International Journal on Magnetic Particle Imaging
Vol 6, No 2, Suppl 1, Article ID 2009059, 3 Pages

Proceedings Article

OS-MPI: an open-source magnetic particle imaging project

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Abstract

Magnetic Particle Imaging (MPI) is an emerging imaging modality with a growing research community and commercial foundation. Despite being introduced over a decade ago and having hundreds of associated publications, the bar for entry to the field remains quite high due to instrumentation costs and the inherent design complexity. Here we introduce an open-source project, OS-MPI, with the aim of facilitating entry into the field by providing design details of a field free line (FFL)-based pre-clinical scale imager and supporting systems and software. Our initiative is hosted on GitHub and presents a selection of MPI systems including our small-bore imager, a spectroscopy device, and a magnet winding jig. We will continually update as our designs evolve and encourage community-driven development. For each system, we describe all relevant mechanical and electrical designs, design rationale and simulations, assembly guidelines, and a parts list and cost breakdown.

I Introduction and Motivation

Magnetic Particle Imaging (MPI) is an emerging imaging modality with a growing academic and commercial research community working to develop and share further advances across all facets of the field. Yet for new investigators interesting in working on or employing MPI, the options are limited; they must either purchase a commercial system or develop their own imaging or spectroscopy system. Developing a scanner from the ground-up requires substantial engineering efforts including mechanical and electrical design, magnet construction, and thermal analysis among other technical considerations. Our goal for this community-focused open-source project (“OS-MPI”) is to provide designs as a starting point to aide those constructing an MPI system in-house and lower the bar for entry into the field and accelerate learning curves. We hope the effort will be a springboard for new groups to participate and add to the field by creating a repository for ideas.

There are open source projects relevant to MPI that have already been published: an open-source reconstruction program ‘MPIReco.jl’ [4] and a coil design program [5]. We are initiating OS-MPI as a broader, system-level, hardware focused initiative starting with three systems: a small-bore FFL imager, a spectrometer, and an electromagnet winding jig. For each system, we have developed a GitHub page to present all relevant mechanical

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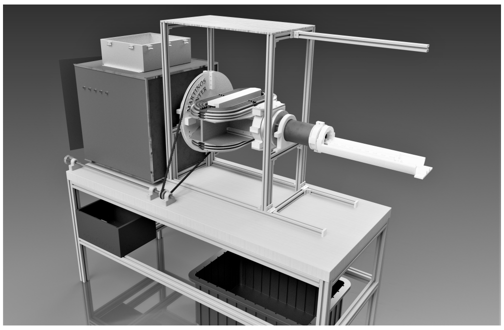

Figure 1: The small-bore imager described in the project.

designs and CAD drawings, 3D print files, component lists and cost breakdowns, electronic schematics and board files, coil geometries, software, discussion of many of the design decisions, and assembly recommendations.

II Methods

We introduce this project as a starting point; it is intended to evolve and grow as the field progresses. We hope other groups who employ components or the system as a whole will become an active part of the OS-MPI community. To that end, we have chosen GitHub as the platform to host the design files and documentation due to its support of open-source and community-driven projects and integrated Wiki to facilitate documentation.

II.I File hosting and licensing

The files included in this project are accessible on a GitHub open-source project page (https://github.com/os-MPI/OS-MPI-Main/wiki) that includes a Wiki page describing the rationale. The project is released with the GNU General Public License v3.0 [1] covering software. This license allows free access, though limits future closed-source version of the material—it does not prohibit commercial ventures utilizing the information if these subsequent projects acknowledge the source and employ the same license. The hardware is described by the CERN-Open Hardware License v1.2 [2] which also entails similar freedoms and restrictions.

Table 1: Specifications for the small-bore imager.

Sensitivity	50 ng in 75 seconds
Resolution	∼2 mm
Temporal Resolution	Under 3 seconds
Gradient	2.83 T/m
Drive Field Strength	12 mT Peak Amplitude
Approx. full-system cost	$60k

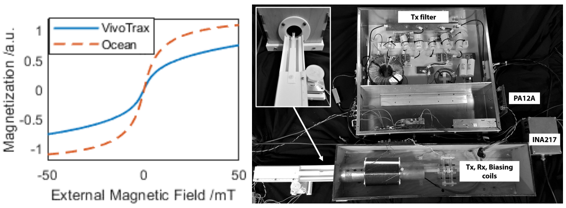

Figure 2: (Left) Magnetization curves of undiluted Vivotrax (5.5 mg/ml, Magnetic Insight, Alameda, CA) and undiluted SP-025 (5 mg/ml, Ocean Nanotech, San Diego, CA). The curves are scaled by concentration, and each sample contained 18 ul of particles. Acquisition time was 1 minute. (Right) Photograph of current system.

