International Journal on Magnetic Particle Imaging
Vol 6, No 2, Article ID 2106001, 3 Pages

Infinite Science Publishing

Guest Editorial

Recent advances and prospects for accelerated development in magnetic particle imaging

James Wells[a,*]

[a]Physikalisch-Technische Bundesanstalt, Berlin, Germany
[*]Corresponding author, email: james.wells@ptb.de

Published online 05 June 2021

Abstract

The second issue of the sixth volume of the International Journal on Magnetic Particle Imaging presents three original research papers spanning theoretical and experimental studies designed to improve various aspects of existing MPI technology. The papers present methods for improving image reconstruction processes during magnetic particle imaging by the adoption of new statistical methods, for reducing artifacts in reconstructed images arising from non-ideal selection-field gradients, and a theoretical study modelling how the magnetic particle imaging signal is influenced by parameters of the nanoparticle tracer including the magnetic anisotropy and core radius. The papers provide a snap-shot of current advances in the engineering of magnetic particle imaging systems, and provide insight into how the development and uptake of the technology can be accelerated.

Magnetic particle imaging (MPI) is a unique medical imaging technology with the potential to provide new and improved methods for both diagnosis and therapy of a multitude of medical conditions [1–7]. It can additionally be used to support innovative studies in the life sciences [8, 9]. MPI has attracted much interest in the 15 years since it was initially unveiled to the scientific community [10]. This has produced focused research resulting in significant technological development and validation for both the hardware and signal processing aspects of MPI [11–15], and also in a large number of exploratory studies being undertaken to evaluate the capabilities of the technology in a diverse range of biomedical applications. Despite these great advances, and an ever-increasing number of researchers interested in the topic, a significant gulf still exists between the technology's current situation and a final goal of it achieving widespread regulatory approval and clinical implementation.

The first article in this issue details an alternative approach to MPI image reconstruction using L1 data fitting instead of the commonly implemented L2 fitting based Kaczmarz method [16]. The authors present both qualitative and quantitative comparisons between image reconstructions using the L1 and L2 fitting techniques. The results show that the L1 fitting method reduces the influence of outliers during image reconstruction and that it can compete with the standard L2 method when combined with frequency selection processes based on the signal-to-noise ratios. The L1 method only requires the input of a single tuning parameter (compared with 2 parameters for the standard L2 technique), making it advantageous for developing tools for non-expert users. In addition to being a prime example of the improvements in MPI technology which can be achieved by the broad inclusion of fresh engineering and data processing concepts, this work is also an excellent example of the type of progress which can be realized by the provision of freely available MPI data as well as open-source code for the research community. All of the results presented in this paper are based on data sets made publicly available through the OpenMPI project [17]. At present, a major bottleneck in the progression of MPI technology is the small number of MPI scanners existing in the world, and the subsequent inaccessibility of the technique and raw measurement data for many interested researchers. The OpenMPI project is a recent initiative to address this issue by providing a web platform offering freely accessible MPI measurement data in a standardized format for all researchers interested in developing fresh approaches to MPI data processing. The study [16] in this issue represents the first published quantitative study undertaken using the data made available in the OpenMPI project, clearly demonstrating the progress which this approach can foster.

The topic of image artifacts introduced by non-ideal field gradients during MPI is addressed in the second paper in this issue [18]. Here the effects arising from deviations from ideal linear gradients in the selection field of an X-space MPI scanner are for the first time identified. Algorithms to compensate for these effects are presented, although the unwarping process does not correct the loss of resolution arising from the original field deviation. The results represent another important step towards the realization of quantitative MPI measurements which are both optimized and validated.

Modelling and simulations are also key to the efficient realization of optimized MPI systems. These tools are highly useful in the development of all aspects of drive-field generation, scanner receive-chains, and of course in the engineering of magnetic nanoparticles as MPI tracers. The third article in this issue presents the results of a range of simulations which explore how differing parameters of magnetic nanoparticles such as their anisotropy and core radius influence the MPI spectrum produced by the particles under 1-dimensional drive fields [19]. The results are of interest to the large community of researchers interested in synthesizing magnetic nanoparticles engineered to offer optimal signal for magnetic particle imaging applications.

