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Measurement-based Synthesis of Field Free Line Trajectory Data

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Abstract

Calibrating Magnetic Particle Imaging systems is time-consuming when done with a robot. Synthesizing calibration data from fast calibration measurements can be a significant advantage when dealing with multiple magnetic particle types and trajectories. An approach for this synthesis is presented and evaluated using measured data from an arbitrary waveform Magnetic Particle Spectrometer.

I. Introduction

The calibration measurements for conventional robot-based system matrix reconstruction in Magnetic Particle Imaging capture both the particle behavior and field inhomogeneities at the expense of a potentially long calibration time. Another disadvantage is the limitation on a single trajectory. A different trajectory or a different particle type requires a new calibration measurement. Model-based reconstruction aims at eliminating the long calibration time but still needs parameter estimation for both the field and the particle behavior.

The applied field with its inhomogeneities can be described in terms of spherical harmonics and measured efficiently [1]. Modelling the particle behavior however requires solving partial differential equations and still needs a parameter estimation for a specific particle [2]. Here, we want to present an alternative approach using measurements from a Magnetic Particle Spectrometer (MPS) directly instead of performing a parameter estimation on the data.

II. Methods and materials

The main idea of the approach presented here is to separate field, trajectory and particle behavior (cf. [3]). The setup considered here is based on the Field Free Line (FFL) selection field (SF) in [4] combined with a fast drive field (DF) along the bore axis. An additional focus field (FF) rotating in conjunction with the SF is used to slowly, sinusoidally shift the FFL in its rotation plane at $z = 0\,\text{mm}$. The exemplary trajectory is based on an ideal FFL with a gradient of $2.4\,\text{T}\,\text{m}^{-1}$ which is rotated at 50 Hz. The DF operates at 25 kHz with a strength of 12 mT. The FF translates the FFL with 180 Hz and a strength of again 12 mT.

Only the central FFL plane at $z = 0\,\text{mm}$ is considered in the following for brevity. Thus, only the two remaining directions orthogonal to the FFL contribute to the superpositioned field of SF and FF of the full trajectory. In a coordinate system rotating in conjunction with the FFL, only one field component would determine the field at a certain position in the field of view (FOV). From this

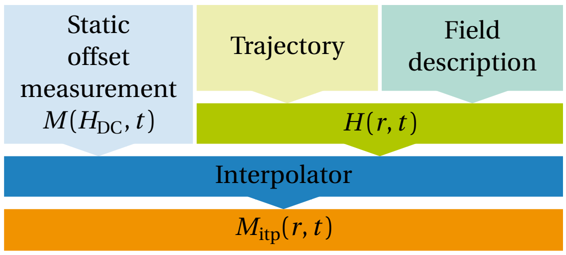

Figure 1: Schematic of the synthesis process. The trajectory and the field description (e.g. idealized fields or spherical harmonics) determine the magnetic field at the position r. The static offset measurement encodes the magnetization at time point t for a certain static offset H_{DC} and is used in the interpolator to interpolate between a range of static offsets. The field $H(r, t)$ is then fed to the interpolator which results in the magnetization $M_{itp}(r, t)$.

property we can assume that only one offset direction orthogonal to the DF is required to characterize the particle behavior. We assume that only the DF and a quasi-static offset due to SF and FF influence the particle magnetization and that we can thus synthesize the particle response of the full trajectory by interpolating the particle response to static offsets over a single DF period in time domain (cf. Figure 1). This method is derived from [5] but instead of rotating the whole system matrix which works only for an ideal FFL, an arbitrary field can be used for synthesis. For method assessment, both the data for the synthesis and the evaluation are measured with an in-house arbitrary waveform MPS [6]. A measurement with static offsets orthogonal to the DF direction ranging from −25 mT to 25 mT with a step size of 1 mT were acquired. Since the field needs time to stabilize 10 DF periods both at the start and the end of each offset are cut. This calibration measurement takes approximately one second. The resulting 530 periods are averaged for each offset and a cubic B-spline interpolation is used to interpolate between the offsets in time domain. The evaluation data is generated with the MPS by running a full trajectory of 100 ms duration for a grid of 11 × 11 pixels in a FOV of 10 mm × 10 mm. The feedback signal of the current in the spectrometer's send coils from the full-trajectory dataset is used as a reference for the applied field and fed into the interpolator for synthesis.

III. Results and discussion

The synthesis of the measured data obtains results close to the reference signals. Exemplary plots can be found in Figure 2. Some frequencies however show a rotated phase. This is not expected from previous fully simulation-based studies and needs further investigation. This issue can be fixed by a correction factor.

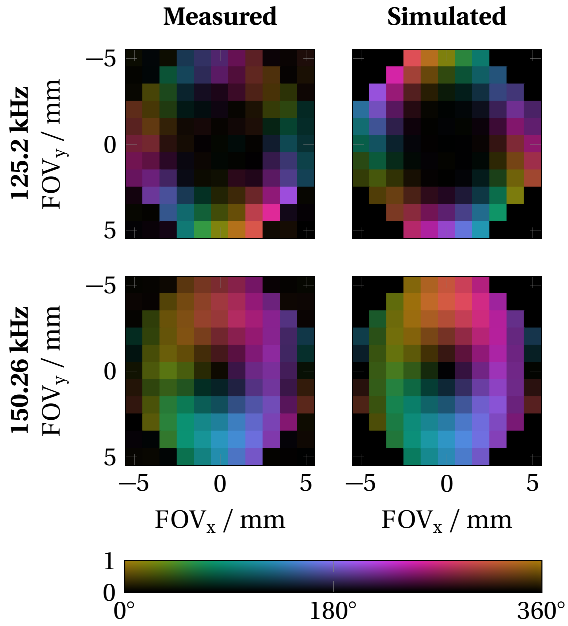

Figure 2: Color-coded plots of the slice at $z = 0$ for the frequency components 125.2 kHz (upper row) and 150.26 kHz (lower row) in the receive coil sensitive along x. The legend below shows the encoding of the amplitude in the range $0\ldots1$ by brightness and the encoding of the phase by color.

IV. Conclusion

The results show that for single-frequency excitation a full trajectory dataset can be synthesized for sufficiently slowly changing fields. This can aid in faster calibration of MPI systems. The method can be extended to incorporate inhomogeneities of all applied fields including the DF.

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Author's statement

Conflict of interest: Authors state no conflict of interest. JF and SI are employees of Bruker BioSpin.

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