III Results and Discussion

The imager (seen in Fig.1) which forms the majority of the initial information is FFL-based and was designed with the goal of high sensitivity rodent brain imaging. The specifications of the system at the time of submission are described in Table 1. Within the scope of the imager, the documentation includes Inventor (Autodesk Inc. San Rafael, CA, USA) part and assembly files, experiment control software including a user interface and image reconstruction written in LabVIEW (National Instruments, Austin, TX, USA) and MATLAB (MathWorks, Natick, MA, USA), a part numbering scheme, an associated spreadsheet to track part manufacturing, an analysis of the thermal limits of the shift coils, and simulations describing the magnetic fields and heat transfer.

The spectroscopy platform is still under development (seen in Fig. 2) and, it produces magnetization curves of particles in ∼1 minute of acquisition time, as seen in Fig.2 with undiluted samples. The MPS system has two main modes of operation, spectroscopy and magnetometry. The spectroscopy mode utilizes high-amplitude fields (up to ∼25 $\mathrm{mT_{pk}}$, based on the current limits of the transmit amplifier (Apex PA12A) and on our coil geometry) at the drive frequency. The second mode of operation, the magnetometry mode, functions similarly to the Superparamagnetic Quantifier [3] with a low amplitude field (∼1 $\mathrm{mT_{pk}}$) at the drive frequency and high amplitude near-DC field (currently up to ∼50 $\mathrm{mT_{pk}}$ at 20 Hz). The bore is 5 mm to maximize sensitivity to SPIONs contained in a 3 mm diam. glass bulb while minimizing power requirements. Excluding the computer and data acquisition console we expect the system cost to be approximately 500 USD. The precise cost estimate and bill of materials the is archived on the GitHub page. The documentation on that page is organized similarly to the imager.

The third system we present is an electromagnet winding jig. By winding electromagnets in-house, the overall cost of a system is greatly diminished. Additionally, having the capability to rapidly prototype electro-

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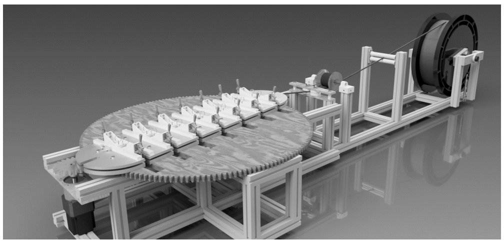

Figure 3: A digital rendering of the winding jig.

magnets with varying geometry facilitates design iteration and exploration. Fig. 3 shows a rendering of the jig designed for winding planar coils. To form multi-layer magnets, we have wound multiple single coils and stacked them, soldering connections between layers. The documentation consists of the Inventor CAD files, assembly, and use guidelines.

IV Conclusions and Future Directions

The OS-MPI project is intended to enable open communication and sharing within the MPI community while lowering the barrier to entry for new groups joining the field. The suite of instrumentation we present with the OS-MPI project, is intended as a low-cost "starter" system that can be assembled in-house. This system's functionality enables research explorations spanning a broad spectrum of applications and is not intended to compete with more polished commercial products.

While the GitHub page is currently supplied with many designs, price estimates, discussions of design rationale, and application notes, we are actively working on providing more supporting documentation. One addition we are working toward is a more sophisticated reconstruction algorithm that utilizes data from the spectrometer. Future work will also include finding a solution to compatible structures for data sharing. Like the format proposed by Knopp *et al.* [6], we use a Hierarchical Data Format (HDF), but with a data structure tuned to the needs of a time-series imaging FFL scanner.

Acknowledgments

We thank Simon Sigalovsky for his work on the mechanical components and Jochen Franke, Thomas Witzel, Matthew Rosen, and Jason Stockman for their insights along the way.

Author's Statement

Research funding: Funding for the work comes from NIBIB U01EB025121, NIMH R24106053, and NSF GRFP 1122374. Authors state no conflict of interest.

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