The papers included in this issue are an encouraging display of recent incremental advances in MPI technology. The accessibility of scanner hardware in the MPI community remains low, however, and is likely to do so in the foreseeable future. It is the author's opinion that accelerated progression of MPI towards higher technology readiness levels can only be achieved by the realization of broad accessibility of all aspects of the technology (hardware, software, measurement data), and the creation of fresh opportunities for the exchange of ideas, expertise and researcher mobility between laboratories.

The early success of the OpenMPI project reported in this issue suggests that much can be achieved via the provision of freely accessible MPI data, and that this is an initiative which deserves to be expanded. In addition to this, there remains a need for new collaborations and projects to facilitate the spread of MPI expertise between research groups, permit researchers to visits to laboratories possessing MPI equipment, and accelerate the spawning of new ideas for engineering MPI technology and applications thereof. A particular emphasis should be placed upon enhancing these links between the few countries with established MPI research ecosystems, and researchers in other countries which have no MPI equipment currently available, but who are keen to engage with the technique.

In the longer term, increasing the global availability of MPI systems will largely hinge upon continued growth in the commercial MPI sector. Since the beginning of MPI research, the involvement of business enterprises has been crucial to the continuation and progression of this field. Tremendous progress has already been made, with multiple preclinical MPI systems and various add-on packages for different applications being sold by different companies. Further advances in the capabilities of these commercial MPI products are anticipated in the coming years. A healthy symbiosis is required between mutually supporting activities in both the Open Research and commercial sectors for MPI technology to progress at the maximum possible rate.

In conclusion, the latest issue of the International Journal on Magnetic Particle Imaging showcases an encouraging assortment of studies which will undoubtedly aid the technology's progress towards future clinical implementation. In addition, this editorial conveys the author's own opinions on how existing progress in MPI technology and applications can be accelerated via the enhanced provision of opportunities for data sharing, improved access to measurement equipment and broad sharing of ideas and concepts among the international MPI community.

References

[1] N. Talebloo, M. Gudi, N. Robertson, and P. Wang. Magnetic Particle Imaging: Current Applications in Biomedical Research. *Journal of Magnetic Resonance Imaging*, 51(6):1659–1668, 2020, doi:10.1002/jmri.26875.

[2] B. Gleich, Principles and Applications of Magnetic Particle Imaging. Wiesbaden: Springer Fachmedien Wiesbaden, 2014, doi:10.1007/978-3-658-01961-7.

[3] S. Hildebrand, N. Löwa, H. Paysen, R. M. Fratila, L. Reverte-Salisa, T. Trakoolwilaiwan, Z. Niu, G. Kasparis, S. F. Preuss, O. Kosch, J. M. de la Fuente, N. T. K. Thanh, F. Wiekhorst, and A. Pfeifer. Quantification of Lipoprotein Uptake in Vivo Using Magnetic Particle Imaging and Spectroscopy. *ACS Nano*, 15(1):434–446, 2021, doi:10.1021/acsnano.0c03229.

[4] J. Wells, S. Twamley, A. Sekar, A. Ludwig, H. Paysen, O. Kosch, and F. Wiekhorst. Lissajous scanning magnetic particle imaging as a multifunctional platform for magnetic hyperthermia therapy. *Nanoscale*, 12(35):18342–18355, 2020, doi:10.1039/D0NR00604A.

[5] X. Zhu, J. Li, P. Peng, N. Hosseini Nassab, and B. R. Smith. Quantitative Drug Release Monitoring in Tumors of Living Subjects by Magnetic Particle Imaging Nanocomposite. *Nano Letters*, 19(10):6725–6733, 2019, doi:10.1021/acs.nanolett.9b01202.

[6] A. Meola, J. Rao, N. Chaudhary, G. Song, X. Zheng, and S. D. Chang. Magnetic Particle Imaging in Neurosurgery. *World Neurosurgery*, 125:261–270, 2019, doi:10.1016/j.wneu.2019.01.180.

