International Journal on Magnetic Particle Imaging
Vol 3, No 1, Article ID 1706000, 3 Pages

Infinite Science Publishing

Guest Editorial

Recent Progress in MPI Imaging Methodology, Scanner Instrumentation, and Image Reconstruction

Ludek Sefc*

Center for Advanced Preclinical Imaging (CAPI), First Faculty of Medicine, Charles University, Prague, Czech Republic
*Corresponding author, email: sefc@cesnet.cz

Received 23 May 2017; Accepted 7 June 2017; Published online 20 June 2017

Abstract

The first issue of the third volume of the International Journal on Magnetic Particle Imaging (IJMPI) offers 21 papers, most of them presented at the 7th International Workshop on Magnetic Particle Imaging. The number of contributions in this issue exceeds the total number of papers published in previous volumes of IJMPI, which confirms a rapid expansion of the young scientific discipline of Magnetic Particle Imaging (MPI). The main topics covered are hardware development, image reconstruction and improvement, tracer properties, and novel MPI applications.

A number of interesting papers, bringing new insights into the field of the rapidly developing magnetic particle imaging (MPI), are presented in this issue of the International Journal on Magnetic Particle Imaging.

The first contribution by Ilbey et al. [1] entitled "Comparison of System-Matrix-Based and Projection-Based Reconstructions for Field Free Line Magnetic Particle Imaging" compares the relative performance of two approaches used for processing a field free line (FFL) MPI signal. FFL MPI data can be processed via a system-matrix or a projection-based reconstruction. The authors simulated the acquired data for a broad range of noise levels and proposed an optimization of the signal reconstruction for both methods.

The paper by Franziska Weigl et al. [2] "Determination of the Total Circulating Blood Volume using Magnetic Particle Spectroscopy" is the first paper in this issue that describes a new application with clinical potential. The gold standard for blood volume determination is a dual-isotope blood volume method. The authors proved on a rat model that Magnetic Particle Spectroscopy (MPS) is a suitable tool to measure the total circulating blood volume with a high accuracy and without radiation or toxic effects.

The contribution of Franke et al. [3] "MPI Flow Analysis Toolbox exploiting pulsed tracer information - an aneurysm phantom proof" demonstrates a successful cooperation between industry and university. The authors presented an aneurysm phantom perfused by a periodically pulsing tracer solution. They show that MPI can be used for accurate, fast, and non-radioactive blood flow measurements. The authors developed a MATLAB based Flow Analysis Toolbox for this purpose.

An interesting approach for improving the signal quality of the system matrix measurement was published by Graeser et al. [4] in their paper "SNR and Discretization Enhancement for System Matrix Determination by Decreasing the Gradient in Magnetic Particle Imaging". The method uses a reduced gradient strength allowing the use of a finer sampling grid and/or a larger calibration sample. Both can be utilized to enhance the signal-to-noise ratio as well as the spatial resolution of reconstructed MPI data. Although the method was applied to 2D phantom data it can be extended to 3D imaging as well.

MPS has been employed by Draack et al. [5]. Their article "Temperature-dependent MPS measurements" shows the temperature dependence of the harmonics spectra of superparamagnetic iron oxide (SPIO) nanopar-

10.18416/ijmpi.2017.1706000

ticles (FeraSpin™ XL, diameter of 50 nm to 60 nm) during measurements in a wide range of temperatures (-13 °C to +114 °C), with a bigger temperature response of freeze-dried nanoparticles to those in suspension. The possible reason of this difference is discussed.

A new possibility for an anatomical co-registration of MPI images with ultrasound signals was opened by Kranemann et al. [6]. They confirm in their paper "Towards the Integration of an MPI Compatible Ultrasound Transducer" that a modified ultrasound probe can be used in an MPI scanner. Regardless the fact that both modalities can influence each other, they can be used consecutively and after a proper shielding and optimization a simultaneous use might be possible as well.

The work "Improved image reconstruction in magnetic particle imaging using structural a priori information" published by Bathke et al. [7] extends the range of papers that deal with image improvement in MPI. In a simulation study, they proved that the inclusion of additional a-priory information obtained by MRI led to both, qualitative and quantitative, improvement of the MPI images. The algorithm presented works on a 2D setup, but is applicable to 3D images.

