Narrowband MPI and Image Reconstruction for Small Animals

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Intro: Magnetic Particle Imaging (MPI) is a new imaging modality that promises long-term detection and tracking of nano-mol/L concentrations of super-paramagnetic iron oxide (SPIO) particles commonly used as MRI contrast agents. The MPI method does not use an MRI scanner, instead it directly detects the magnetization from an SPIO whose saturation magnetization approaches 0.6T, or 10^6 times larger than the nuclear paramagnetism detected by MRI at 7 Tesla.

Methods: We have developed a MPI system that directly detects the magnetization of iron with remarkable sensitivity and resolution over a 3cm field of view, sufficient for a whole mouse. Our narrowband MPI system is a variant of MPI [1,2] that enables small receive bandwidths at high frequencies using intermodulation, with a clear path towards body noise dominance[3]. The system is built with water cooled electromagnets that move the field free point up to ±1.5cm in any direction. The electromagnets are powered using standard MRI gradient amplifiers (Copley Controls 234), requiring up to 450A pulses to image the FOV. Continuous RF power of 10mT at 240kHz elicits a strong signal from the 50nm SPIO particles (FluidMAG-DX, Chemicell GMBH), and is well below the SAR limit for a mouse. The system has a permanent NdFeB magnet gradient (dB/dz=6500mT/m, dB/dx,y=4500mT/m), and is controlled by a MRI console capable of working at low frequencies [4].

We have also developed a novel method for reconstructing the harmonic images resulting from a MPI system. When imaging using MPI, we can receive over 20 images of the phantom, each with different point spread functions. We represent the multiple harmonic point spread functions in Fourier space as: $H_n(k) = \Im[h_n(x)]$. Our signal is: $Y_n(k) = H_n(k)M_n(k) + N(k)$ where $M_n(k)$ is the magnetization of the image in Fourier space. Then we can solve for the magnetization using least squares with care used to prevent ringing.

Results and Conclusion: We successfully built a MPI system that directly detects the magnetization of iron with remarkable sensitivity and resolution. We used our imager to image a complex angiography phantom and reconstruct the resulting harmonic images using the method detailed above. The full system and reconstructed phantom are shown in Figure 1.

MPI results in an image with perfect contrast – tissue has no signal. As seen in the Figure, our system has excellent spatial resolution and is capable of full 3D imaging. The phantom is 300um ID plastic tubing filled with undiluted contrast agent, and the resulting point spread FWHM of the imaged plastic tubing is approximately 1.2mm. Significant gains in SNR and resolution are possible as we continue to develop pulse sequences, reduce vibration, improve electronics, and develop new hardware.

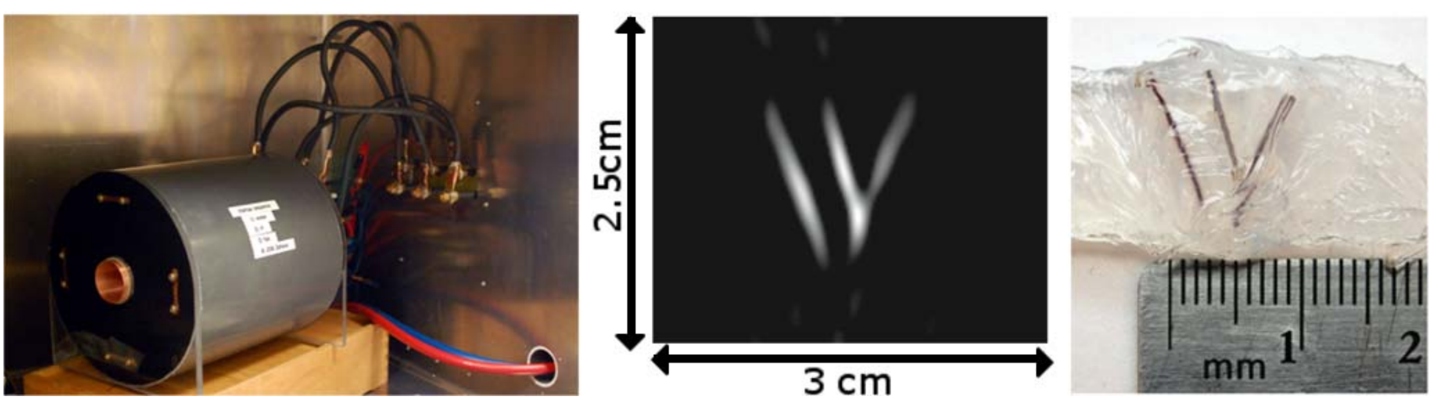

Figure 1: (left) MPI mouse Imager. (middle) MPI Image of angiography phantom with 300um ID tracer filled tubing to simulate blood vessels. The image is in full 3D and has FOV = 2.5 cm x 2.5 cm x 3 cm. (right) plastic phantom.

References: 1. Goodwill et al. IEEE TMI 28, 8 (2009). 2. B Gleich et al. Nature 435,1214-1217(2005); 3. A Macovski. *Mag Res Med*, 36(3)494-7(1996); 4. P. Stang et al. Proc. 16th ISMRM, p925, 2007.