Two-channel visualization of a passive nitinol guidewire with iron oxide maker created from a single image acquisition

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TARGET AUDIENCE: This work will be of interest to researchers in the field of MRI-guided interventions, and those interested in iron oxide imaging.

PURPOSE: Image guided procedures rely on the accurate visualization of devices. Simultaneous visualization of both the device shaft and the device tip is important to improve navigation and procedural safety. Thus, "active" guidewire-antennas for MRI-guided procedures are often designed such that the tip and shaft have distinct signals [1]. In addition, a distinct tip signal helps to identify when the tip moves out-of-slice on MRI images.

Paramagnetic materials such as nitinol and iron oxide can be used for "passive" device visualization. These materials will perturb the local magnetic field leading to off-resonance spins, which causes blurring in spiral imaging. Blurring can be corrected by reconstructing images at an off-resonance frequency (ω), by multiplying complex raw data by $exp(i\omega t)$ [2]. Off-resonance reconstruction has previously been used to isolate paramagnetic devices with radial imaging [3].

Here, we use off-resonance reconstruction to produce a two-channel visualization, with distinct tip and shaft signals, for a passive nitinol guidewire with an iron oxide marker.

METHODS: An iron oxide marker was added at the tip of a 0.035" commercial nitinol guidewire (Nitrex, Covidien, Plymouth, MN). Imaging was performed on a 1.5T MRI scanner (Aera, Siemens, Erlangen, Germany) and image processing was performed in MATLAB (R2013a, Mathworks, Natick, MA). A gradient echo spiral imaging sequence was used for phantom and in vivo imaging (8 interleaves, TE/TR = 0.86 ms/10ms, flip angle = 10°). Animal experiments were approved by the animal care and use committee according to contemporary NIH guidelines. The image data was reconstructed three times: on-resonance (0 Hz), -100 Hz off-resonance and +100 Hz off-resonance. The on-resonance reconstruction was used as the background anatomical image and unique signatures for the iron oxide marker and nitinol shaft were isolated as follows.

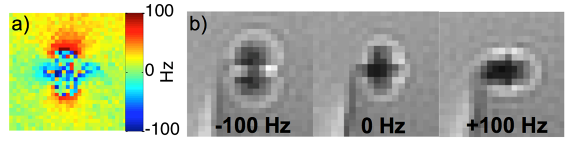

Figure 1: Frequency map (a) and demonstration of off-resonance reconstruction (b) for the iron oxide marker.

Channel 1 – Iron marker: In the magnitude images, the off-resonance reconstruction caused local de-blurring in areas where spins were off-resonance (Figure 1). A subtraction of the magnitude images [$image_{-100Hz} - image_{+100Hz}$] generated a characteristic dark-bright-dark pattern from the iron marker. This unique signature was detected using a specifically designed convolution kernel.

Channel 2 – Nitinol guidewire: A complex subtraction of two image reconstructions [$image_{on\text{-}resonance} - image_{+100Hz}$] was used to depict the nitinol shaft of the wire. Complex subtraction emphasizes the phase difference in regions of significant field inhomogeneity. The nitinol shaft signal was isolated from the background signal using signal thresholding and searching for elongated structures at the center of the image.

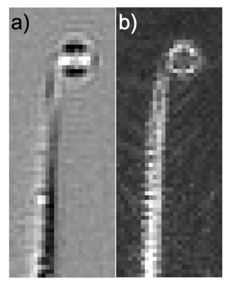

Figure 2: Magnitude subtraction (a) and complex subtraction (b) of phantom image reconstructions (on resonance and ±100Hz off resonance). Dark-bright-dark pattern created by the iron oxide marker is obvious in (a), and contrast from the nitinol shaft is clear in (b).

RESULTS: A temporal resolution of 80 ms/frame or 12.5 frames/s was achieved. Figure 2 shows phantom images of the nitinol wire with iron oxide marker and demonstrates the unique signature created by magnitude and complex subtraction of on-resonance and ±100Hz off-resonance reconstructions. The modified nitinol guidewire was inserted transfemorally to the aortic arch of a Yorkshire swine and imaged. The imaging signatures of the iron oxide marker and nitinol shaft were observed in vivo, and isolated using image processing to produce a two-channel color overlay of the nitinol shaft (green) and iron-oxide tip marker (red) (Figure 3).

DISCUSSION: This method allows simultaneous visualization of the shaft and the tip of a passive guidewire with distinct signals. Importantly, only one image acquisition is required, and distinct overlay channels are generated entirely during post-processing, meaning that frame rate is not affected. Spins surrounding the iron oxide marker are much further off-resonance (50-100Hz) than those surrounding the nitinol shaft (~10Hz off-resonance). The iron oxide marker is depicted using gross changes in magnitude images following off-resonance reconstruction. Whereas, the nitinol shaft is more clearly visible from complex subtraction highlighting regions of local field inhomogeneity. This method is limited by the presence of confounding background signal in vivo, and slice orientation dependence of imaging signature. Future work will investigate methods to improve the signal specificity in vivo.

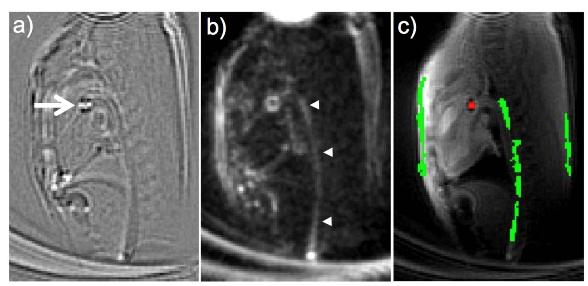

Figure 3: In vivo demonstration of magnitude (a) and complex (b) subtraction of image reconstructions (on and off resonance). The iron oxide marker (arrow) and nitinol shaft (arrowheads) were isolated and overlaid onto the anatomical image as two separate color channels (c).

CONCLUSION: We have presented proof-of-concept experiments to generate a two-channel color overlay to distinctly visualize the nitinol shaft and iron oxide tip marker of a passive guidewire using spiral imaging with on- and off-resonance reconstructions.

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