International Journal on Magnetic Particle Imaging
Vol 6, No 2, Suppl 1, Article ID 2009073, 3 Pages

Infinite Science Publishing

Proceedings Article

Simulation studies of image reconstruction for field free line single-sided magnetic particle imaging scanner

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Abstract

Magnetic Particle Imaging is an imaging modality that exploits the nonlinear response of superparamagnetic iron oxide nanoparticles to a time-varying magnetic field. In the past years, various scanner topologies have been proposed. Among these, a single-sided scanner was presented in 2009. Such a scanner features all its hardware located on one side, offering accessibility without limitations due to the size of the object of interest. In this paper, we present image reconstruction simulation studies for a novel single-sided field-free line scanner. Specifically, we implemented a filtered backprojection algorithm allowing a 2-D image reconstruction over a field of view of 2 cm.

I Introduction

Magnetic Particle Imaging (MPI) is an emerging medical imaging technology, free of ionizing radiation, which detects and visualizes the three-dimensional distribution of superparamagnetic iron oxide nanoparticles (SPIONs), which are injected as tracers [1]. To achieve spatial resolution, a gradient of the magnetic field, also called a selection field (SF), is superimposed on the drive field (DF). The SF generates an area of zero magnetic field strength, producing a field free point (FFP) [1] or a field free line (FFL) [2].

Among the MPI developments is a single-sided MPI scanner, which was first introduced for FFP field topology [3]. The single-sided MPI scanner topology confines all the hardware to one side of the device, which is beneficial, as it provides the patient with unrestricted access to the scanning area [4]. Unlike the original single-sided MPI scanner, which utilizes an FFP [4-6], we designed a single-sided device with an FFL [7,8] with a promise of a higher sensitivity and more robust image reconstruction.

In this work we present a simulation study by means of an image reconstruction technique, which is specifically tailored for a single sided device that uses an FFL for spatial encoding.

II Theory

Our single-sided scanner topology is shown in Fig. 1. It uses an FFL to spatially encode the signal. In this approach, the sample is placed on a rotating platform, which is located above the SF coils. In order to collect data at different angles, the platform is mechanically rotated to a discrete angle position. At each angle, the FFL is translated along the x axis incorporating the desired field of view (FOV) to form a single projection. Hence, a sinogram can be generated. This is used to reconstruct an image from the measured signals with the filtered backprojection (FBP) method [9,10]. The coil's schematic

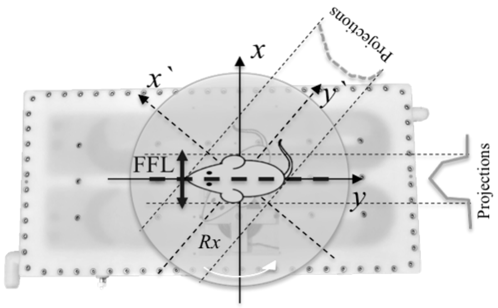

Figure 1: Single-sided MPI scanner. The FFL is generated through the selection coils along the y axis and translated along x axis while the subject turntable is mechanically rotated.

with the applied current pattern are shown in Fig. 2. The two SF coils and the DF coils are located near the surface of the device in two layers as shown in Fig. 2b. The DF coil generates the excitation and the bias fields, which are superimposed with the SF. Varying the currents in the two SF coils according to the pattern shown in Fig. 2a translates the FFL in xy plane, providing 2-D spatial encoding. Applying a bias current to the DF coil allows height adjustment for the FFL to flatten the trajectory.

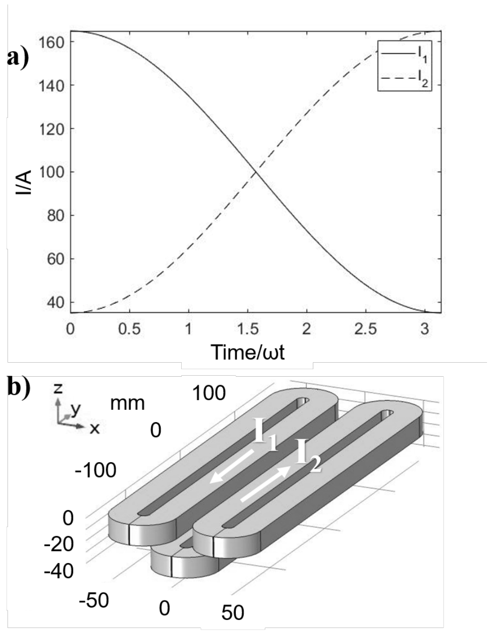

Figure 2: a) Current patterns applied to the selection coils. b) Coil system used in simulations. Upper and lower coils generate selection and drive fields, respectively.

