# Modulation of Magnetic Susceptibility Markers with Laser-induced Demagnetization of Nickel Nanoparticles

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**Introduction:** Performing catheter and needle-based interventional procedures under MRI guidance remains a promising area, where the extra soft tissue contrast can be used to improve outcomes in certain procedures [1]. Passive tracking with susceptibility effects offers an easy-to-make and cost efficient method for tracking interventional devices, however difficulty locating devices when they are out-of-slice, or in projection images, is a major drawback. Laser-induced demagnetization of metal films has been used in magneto-optic devices [2]. In this abstract, the possibility of using laser-induced demagnetization to modulate the susceptibility artifact from Ni nanoparticles in MR-images was investigated, making the artifact “flicker” and enabling detection in projection images [3].

**Materials and Methods:** A continuous-wave fiber-coupled laser diode source (S1FC808, Thorlabs Inc., Newton, New Jersey, USA) with the maximum power of 24.54 mW was used to demagnetize Ni particles. The wavelength of the light is 808 nm, which is in near-infrared (NIR) spectrum. A 5-µm diameter optical fiber with 125 µm cladding in a protective kevlar layer was coupled to the laser machine using a FC/PC connector. The output power fluence at the tip of the fiber is 127.4 W/cm$^2$. The distal end of the fiber optic cable was stripped to expose the cladding layer. Ni nano-powder particles with average size smaller than 100 nm (Sigma-Aldrich Co., #577995-5G, St Louis, MO, USA) were glued to the tip of the stripped fiber using superglue (Loctite 401, Westlake, Ohio, USA) to block the laser photons from emitting out of 5 µm inner core, shown in Fig. 1a. The tip of the fiber was immersed into a 50 ml container filled with water. All of the experiments were performed in a 1.5 T wide-bore scanner (Optima MR450w, GE Healthcare, Waukesha, WI, USA). A 5-inch receive-only surface coil was used to acquire MR images. Multiphase fast gradient-recalled echo (Fast GRE) sequence with following parameters was used to acquire N = 36 images: matrix size = 128 × 128, flip angle = 40, bandwidth = 31.3 kHz, FOV = 13 cm, slice thickness = 5 mm, TR/TE = 5.6/2.6 ms, 5 second delay between images, and NEX = 10. Fig. 1b shows one of the FGRE images with susceptibility artifacts of Ni particles. The laser output power was changed according to the modulation pattern shown in Fig. 2a. The same imaging protocol was repeated when the laser was OFF throughout the acquisition of all 36 images. Complex signal of each voxel through all N = 36 images was correlated to the laser output power vs. time. Eq.1 was used to calculate the cross covariance and an image was built based on the absolute values of CC(i,j) for each voxel at zero lag between signal of the voxel and laser output power. $S_{ij}$ (n + 0) is the real signal vs. time of voxel i, j at zero lag and $L_{i,j}$(n) is the laser output power vs. time.

$$CC_{ij}(0)=\left|\sum_{n=1}^{N} S_{ij}^{*}(n+0)L_{ij}(n)\right|$$

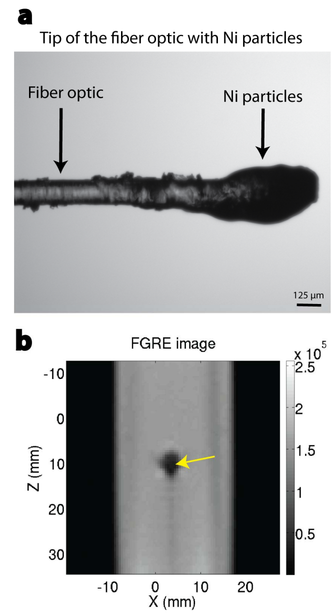


Fig. 1: **(a)** Fiber optic with the Ni nanoparticles at the tip **(b)** FGRE image of the fiber optic with Ni particles inside a water tube showing the susceptibility

**Results:** Fig. 2b shows the magnitude of signal of a voxel (shown by arrow in Fig. 1b) that shows high positive correlation with the laser output power. Fig. 3a shows the cross covariance map. The highly correlated voxels were located where there was susceptibility artifact from the Ni particles. Fig. 3b illustrates the cross covariance map in which the laser was OFF for all acquired images, however, cross-covariance between signals of all voxels and the laser output power was calculated. Manually touching the fiber tip with the laser activated confirmed that any bulk heating was undetectable under any of the conditions investigated.

