International Journal on Magnetic Particle Imaging
Vol 12, No 1, Suppl 1, Article ID 2603026, 3 Pages

Infinite Science Publishing

Proceedings Article

Influence of System Matrix Concentration and Frequency Selection on Reconstructed MPI Signals

Sathurya Jegatheeswaran [a,*] · Hanna Meenen [a,*] · Thorsten M. Buzug [a,b] · Ksenija Gräfe [a]

[a] Institute of Medical Engineering, University of Lübeck, Lübeck, Germany
[b] Fraunhofer IMTE, Research Institution for Individualized Medical Technology and Engineering, Lübeck, Germany
[*] Corresponding author, email: s.jegatheeswaran@uni-luebeck.de

Abstract

In Magnetic Particle Imaging (MPI), the system matrix (SM) characterizes the spatial encoding properties of the imaging system and the magnetic nanoparticle response. Ideally, for linear particle magnetization behavior, the concentration at which the SM is measured should not affect the reconstructed image. In this study, two SMs recorded with tracer concentrations of 8.5 mg(Fe)/ml and 1.92 mg(Fe)/ml were investigated. We show that, although the same SM is used, reconstruction discrepancies occur when the frequency coverage differs. We therefore propose to determine the usable frequency components based on the lower concentration SM to ensure a consistent reconstruction basis.

I. Introduction

Magnetic Particle Imaging (MPI) reconstructs magnetic nanoparticle distributions using a system matrix (SM) that characterizes the scanner response. Under ideal linear tracer behavior, the SM should be independent of tracer concentration [1]. In practice, nonlinear effects and SNR differences can cause deviations. Here, we examine the influence of SM concentration and frequency selection on reconstructed images using two SMs at 8.5 mg(Fe)/ml and 1.92 mg(Fe)/ml, representing concentration-independent and clinically relevant concentrations, respectively [2].

II. Methods

Two system matrices (SMs) were measured underidentical drive field conditions using the Bruker® preclinical MPI Scanner (Bruker BioSpin, Ettlingen, Germany) [3].

Both were acquired at $26 \times 26 \times 14$ positions, resulting in a field of view (FOV) of $52 \times 52 \times 28$ mm^3 with a voxel size of $2 \times 2 \times 2$ mm^3. The point sample used for the SM acquisition had the same physical dimensions as a voxel and contained 8 µl diluted Magtrace® tracer solution (Endomagnetics Ltd, Cambridge, UK) derived from a stock concentration of 28 mg(Fe)/ml. The first SM was recorded at a concentration of 8.5 mg(Fe)/ml, corresponding to typical values used for conventional MPI applications [1]. The second SM was measured at a concentration of 1.92 mg(Fe)/ml, representing the expected tracer concentration for future clinical applications [2].

Two separate samples of size $2.5 \times 2.5 \times 2.5$ mm^3 were prepared, containing Magtrace stock concentration and a dilution of 2.8 mg(Fe)/ml. They were measured next to each other with a center-to-center distance of 10 mm for image reconstruction using both system matrices. All other imaging parameters were kept constant to ensure comparability.

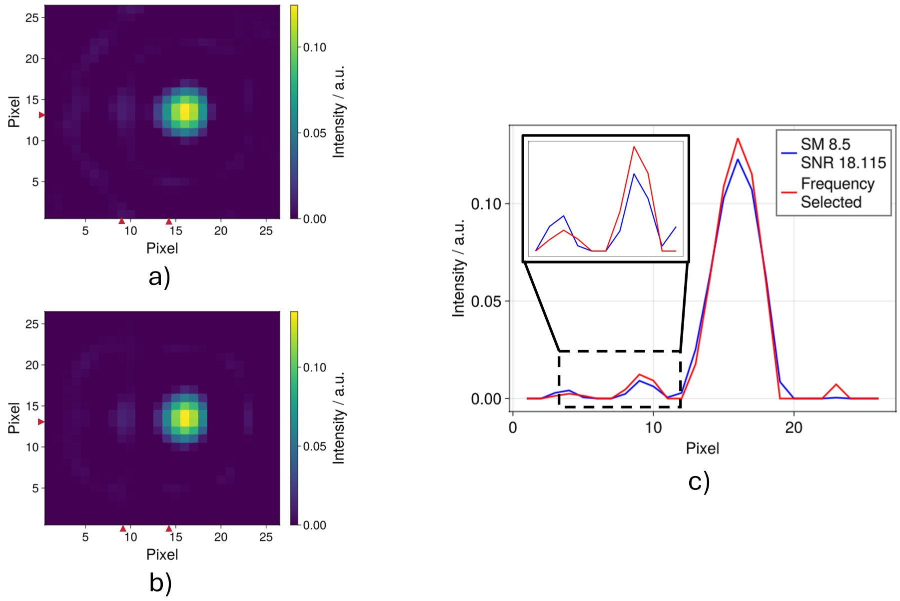

Figure 1: Reconstructed point sample data using SMs acquired at different concentrations. a) and b) show two point samples with a spacing of 10 mm (5 px) reconstructed using the SM measured at 8.5 mg(Fe)/ml and the SNR-threshold set to 18.118 for a). The same frequency mask derived from the low-concentration SM (1.92 mg(Fe)/ml) was applied to b). Arrows along the image axes mark the expected point sample positions. c) Line profile along the point sample axis for comparison of reconstructed intensity and background level.

II.I. Frequency Component Selection

For spectral analysis, the signal-to-noise ratio (SNR) for each frequency component $\overline{SM}(f_j)$ was calculated according to [3], as shown in Equation (1), where j denotes the frequency index. Here, $\overline{SM}(f_j)$ represents the absolute mean of the background-corrected system function over all spatial positions, and $\overline{BG}(f_j)$ denotes the corresponding background mean. This SNR-based evaluation was used to identify frequency components that contribute effectively to the image reconstruction.

$$\mathrm{SNR}(f_j) = \frac{\overline{SM}(f_j)}{\overline{BG}(f_j)} \qquad (1)$$

Due to the differing tracer concentrations, the number of frequency components above the threshold varied between the two SMs.

For reconstruction with the low-concentration SM, an SNR-threshold of 2 was used, leaving 2626 frequency components for image reconstruction. To ensure comparability between reconstructions, the same number of frequency components was used for reconstruction with the high-concentration SM which corresponds to an SNR-threshold of 18.115.

III. Results and Conclusion

In Figure 1a and Figure 1b, the reconstructed images of the sample plane are shown. Figure 1b illustrates the result obtained using the frequency component selection approach. The comparison in Figure 1c shows that the reconstruction based on the low-concentration SM yields slightly higher peak intensities and reduced background noise in regions without signal. This indicates that applying the frequency mask derived from the 1.92 mg(Fe)/ml SM provides a cleaner reconstruction and suppresses noise contributions. The noise level is 3×10^{-4} in $a.u.$ compared to 4.5×10^{-4} in $a.u.$, which also confirms this observation. The presented findings are based on controlled point sample measurements. Comparable behavior was also observed when applying additional SNR thresholds for frequency selection to both SMs. For practical applications, where the actual iron amount or tracer concentration may be unknown, applying the frequency mask derived from the low-concentration SM can help achieve consistent and optimal reconstruction results.

IV. Acknowledgments

Research funding: This project is supported by the Damp Stiftung (Grant Number 2022-08). Travel funding: This work was supported by the COST Action NexMPI (Grant Number CA23132).

V. Author's Statement

Conflict of interest: The authors state no conflict of interest.

10.18416/ijmpi.2026.2603026

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