plot for results with off-resonance in H/F direction. 0 equals iso.