**Conclusions:** In this work, the feasibility of using laser-induced demagnetization of Ni particles as a means for making susceptibility artifacts flicker was investigated. This could have applications in passive tracking of interventional instruments. Experimental results suggested that laser photons interact with Ni particles through the demagnetization process, thus changing the volume susceptibility of the particles. Signals of the voxels around the Ni particles were highly correlated with the laser output power suggesting that the susceptibility artifacts were changing due to the effect of the laser. In the experimental setup, Ni particles were glued to the cladding of the fiber optic, which was 125 µm. However, laser photons emanate from the the inner core which was 5 µm diameter, so it is estimated that only a small fraction of the Ni particles (roughly 10% of total volume) were absorbing the laser photons and demagnetized leading to SNR of the signal changes equal to 3.15 (which is equivalent to a 7% change in the bulk signal) in the images with NEX = 10. Moreover, additional experiments have been performed (data not shown) to investigate whether the observed effect was merely due to the heating of Ni particles. A tip was fabricated with graphite particles to absorb the laser photons in a similar fashion. No changes were observed in phase/magnitude of the signals of the voxels close to the tip, giving evidence that the effect results from interaction of the laser with the Ni particles and not simply heating of the surrounding structures.

**Future Work:** In future studies, it can be expected that with a better coupling between the Ni particles and the laser photons, a more substantial change in susceptibility values of the particles may be observed. Such efficient coupling could be achieved by embedding Ni particles in the fiber inner core in the manufacturing process. Also a higher laser power (<1W) is expected to create larger demagnetization effect [2].

**Reference:** [1] Kariniemi et al, Eur Radiol (2009) 19: 1296–1301 [2] Roth et al, PHYSICAL REVIEW X 2, 021006 (2012) [3] Dominguez-Viqueira et al, ISMRM proceeding 2014

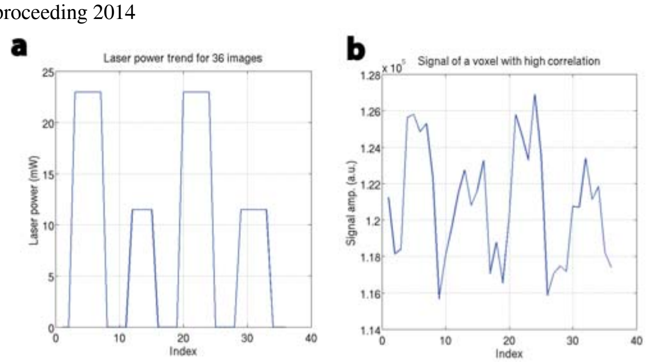


Fig. 2: **(a)** The trend of laser output power throughout all 36 images **(b)** Signal of the voxel, shown with arrow in Fig. 1b, throughout all 36 images which is showing a high correlation with the laser output power

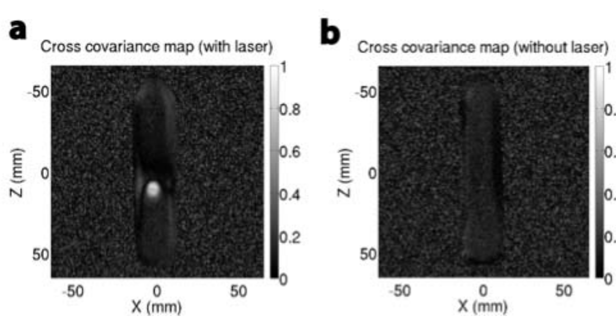


Fig. 3: **(a)** Cross-covariance map showing voxels whose signal is correlated with the laser output power **(b)** Cross-covariance map in which the laser was not used during image acquisitions showing no correlated voxels with the laser output power trend in Fig. 2a