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The "harmoMPI" Project: Harmonizing Magnetic Particle Imaging Through Scanner-Independent Functional Phantoms

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Abstract

Magnetic Particle Imaging (MPI) is an emerging tomographic modality recognized for its capability of directly detecting magnetic nanoparticles (MNPs), enabling real-time 3D imaging with high sensitivity. Since its introduction in 2005, various preclinical MPI scanners have been developed, but cross-platform comparisons lack due to missing standardized phantoms and operation protocols. Recently, efforts towards development of human-sized MPI have intensified. To facilitate the transition beyond the preclinical research phase, harmonization of MPI technology is essential. Within the "harmoMPI" project, we seek to develop platform-independent, modular phantoms that enable reliable assessment of key performance parameters for a consistent performance evaluation across different MPI systems. With the support from the MPI research community, the "harmoMPI" initiative aims to harmonize MPI technology, advance collaboration research, and pave the path toward clinically relevant applications.

I. Introduction

Magnetic Particle Imaging (MPI) is an innovative functional tomographic imaging technique, renowned for its high sensitivity and spatial-temporal resolution, enabling real-time 3D imaging. MPI employs magnetic nanoparticles (MNPs) as a versatile signal source for various biomedical applications. First introduced in 2005 [1], a variety of preclinical MPI scanner designs have been developed, including commercial and research systems. In recent years, increasing activities towards human-sized MPI have intensified, particularly for imaging of the head [2–6] and lower limbs [7]. However, harmonization of MPI scanner systems is still lacking, although it is a crucial prerequisite for clinical translation. Here we want to give a conceptual introduction of the project to the MPI community, detailed methodological elaboration will be performed during the course of the project.

II. Methods

To enable consistent comparison and harmonization across different MPI developments, we are initiating the development of scanner independent phantoms and standardized operational recommendations. Therefore, we have designed a collaborative workflow based on existing literature, preliminary tests, and the expertise of the research community. As a first step, we start by developing a classification scheme for MPI scanners to elaborate the requirements for harmonization.

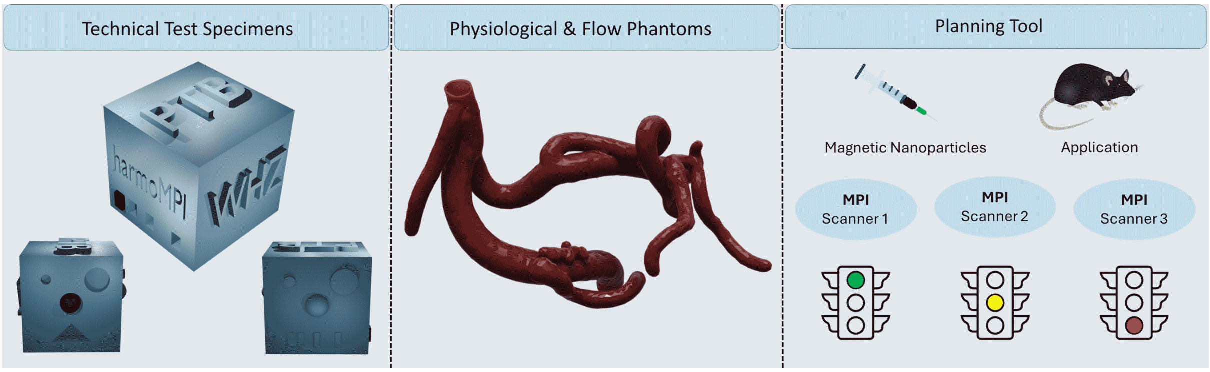

Figure 1: Workflow of the project: Dedicated test objects and functional phantoms for developing a consistent performance evaluation procedure and a planning tool for efficient experiment planning.

The subsequent steps involve developing static, flow and physiological phantoms that can be modularly adapted to different scanner architectures, as shown in Figure 1. Using a dedicated, standardized evaluation protocol, we will then perform cross-platform comparative measurements. Using the data collected during this project, a planning tool will be built that helps identify the optimal scanner configuration for given research questions. The planning tool will then provide efficient experiment planning, support quality assurance, and minimize unnecessary animal testing by reducing trial-and-error approaches.

III. Results and Current Progress

For the first phase of the project, we developed a simple static test object and segmented a brain vessel structure to fabricate an initial physiological phantom (Figure 1). The phantoms are 3D-printed using stereolithography with Formlabs Form 2. To enable quality assurance in terms of 3D printed geometry sizes, we scan the printed test object using the Revopoint MINI 3D scanner and a photometric method with 3DF Zephyr software. To quantify geometry and to obtain actual object dimensions, MeshLab is used. By embedding MNP into a polymer matrix, long-term stable polymer-MNP composites with defined magnetic properties/concentrations can be produced [8, 9]. Using this approach, we fabricated interchangeable MNP polymer inserts that can be placed into the test object to create various magnetic distributions. These are used to evaluate the spatial resolution and sensitivity of different MPI scanners. To assess the accuracy of MPI reconstructions, the dimensions of the reconstructed objects are compared with the dimensions of the actual objects, thus enabling consistent benchmarking across different MPI platforms.