[7] D. Weller, J. M. Salamon, A. Frölich, M. Möddel, T. Knopp, and R. Werner. Combining Direct 3D Volume Rendering and Magnetic Particle Imaging to Advance Radiation-Free Real-Time 3D Guidance of Vascular Interventions. *CardioVascular and Interventional Radiology*, 43(2):322–330, 2020, doi:10.1007/s00270-019-02340-4.

[8] A. Mimura, Y. Inaoka, S. Asakawa, and K. Murase. A Novel Cellular Imaging Method Using Hemagglutinating Virus of Japan-Envelope (HVJ-E) Vector and Magnetic Particle Imaging. *Journal of Nanoscience and Nanotechnology*, 20(4):2007–2017, 2020, doi:10.1166/jnn.2020.17322.

[9] H. Paysen, N. Loewa, A. Stach, J. Wells, O. Kosch, S. Twamley, M. R. Makowski, T. Schaeffter, A. Ludwig, and F. Wiekhorst. Cellular uptake of magnetic nanoparticles imaged and quantified by magnetic particle imaging. *Scientific Reports*, 10(1):1922, 2020, doi:10.1038/s41598-020-58853-3.

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

[11] M. Graeser, F. Thieben, P. Szwargulski, F. Werner, N. Gdaniec, M. Boberg, F. Griese, M. Möddel, P. Ludewig, D. van de Ven, O. M. Weber, O. Woywode, B. Gleich, and T. Knopp. Human-sized magnetic particle imaging for brain applications. *Nature Communications*, 10(1):1936, 2019, doi:10.1038/s41467-019-09704-x.

[12] M. Graeser, T. Knopp, P. Szwargulski, T. Friedrich, A. von Gladiss, M. Kaul, K. M. Krishnan, H. Ittrich, G. Adam, and T. M. Buzug. Towards Picogram Detection of Superparamagnetic Iron-Oxide Particles Using a Gradiometric Receive Coil. *Scientific Reports*, 7(1):6872, 2017, doi:10.1038/s41598-017-06992-5.

[13] P. Vogel, J. Markert, M. A. Rückert, S. Herz, B. Keßler, K. Dremel, D. Althoff, M. Weber, T. M. Buzug, T. A. Bley, W. H. Kullmann, R. Hanke, S. Zabler, and V. C. Behr. Magnetic Particle Imaging meets Computed Tomography: first simultaneous imaging. *Scientific Reports*, 9(1):12627, 2019, doi:10.1038/s41598-019-48960-1.

[14] J. Weizenecker, B. Gleich, J. Rahmer, H. Dahnke, and J. Borgert. Three-dimensional real-time in vivo magnetic particle imaging. *Physics in Medicine and Biology*, 54(5):L1–L10, 2009, doi:10.1088/0031-9155/54/5/L01.

[15] H. Paysen, O. Kosch, J. Wells, N. Loewa, and F. Wiekhorst. Characterization of noise and background signals in a magnetic particle imaging system. *Physics in Medicine & Biology*, 65(23):235031, 2020, doi:10.1088/1361-6560/abc364.

[16] T. Kluth and B. Jin. L1 data fitting for robust reconstruction in magnetic particle imaging: quantitative evaluation on Open MPI dataset. *International Journal on Magnetic Particle Imaging*, 6(2), 2020, doi:10.18416/IJMPI.2020.2012001.

[17] T. Knopp, P. Szwargulski, F. Griese, and M. Gräser. OpenMPIData: An initiative for freely accessible magnetic particle imaging data. *Data in Brief*, 28:104971, 2020, doi:10.1016/j.dib.2019.104971.

[18] E. Yagiz, A. R. Cagil, and E. U. Saritas. Non-ideal Selection Field Induced Artifacts in X-Space MPI. *International Journal on Magnetic Particle Imaging*, 6(2), 2020, doi:10.18416/IJMPI.2020.2006001.

[19] T. Klemme, T. M. Buzug, and A. Neumann. Exploring Parameters of Magnetic Particles in 1D Field Excitation. *International Journal on Magnetic Particle Imaging*, 6(2), 2020, doi:10.18416/IJMPI.2020.2004001.