High accuracy position estimation of interventional devices using a controllable passive tracking device

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Introduction: Tracking of interventional devices under MRI guidance remains an active area of research. Magnetic resonance imaging offers a superior soft tissue contrast compared to other modalities such as X-ray fluoroscopy. However, unless active tracking methods are used, its ability to track the interventional device is always hampered by the lack of contrast between the device-related effects on magnitude images particularly when projection images are used to find the device within a large volume. In this abstract, a new tracking technique, based on a recently proposed device, has been tested that uses the generated phase profile between ON and OFF states of the device in the acquired image in order to track the device with sub-pixel accuracy.

Theory: Once placed inside the magnetic field, susceptibility markers perturb the magnetic field corresponding to their volume susceptibility ($\Delta\chi$). We proposed a new tracking device that consists of three concentric layers of Titanium (Ti) and Graphite (G) [1]. Once the three layers are aligned (OFF), the device will create minimal magnetic field perturbations, which minimizes the susceptibility artifact in MR images. However, if the graphite layer is retracted (ON), the device will perturb magnetic field quite substantially, which increases the artifact in the images. Figure 1(a) and 1(b) show the arrangement of the layers in ON and OFF states. GRE images of these states are shown in 1(c) and 1(d). A subtraction between ON and OFF state will result in a better visualization of the device, shown in 1(e), especially in phase domain, which is shown in 1(f). Since only the state of the device is changed between acquisitions, background phases, resulting from other susceptibility effects, will be substantially suppressed and the device position is effectively highlighted. The field perturbations caused by the device are simulated using Eq.1 where $\delta\mathbf{B}_d$ is the field perturbation of a single dipole and $\mathbf{D}_\chi$ is 3D spatial distribution of the materials [2]. $\Delta\mathbf{f}$ is the precessional frequency shift in the vicinity the device. Phase maps can be generated using Eq.1 to simulate the phase of the subtracted image as shown in Figure 2. An iterative optimization algorithm has been implemented in MATLAB© in order to track the device position by minimizing the least-square-error between the simulation phase image and the measured one. The algorithm will estimate the centre of outermost titanium cylinder.

$$\Delta \mathrm{f} = \frac{\gamma}{2\pi}\delta \mathrm{B}_d * \mathrm{D}_\chi \quad (1)$$

Methods: A 9F catheter has been assembled with the three layers as originally designed in [3]. The length of the device was in 15mm. The graphite layer was retracted during phantom experiments by 2.5mm using a nylon pull wire, which was glued to this layer during manufacturing. The catheter assembly was placed into a tube and the whole setup was submerged into 14 mM doped water ($CuSO_4$, $T_2 \approx 100$ms) to resemble an artery or vein. Two sets of slice-selective GRE images were acquired for ON and OFF states with TE=20ms, TR=100ms, FA = 60° and FOV=150mm for 512x512 image size. The experiment was repeated for different locations of the device centre at -7.5, -2.5 and 2.5mm. Three subtracted images were fed into the optimization process one-by-one to estimate the device centre, thereby the location of the device.

Results: The phase map resulting from different states of the device was simulated for TE=20ms (Figure 2). The simulated phase map agrees with the measured phase map, shown in Figure 1(f). Simulated and measured phase maps were fed in to optimization process, which converged to a reasonable accuracy of the estimation, shown in Figure 3, in an average of 9 iterations with an average of 9.3s on AMD 3.2GHz cpu. Figure 3 shows the correlation between the actual positions of the device centre with the estimated values from optimization process. The average error between estimation of the device centre was 147µm, which is well below the pixel size (293µm).

Conclusion and Discussion: A tracking method based on previously proposed device with a controllable susceptibility artifact was developed and validated using phantom experiments. Since the device has two configurations (ON and OFF), the phase difference between these two configurations can be used as the basis for tracking, which removes background phase effects and greatly improves the accuracy over magnitude based methods. It was demonstrated that this tracking technique was capable of estimating position of the device centre with sub-pixel accuracy. Future improvement involves using spectrally selective RF excitations, which only excite certain region in vicinity of the device (e.g. yellow arrow in Figure 2), thus enabling a higher accuracy estimation of the position.

References: [1]Dominguez-Viqueira *et al*, ISMRM 4082, 2012 [2] Schenck J. *et al*, Med. Phys. 23, 1996 [3] Dominguez-Viqueira *et al*, SCMR ,2012

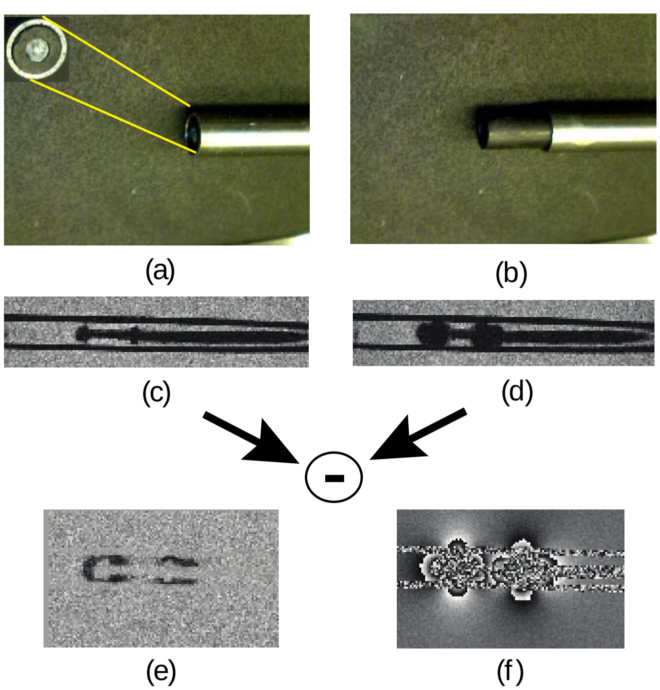

Figure 1: (a) Device in OFF state (b) Device in ON state (c) GRE image of OFF state (d) GRE image of ON state (e) Magnitude of the subtraction image (f) Phase of the subtrsc - tion image

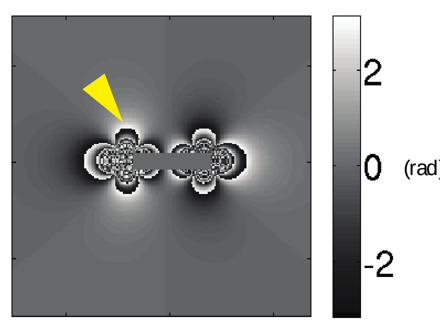

Figure 2: Simulated phase map using subtracted field perturbations of ON and OFF states with TE=20ms

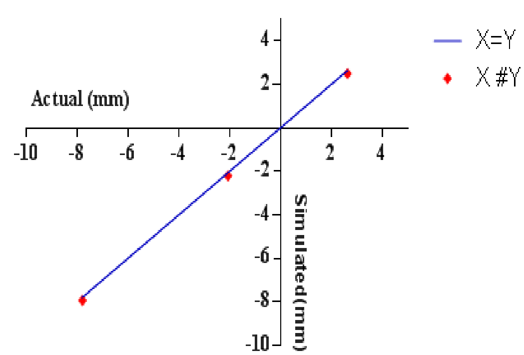

Figure 3: Optimization results (red dots) vs measured values