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Guest Editorial

Recent Developments on System Function/Matrix Representation, Hybrid Simulation Techniques, and Magnetic Actuation

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Abstract

The first issue of the sixth volume of the International Journal on Magnetic Particle Imaging presents four papers focusing on different aspects of the image reconstruction problem in magnetic particle imaging (MPI) and developments in magnetic actuation. The original research articles provide deeper insights into system function/matrix representation in terms of Chebyshev polynomials and they exploit a singular value decomposition (SVD) approach to reduce the size of the imaging problem. Introducing new experimental techniques enable gathering insights in the MPI methodology and magnetic actuation applications benefit from the development and analysis of new tools.

As an emerging imaging modality, magnetic particle imaging (MPI) provides a rich bag of current research directions. Many questions in the fields of system design, modeling, representation, and analysis, image reconstruction, and medical applications are still open. The first issue of the sixth volume includes four research papers addressing selected new and old questions in this context. One important prerequisite for accurate and efficient image reconstruction is a proper understanding of the system function/matrix in MPI. The first two articles of this issue particularly address the problem of system function/matrix representation from two different point of views.

Already in the early days of MPI research it was found for 1D excitation that the signal in Fourier domain corresponds to a certain Chebyshev polynomial when using the simplified "equilibrium" model based on the Langevin function [1]. In the same work the authors also reported empirically on multi-dimensional sinusoidal excitation patterns which motivated the conjecture that the multi-dimensional case extends to tensor products of Chebyshev polynomials. The first article of the present issue [2] addresses this open questions and provides the desired solution by deriving an explicit system function representation in terms of a series of tensor products of Chebyshev polynomials. It is further accompanied by empirical results on two approximation approaches exploiting this series expansion.

Another aspect in system matrix representation is its size which often result in large scale problem formulations for the image reconstruction problem, particularly for 3D imaging applications. Theoretical works indicate that the MPI image reconstruction problem can suffer from a high degree of ill-posedness [3–5]. But these findings also predict the high potential of low-rank approximations, such as sparse representations in certain bases

[6–8], optimized orthogonal transforms [9], or exploiting the singular value decomposition (SVD) [10]. The second article of this issue [11] proposes an efficient approach for system matrix representation of a frame-by-frame 1D excitation sequence (each frame corresponding to a different offset field, respectively position of the Cartesian excitation pattern). For any calibration measurement, the measured time signal (concatenated for all frames) is rearranged in a 2D frame-time matrix from which the SVD is carried out to obtain low-rank representations and their subsequent combination is used to solve the image reconstruction problem. Various heuristic rules for these steps are investigated by the authors illustrating the advantages of the proposed method in terms of reconstruction errors and computation times in a simulation study.

The third article [12] introduces a novel simulation technique to investigate the capabilities of MPI by introducing so-called "hybrid phantoms" which are in line with the hybrid system matrix approach [13–16]. The authors illustrate how a multi-dimensional MPS system can be exploited to emulate measurements of these hybrid phantoms. The phantoms benefit from superior properties of the MPS system, i.e., they yield high SNR measurement signals. Furthermore, another advantage of the hybrid phantoms is that they implicitly encode the physical behavior of the nanoparticles and thus allow more realistic simulations of phantom measurements in cases where model-based simulations are less accurate. Static 1D and 2D phantoms, and dynamic 3D phantoms are emulated in the article. Based on this approach effects on spatial resolution for 1D excitation (multiple vs. single receive coil) and 2D excitation (sine vs. cosine excitation) are investigated experimentally. In addition, an example for dynamic concentration reconstruction in 3D is provided which further illustrates the potential of hybrid phantoms.

Compared to the first three articles of the present issue, the fourth article [17] mainly addresses the topic of magnetic actuation to move magnetic swimmers in the field of view and uses MPI as a tool for the purpose of visualization, respectively potential tracking, only. In contrast to earlier works [18] where the swimmer has been coated by magnetic nanoparticles, the authors propose a new approach where the entire swimmer is made of 3D-printing material. These 3D-printed swimmers are then analyzed with respect to their material properties and steerability. In addition, its visualization by MPI is investigated further.

In summary, the articles of this issue include deeper insights into the MPI system function/matrix representation, new hybrid simulation techniques, and novel developments in magnetic actuation applications. The answers to the open questions in this issue will further guide image reconstruction and application research in MPI.

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