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MPI-CT: Dual-Modality imaging and reconstruction system

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Abstract

Magnetic particle imaging (MPI) is an emerging functional molecular imaging technique capable of real-time, quantitative visualization of superparamagnetic iron oxide nanoparticles (SPIONs). However, the lack of anatomical information limits its standalone diagnostic capability. To address this, we developed an MPI-CT dual-modality imaging system that integrates molecular sensitivity with structural precision. The system employs a sequential acquisition strategy to achieve spatially co-registered multimodal imaging. The MPI subsystem operates under a 3 T/m gradient field and achieves a spatial resolution of 1 mm. The spectral computed tomography (CT) subsystem consists of an X-ray emission unit, a photon-counting detector, a motion control unit, and a centralized data processing module. Finally, a mouse–magnetic particle phantom was fabricated for experimental validation, and dual-modality fusion of MPI and spectral CT images was successfully achieved, demonstrating the feasibility of high-resolution, quantitative MPI-CT imaging.

I. Introduction

Since its introduction in 2005 [1], Magnetic Particle Imaging (MPI) has attracted significant attention in molecular imaging due to its high sensitivity, quantitative capability, and non-ionizing nature. MPI reconstructs the spatial distribution of superparamagnetic iron oxide nanoparticles (SPIONs) by detecting their nonlinear magnetization response under an oscillating magnetic field. However, MPI signals solely originate from magnetic tracers and lack anatomical context, making it insufficient for precise localization and diagnostic interpretation. To address this limitation, MPI can be combined with structural imaging modalities such as MRI [2] or CT [3]. Compared with MPI-MRI systems, CT offers faster acquisition and easier integration, making it well-suited for synchronous or sequential imaging. In this work, we propose a multi-modal imaging system that integrates projection-based MPI with spectral CT, achieving a synergistic combination of molecular sensitivity and structural resolution.

II. Method

The proposed system employs multiple high-performance NdFeB (N52) permanent magnets configured in an oppositely magnetized array to

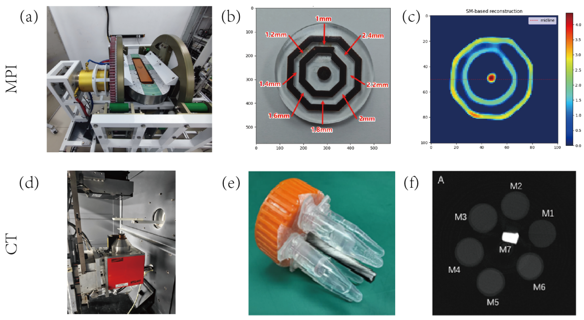

Figure 1: (a) , (d) show the MPI and CT imaging systems, respectively. (b) , (e) present the phantoms, while (c) , (f) display the corresponding imaging results.

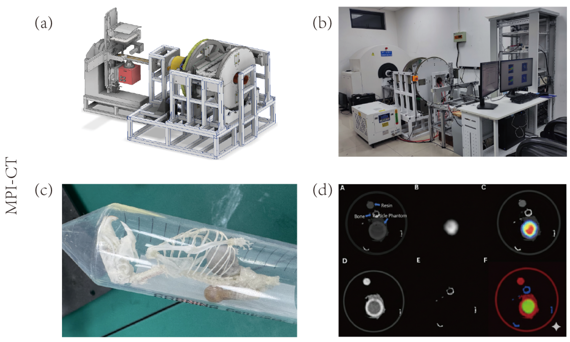

Figure 2: (a) MPI-CT structural design diagram; (b) Physical system; (c) Mouse skeleton and magnetic particle phantom; (d) Dual-modality fusion image.

generate a static field-free line (FFL) at the center. Finite element simulations were used to optimize the magnet geometry, achieving a magnetic field gradient of approximately 3 T/m while maintaining an open imaging channel of about 100 mm. To enable vertical FFL scanning, symmetrically arranged racetrack coils were designed and driven by ±36 A bias currents, providing a linear displacement range of ±14 mm. A transmit–receive integrated coil structure was implemented to suppress main-field interference, with an excitation frequency of 25 kHz and a sampling rate of 1.95 MS/s. MPI and CT data were acquired sequentially, followed by spatial co-registration during post-processing. The CT subsystem consists of a Hamamatsu L9421-02 microfocus X-ray source and an XC-Thor photon-counting detector, enabling high-resolution spectral imaging. MPI data were amplitude- and phase-corrected, then reconstructed using a hybrid method combining filtered back projection (FBP) and the proposed PARNet algorithm. CT images were reconstructed using a one-step decomposition approach based on a deep declarative network (DDN). Finally, spatial registration and multimodal fusion were performed to integrate the structural information from CT with the functional mapping provided by MPI.

III. Results

A bimodal sample containing SPION solution (Synomag®-D, Micromod) and iodine solution was used for validation experiments. The MPI image clearly visualized the distribution of magnetic nanoparticles, while the CT image accurately depicted the sample structure and non-magnetic regions, as Figure 1. After spatial fusion, the two modalities exhibited excellent consistency in both position and morphology, demonstrating that the system enables interference-free simultaneous acquisition, shown in Figure 2.

IV. Conclusion

A dual-modality imaging system combining spectral CT and MPI was developed, achieving 1 mm resolution in magnetic particle imaging under a 3 T/m gradient field and integrating it with high-resolution structural images from spectral CT. The results verify the feasibility of simultaneous acquisition of functional and structural information, providing a new pathway for multimodal molecular imaging and precision diagnostics.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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