To further investigate the performance of MPI scanners in terms of detecting dynamic changes in MNP dispersion concentration, we developed a MNP mixing flow phantom. By applying known flow rates of MNP and diluent to a mixing setup, a specific MNP concentration can be set and continuously modified in the flow setup, thereby simulating the MNP concentration change in the circulatory system.

IV. Conclusion

We have established an initial workflow, based on literature, as well as our own and community expertise, to enable a consistent performance evaluation framework for MPI systems. Using our test objects and a mixing flow phantom, defined static and dynamic particle distributions/concentrations can be generated to assess key performance parameters of MPI scanners. These developments mark the first steps toward harmonizing MPI system evaluation. As the “harmoMPI” project progresses, our aim is to expand the set of standardized phantoms, refine measurement protocols, and validate them across multiple platforms. Collaboration within the MPI community is strongly encouraged to jointly advance this harmonization effort and support the translation of MPI to clinical applications. As a community-wide initiative, open dissemination of phantom designs and operational procedures is crucial for adoption. Therefore, developed protocols and phantom files, as well as the final planning tool, will be provided in an open repository.

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Author’s statement

Conflict of interest: Authors state no conflict of interest.

References

[1] B. Gleich and J. Weizenecker. Tomographic imaging using the nonlinear response of magnetic particles. *Nature*, 435(7046):1214–1217, 2005, doi:10.1038/nature03808.

[2] F. Thieben, F. Foerger, F. Mohn, N. Hackelberg, M. Boberg, J.-P. Scheel, M. Möddel, M. Graeser, and T. Knopp. System characterization of a human-sized 3D real-time magnetic particle imaging scanner for cerebral applications. *Communications Engineering*, 3(1):47, 2024, doi:10.1038/s44172-024-00192-6.

[3] K. Nomura, M. Washino, T. Matsuda, S. Seino, T. Nakagawa, T. Kiwa, and M. Kanemaru. Development of human head size Magnetic Particle Imaging system. *International Journal on Magnetic Particle Imaging IJMPI*, 10(1 Suppl 1), 2024, doi:10.18416/IJMPI.2024.2403001.

[4] Z. Wei, Y. Liu, S. Liu, X. Yu, H. Zhang, T. Zhu, B. Zhang, Y. Zhang, H. Huang, Y. Fan, H. Li, J. Wang, J. Tian, and H. Hui. First Nonhuman Primate-Sized Magnetic Particle Imaging System Based on Digital-Scanned Focus Field. *IEEE Transactions on Instrumentation and Measurement*, 73:1–11, 2024, doi:10.1109/TIM.2024.3418109.

[5] E. Mattingly, M. Śliwiak, E. Mason, J. Chacon-Caldera, A. Barksdale, F. H. Niebel, K. Herb, M. Graeser, and L. L. Wald. Design, construction and validation of a magnetic particle imaging (MPI) system for human brain imaging. *Physics in Medicine & Biology*, 70(1):015019, 2025, doi:10.1088/1361-6560/ad9db0.

[6] T.-A. Le, M. Phu Bui, Y. Hadadian, K. Mohamed Gadelmowla, S. Oh, C. Im, S. Hahn, and J. Yoon. Toward Human-Scale Magnetic Particle Imaging: Development of the First System With Superconductor-Based Selection Coils. *IEEE Transactions on Medical Imaging*, 43(12):4266–4280, 2024, doi:10.1109/TMI.2024.3419427.

[7] P. Vogel, M. A. Rückert, C. Greiner, J. Günther, T. Reichl, T. Kampf, T. A. Bley, V. C. Behr, and S. Herz. iMPI: Portable human-sized magnetic particle imaging scanner for real-time endovascular interventions. *Scientific Reports*, 13(1):10472, 2023, doi:10.1038/s41598-023-37351-2.

[8] N. Löwa, R. Hoffmann, D. Gutkelch, O. Kosch, S. Dutz, and F. Wiekhorst. A multi-purpose phantom kit for magnetic particle imaging. *Current Directions in Biomedical Engineering*, 7(2):319–322, 2021, doi:10.1515/cdbme-2021-2081.

[9] L. Wöckel, J. Wells, O. Kosch, S. Lyer, C. Alexiou, C. Grüttner, F. Wiekhorst, and S. Dutz. Long-term stable measurement phantoms for magnetic particle imaging. *Journal of Magnetism and Magnetic Materials*, 471:1–7, 2019, doi:10.1016/j.jmmm.2018.09.012.

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