In their article "Influence of the Receive Channel Number on the Spatial Resolution in Magnetic Particle Imaging" Szwargulski and Knopp [8] show a possible simplification in the construction of 3D Lissajous type MPI scanners. When a signal from just one receive channel is used for reconstruction, there is only a slight loss of spatial resolution. Nevertheless, the reconstruction using a signal obtained by all three receive channels gives still a better image quality. In this case, a substantial part of redundant information can be omitted from the reconstruction process without final image deterioration. This can significantly speed up reconstruction time. The authors also discuss the possibility of designing an MPI scanner with a larger single channel receive coil that will grant a better SNR and thus potentially a better image.

Bakenecker's et al. [9] contribution "Experimental Validation of the Selection Field of a Rabbit-Sized FFL Scanner" tested properties of their FFL MPI scanner with a bore diameter of 180 mm presented previously. Their experimental measurements show that a compromise between power losses in shielding due to a high FFL rotation frequency and actual current can be achieved by an installed transformer. Therefore, the scanner should operate at a lower frequency than originally designated and a modification of the electronics and filters will be needed for fulfilling the expected settings.

Further investigations on the rabbit-size scanner presented in previous paper were described by Stelzner et al. [10] in their contribution "Measurements Inside a Rabbit Sized FFL-MPI Device Using a Gradiometric Receive Coil". Their results suggest that by use of a gradiometric receive coil the scanner sensitivity can be increased. Additional steps in scanner modification are discussed.

The study "Submillimeter-Accurate Marker Localization within Low Gradient Magnetic Particle Imaging Tomograms" by Griese et al. [11] leads towards the use of MPI for medical device tracking and navigation. The authors demonstrated an effective marker tracking using a temporal resolution of 46 frames/ms.

The effect on the peripheral nerve stimulation in a human subject for different length of the MPI duty cycle was studied by Demirel and Saritas [12] in their paper "Effects of Duty Cycle on Magnetostimulation Thresholds in MPI". The duty cycles varied from 5 % to 100 % (percentage of 2 s interval covered by 100 ms pulses). They conclude that the effect of the duty cycle on magnetostimulation thresholds is significantly lower compared to the effects of the frequency or the pulse duration.

A new coil setup for an FFL MPI device has been proposed by Tonyushkin [13] in the contribution "Single-Sided Hybrid Selection Coils for Field-Free Line Magnetic Particle Imaging". This MPI scanner where all components are on one side could be useful, e.g. for intraoperative device tracking. The selection field simulated by the author consists of four permanent magnets and he concluded that such a concept is a feasible solution for single-sided FFL generation in a large FOV.

A possible breakthrough application for clinical MPI was proposed by Mason et al. [14]. In their paper "Design analysis of an MPI human functional brain scanner" they showed that it is feasible to design an FFL MPI system for measuring an increase in blood flow in activated brain regions. This functional MPI could possibly outperform fMRI in terms of speed and sensitivity.

An improvement in image reconstruction for scanners using a cartesian sampling trajectory was reported by Werner et al. [15]. In their paper "Improving the Spatial Resolution of Bidirectional Cartesian MPI Data using Fourier Techniques" they propose an image combination algorithm that allows to obtain isotropic spatial resolution in 2D image using bidirectional imaging trajectories.

A new concept of a low frequency (less than kHz) mechanical MPI scanner has been proposed by Colombo et al. [16]. In the paper "Towards a mechanical MPI scanner based on atomic magnetometry", the authors describe the design, performance, and simulation study of the scanner with atomic magnetometer used for magnetic particle spectra recording. The low frequencies allow the use of a much broader variety of particles, i.e. larger particles, than in conventional MPI.

The application related paper "Detection of flow dynamic changes in 3D printed aneurysm models after treatment" by Sedlacik et al. [17] used a realistic aneurysm model before and after treatment (endovascular material filling of aneurysm) with pulsating physiological flow of a SPION contrast solution for visualization of differences in blood flow. MPI was able to detect a delay and the dynamics in the contrast flow through different treatment models.

10.18416/ijmpi.2017.1706000

Baki et al. [18] describe in "Continuous synthesis of single core iron oxide nanoparticles for MPI tracer development" an optimized production of iron nanoparticles of different sizes and morphology by use of a micromixing device. The method allows a controlled tuning of the particle characteristics and structure-performance properties.