III Material and methods

The two racetrack SF coils simulated to generate the FFL have a length of 24.5 cm, a width of 54 mm, a height of 18.3 mm, 26 turns, a core gap of 10 mm and a gap between the selection coils of 11 mm. The conductor wire is made of copper with a rectangular cross-section of 1x1 mm^2. The upper surface of the drive coil is located 5 mm from the lower surface of the selection coils. The DF coil is centered between the SF coils. Computation of the Biot-Savart law for all magnetic fields and image reconstruction were performed with MATLAB (Mathworks). For this simulation, a reference current I_0 was chosen corresponding to the gradient of 1.5 T/m at the height of 17 mm above the surface of the scanner. Translation of the FFL was simulated with MATLAB by applying currents I_1 and I_2 for the SF coils as depicted in Fig. 2a. All the fields are uniformly rotated with a discrete angle with respect to the phantom (see Fig. 1). Consequently, that allows data to be acquired and reconstructed to image the sample.

Two image reconstruction studies were performed with 2 cm x 2 cm FOV to study the spatial resolution of the system. The first study was simulated for three different filters, *i.e.* Hann, Ram-Lak and Shepp-Logan filters, with 41 translations of FFL and 18 projections (0°-180°). In the second study, only the Ram-Lak filter was considered, whereas the distance separating the SPIONs was varied to determine the achievable spatial resolution of the system. In both studies, a drive frequency of 25 kHz and a sine wave with a drive amplitude of 10 mT was used. No noise was considered in these studies.

IV Results and discussion

Fig. 3 illustrates one unfiltered and three FBP reconstructed images of two 1x1 mm^2 dots separated by 7 mm along x-axis and contained 5 mg/ml SPION with the diameter of 30 nm, whose magnetization behavior follows the Langevin model without relaxation. This study simulated a projection time of 164 ms resulting in a total imaging time of 2.952 s. Moreover, the Ram-Lak-filter features the highest contrast (C=0.159) compared to the other filters, which implies higher spatial resolution. This may be due to its behavior in the frequency spectrum, as it exhibits a stronger amplification for higher frequencies compared to Hann and Shepp-Logan filters.

Figure 4 visualizes the results for the simulations with the Ram-Lak filter and various distances between the dot phantoms. As seen in Fig. 4, the method can resolve up to 5 mm separation. Nevertheless, a clear spatial resolution is achieved at 7 mm with a conservative choice of numbers of projections and FFL-translations. Furthermore, we found no increase in contrast with the increased number of projections, however, increasing the number of translations from 21 to 41 contributes to higher contrast, C=0.1381 to C=0.1590 (Ram-Lak filter), respectively.

10.18416/ijmpi.2020.2009073

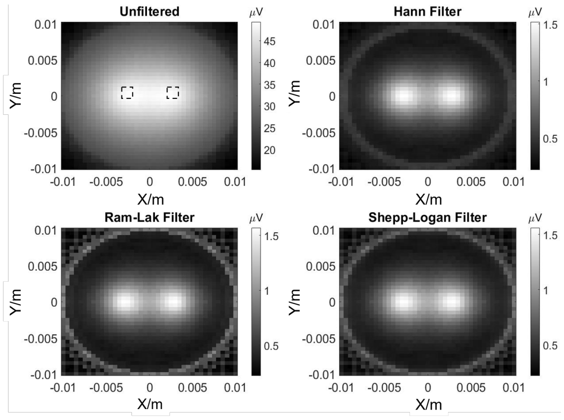

Figure 3: Reconstructed images of two dots 1x1 mm^2 separated by 7 mm: Unfiltered, Hann, Ram-Lak and Shepp-Logan filters for 41 FFL-translations and 18 projections

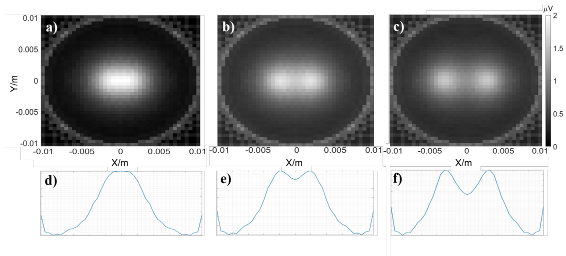

Figure 4: Reconstructed images using the Ram-Lak filter with 41 FFL-translations, 18 projections and a distance between the two SPIONs of (a) 3, (b) 5, and (c) 7 mm. The corresponding cross sections profiles are: (d) 3, (e) 5, and (f) 7 mm.

V Conclusions

We applied an FBP method to reconstruct images for a single-sided FFL MPI scanner. Two simulation studies were performed. Presented results show that 2-D imaging at the static height of 17 mm is feasible on the actual single-sided device with the spatial resolution limit of 5 mm.

Author's Statement

Research funding: this work is supported by NIH under Award R15EB028535, University of Massachusetts President's Office under OTCV Award and Joseph P. Healey Research Grant from UMass Boston. Conflict of interest: Authors state no conflict of interest.

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10.18416/ijmpi.2020.2009073