

Proceedings Article

# A practical advancement in FFL single-sided AM MPI: Achieving rabbit-scale 3D imaging without object movement in depth

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## Abstract

For clinical applications, magnetic particle imaging (MPI) requires a large and open field of view (FOV) for flexible operation and interventional integration. Although an existing field-free-line (FFL) single-sided MPI provides high sensitivity, it typically relies on slow mechanical translation for 3D depth encoding. To overcome this limitation, we employ an amplitude modulation (AM) approach using decoupled drive and excitation coils, enabling pure electronic depth scanning up to 30 mm. The proposed rabbit-scale system achieves a  $40 \times 40 \times 30 \text{ mm}^3$  FOV and provides a practical solution for localized interventional applications such as sentinel lymph node biopsy.

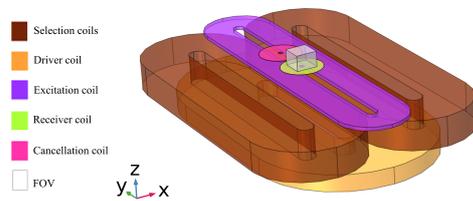
## I. Introduction

Magnetic Particle Imaging (MPI) is a promising technique for directly detecting magnetic nanoparticles [1]. Currently, MPI has four configurations: closed-bore, open-sided, handheld and single-sided. Among these, single-sided MPI is a free and flexible FOV for system operations. The first single-sided based on a field-free point (FFP) was proposed to overcome specimen size limitations of closed-bore MPI [2]. The field free line (FFL) concept was subsequently introduced, offering higher sensitivity and temporal resolution than FFP. More recently, our group demonstrated the first concept of portable single-sided MPI [3]. A FFL-based single-sided MPI using elongated coils has been constructed with a fixed FFL height of  $\approx 17 \text{ mm}$  which limits FOV size and requires mechanical z-axis translation to achieve 3D imaging [4]. To

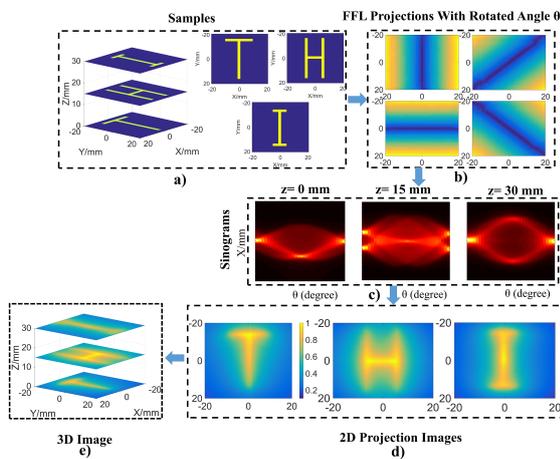
overcome these limitations, a 3D FFL single-sided MPI system based on amplitude modulation (AM) was designed, utilizing separate DC driver and low-amplitude high-frequency excitation coils. This configuration enables electrical control of the FFL trajectory within a  $40 \times 40 \times 30 \text{ mm}^3$  FOV which is suitable for potential application such as sentinel lymph node biopsy.

## II. Methods and materials

AM-based MPI systems have been developed by our group including closed-bore rabbit-scale [5], human-scale systems using superconducting selection coils [6], open-sided configuration [7] and the first portable single-sided MPI system [3]. The proposed AM single-sided MPI consists of four electromagnetic coils, shown in Figure 1. Unlike conventional single-sided MPI systems



**Figure 1:** FFL AM single-sided MPI system [9].



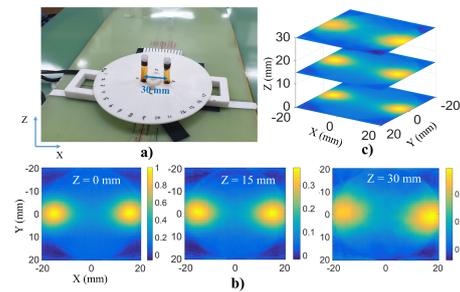
**Figure 2:** Imaging reconstruction simulation: (a) letter phantoms at three depths; (b) FFL projections; (c) sinograms; (d) reconstructed 2D images; (e) concatenated 3D image.

that use only an excitation coil at a fixed depth requiring mechanical in  $z$ -axis translation and limiting FOV [4], the proposed system employs a dedicated DC driver coil combined with a low-amplitude high-frequency excitation coil. By adjusting the driver coil current, the FFL can be electronically translated different depths, enlarging the FOV and eliminating mechanical scanning. All coil geometries were optimized to match available power supplies using the same method described in [8] with final system parameters reported in [9].

### III. Results and discussion

#### III.1. Imaging reconstruction simulation

Two-dimensional reconstruction followed the approach in [5]. The selection and excitation coil frequencies were 0.2 and 20 kHz, respectively, with a sampling rate of 0.25



**Figure 3:** Experimental 3D reconstruction [9]: (a) two phantoms separated by 30 mm; (b) 2D images at depths of 0, 15, and 30 mm; (c) concatenated 3D volume.

MS/s. Before reconstruction, the relationship between coil currents and FFL position for each 2D slice was analyzed for FFL correction [10]. Based on this correction, selection and driver coils currents were controlled to achieve flat FFL scanning in the  $x$ - $y$  plane. For each slice, the sample was manually rotated to acquire sufficient projections [7]. These projections were converted into sinograms, and 2D images were reconstructed using the inverse Radon transform. Simulations assumed magnetite nanoparticles with a core diameter of 30 nm and  $1 \times 1 \text{ mm}^2$  concentration spots. A slice size of  $40 \times 40 \text{ mm}^2$  was used, and signals were interpolated to reconstruct  $200 \times 200$ -pixel images. Receiver sensitivity was assumed uniform. The reconstruction results are shown in Figure 2.

#### III.2. 3D experimental imaging

Two 50  $\mu\text{L}$  phantoms of Synomag-D (60 mg/mL, mean particle diameter 50 nm; micromod Partikeltechnologie GmbH, Germany) were loaded into 8.1 mm diameter glass tubes. The phantoms were placed 30 mm apart and imaged at depths of 0, 15 and 30 mm. The FFL was sequentially translated by reducing the driver coil current from 62 to 0 A, with an excitation field of  $2 \text{ mT}/\mu_0$  at each imaging plane. At depths of 0, 15, and 30 mm, the system resolved phantom separations of 2, 6, and 8 mm using gradients of 0.7, 0.45, and  $0.36 \text{ T/m}/\mu_0$  respectively. Corresponding detection sensitivities were 60, 125, and  $250 \mu\text{gFe}$ . Detailed results are reported in [9]. By concatenating the reconstructed 2D planes, a 3D volume was obtained within a  $40 \times 40 \times 30 \text{ mm}^3$  FOV as shown in Figure 3.

## IV. Conclusions

The proposed AM single-sided MPI system achieves a large electronically accessible FOV of  $40 \times 40 \times 30 \text{ mm}^3$  and enables full 3D imaging at a rabbit scale without mechanical phantom motion along the z-axis. Eliminating mechanical depth scanning is a key step toward robust, real-time MPI systems for clinical and interventional applications. Future work will focus on enhancing the sensitivity and increasing the depth detection limits for in vivo imaging.

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## Author's statement

Authors state no conflict of interest. The results in this manuscript are derived from our accepted paper [9].

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