An extensive evaluation of maghemite nanoparticles with different core diameters and particle structures was the focus of the paper "Effect of particle size and structure on harmonic intensity of blood-pooling multi-core magnetic nanoparticles for magnetic particle imaging" by Ota et al. [19]. The nanoparticles were functionalized for blood pooling and were tested in solid and liquid samples mimicking tumors / organs and blood, respectively. A comparison with Resovist is included.

Another MPI contrast related article published by Yoshida et al. [20], "Effect of Core Size Distribution of Immobilized Magnetic Nanoparticles on Harmonic Magnetization" used numerical simulations to study the effect of the core size distribution of immobilized nanoparticles on the harmonic signals. They proved that nanoparticles with a high polydispersity index lose signal and samples with a narrow size distribution would effectively improve the sensitivity of the MPI system.

The last paper "Artifact Analysis for Axially Elongated Lissajous Trajectories in Magnetic Particle Imaging" from Kaethner et al. [21] returns to image reconstruction cues. They performed a simulation-based analysis of the elongation length for axially elongated Lissajous trajectories in terms of signal loss and artifacts. They conclude that signal loss as well as the occurrence of artifacts can be significantly reduced when the elongation is chosen in accordance to suitable theoretical basics.

References

[1] S. Ilbey, C. B. Top, A. Güngör, T. Çukur, and E. U. Saritas. Comparison of System-Matrix-Based and Projection-Based Reconstructions for Field Free Line Magnetic Particle Imaging. *Intern. J. Magnetic Particle Imaging*, 3(1):1703022, 2017. doi:10.18416/ijmpi.2017.1703022.

[2] F. Weigl, A. Seifert, A. Kraupner, P. M. Jakob, K.-H. Hiller, and F. Fidler. Determination of the Total Circulating Blood Volume using Magnetic Particle Spectroscopy. *Intern. J. Magnetic Particle Imaging*, 3(1):1703021, 2017. doi:10.18416/ijmpi.2017.1703021.

[3] J. Franke, R. Lacroix, H. Lehr, M. Heidenreich, U. Heinen, and V. Schulz. MPI Flow Analysis Toolbox exploiting pulsed tracer information – an aneurysm phantom proof. *Intern. J. Magnetic Particle Imaging*, 3(1):1703020, 2017. doi:10.18416/ijmpi.2017.1703020.

[4] M. Graeser, A. von Gladiss, T. Friedrich, and T. M. Buzug. SNR and Discretization Enhancement for System Matrix Determination by Decreasing the Gradient in Magnetic Particle Imaging. *Intern. J. Magnetic Particle Imaging*, 3(1):1703019, 2017. doi:10.18416/ijmpi.2017.1703019.

[5] S. Draack, T. Viereck, C. Kuhlmann, M. Schilling, and F. Ludwig. Temperature-dependent MPS measurements. *Intern. J. Magnetic Particle Imaging*, 3(1):1703018, 2017. doi:10.18416/ijmpi.2017.1703018.

[6] T. C. Kranemann, T. Ersepke, and G. Schmitz. Towards the Integration of an MPI Compatible Ultrasound Transducer. *Intern. J. Magnetic Particle Imaging*, 3(1):1703016, 2017. doi:10.18416/ijmpi.2017.1703016.

[7] C. Bathke, T. Kluth, C. Brandt, and P. Maass. International Journal on Magnetic Particle ImagingVol 3, No 1, Article ID 1703015, 10 PagesResearch ArticleImproved Image Reconstruction in Magnetic Particle Imaging using Structural a priori Information. *Intern. J. Magnetic Particle Imaging*, 3(1):1703015, 2017. doi:10.18416/ijmpi.2017.1703015.

[8] P. Szwargulski and T. Knopp. Influence of the Receive Channel Number on the Spatial Resolution in Magnetic Particle Imaging. *Intern. J. Magnetic Particle Imaging*, 3(1):1703014, 2017. doi:10.18416/ijmpi.2017.1703014.

[9] A. C. Bakenecker, T. Friedrich, A. von Gladiss, M. Graeser, J. Stelzner, and T. M. Buzug. Experimental Validation of the Selection Field of a Rabbit-Sized FFL Scanner. *Intern. J. Magnetic Particle Imaging*, 3(1):1703013, 2017. doi:10.18416/ijmpi.2017.1703013.

[10] J. Stelzner, M. Graeser, A. Bakenecker, A von Gladiss, G. Bringout, and T. M. Buzug. Measurements Inside a Rabbit Sized FFL-MPI Device Using a Gradiometric Receive Coil. *Intern. J. Magnetic Particle Imaging*, 3(1):1703012, 2017. doi:10.18416/ijmpi.2017.1703012.

[11] F. Griese, T. Knopp, R. Werner, A. Schlaefer, and M. Möddel. Submillimeter-Accurate Marker Localization within Low Gradient Magnetic Particle Imaging Tomograms. *Intern. J. Magnetic Particle Imaging*, 3(1):1703011, 2017. doi:10.18416/ijmpi.2017.1703011.

[12] O. B. Demirel and E. U. Saritas. Effects of Duty Cycle on Magnetostimulation Thresholds in MPI. *Intern. J. Magnetic Particle Imaging*, 3(1):1703010, 2017. doi:10.18416/ijmpi.2017.1703010.

[13] A. Tonyushkin. Single-Sided Hybrid Selection Coils for Field-Free Line Magnetic Particle Imaging. *Intern. J. Magnetic Particle Imaging*, 3(1):1703009, 2017. doi:10.18416/ijmpi.2017.1703009.

[14] E. E. Mason, C. Z. Cooley, S. F. Cauley, M. A. Griswold, S. M. Conolly, and L. L. Wald. Design analysis of an MPI human functional brain scanner. *Intern. J. Magnetic Particle Imaging*, 3(1):1703008, 2017. doi:10.18416/ijmpi.2017.1703008.

[15] F. Werner, N. Gdaniec, and T. Knopp. Improving the Spatial Resolution of Bidirectional Cartesian MPI Data using Fourier Techniques. *Intern. J. Magnetic Particle Imaging*, 3(1):1703007, 2017. doi:10.18416/ijmpi.2017.1703007.

[16] S. Colombo, V. Lebedev, A. Tonyushkin, Z. D. Grujic, V. Dolgovskiy, and A. Weis. Towards a mechanical MPI scanner based on atomic magnetometry. *Intern. J. Magnetic Particle Imaging*, 3(1):1703006, 2017. doi:10.18416/ijmpi.2017.1703006.

[17] J. Sedlacik, A. Frölich, J. Spallek, N. D. Forkert, F. Werner, T. Knopp, D. Krause, J. Fiehler, and J.-H. Buhk. Detection of flow dynamic changes in 3D printed aneurysm models after treatment. *Intern. J. Magnetic Particle Imaging*, 3(1):1703005, 2017. doi:10.18416/ijmpi.2017.1703005.

[18] A. Baki, N. Löwa, R. Thiermann, C. Bantz, M. Maskos, F. Wiekhorst, and R. Bleul. Continuous synthesis of single core iron oxide nanoparticles for MPI tracer development. *Intern. J. Magnetic Particle Imaging*, 3(1):1703004, 2017. doi:10.18416/ijmpi.2017.1703004.

[19] S. Ota, R. Takeda, T. Yamada, I. Kato, S. Nohara, and Y. Takemura. Effect of particle size and structure on harmonic intensity of blood-pooling multi-core magnetic nanoparticles for magnetic particle imaging. *Intern. J. Magnetic Particle Imaging*, 3(1):1703003, 2017. doi:10.18416/ijmpi.2017.1703003.

[20] T. Yoshida, T. Sasayama, and K. Enpuku. Effect of Core Size Distribution of Immobilized Magnetic Nanoparticles on Harmonic Magnetization. *Intern. J. Magnetic Particle Imaging*, 3(1):1703002, 2017. doi:10.18416/ijmpi.2017.1703002.

[21] C. Kaethner, A. Cordes, A. Haensch, and T. M. Buzug. Artifact Analysis for Axially Elongated Lissajous Trajectories in Magnetic Particle Imaging. *Intern. J. Magnetic Particle Imaging*, 3(1):1703001, 2017. doi:10.18416/ijmpi.2017.1703001.

10.18416/ijmpi.2017.1706000