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Receive path calibration to exchange system matrix data of different receivers

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Abstract

In Magnetic Particle Imaging the determination of the system matrix is a time-consuming process. As the transfer function differs depending on the electronics of the receive chain, a system matrix recorded with one chain cannot be used for reconstruction of measurement data using a different receive chain. This leads to huge amounts of data as system matrices have to be recorded for every set of drive field strength, particle system and receiver chain setting. In this paper the complexity of this is reduced by the factor of the receiver electronics. For each receive path of our MPI system the transfer function is recorded and stored on the measurement device. When loading the data, the transfer-function is corrected which allows the exchange of the system matrices data between receiver chains. To demonstrate this system matrix data is compared and a successful reconstruction of an in vivo dataset is shown.

I Introduction

In Magnetic Particle Imaging (MPI) the system matrix encodes all system and particle specific parameters in one dataset. This includes the signal generating field sequence or trajectory, the gradient, the particle dynamics, and the frequency dependent amplification or phase delays caused by the receive electronics. Besides the gradient, which can be assumed to only scale the image when altered in a sufficient small interval [1], each change of these parameters leads to inconsistencies between the measurement data and the system matrix, which in turn leads to a failing reconstruction. However, a second parameter, the transfer-function, which describes the frequency dependent amplification and phase delays of the receive chain is static as long as the electronics are not changed. This has been shown in other work on hybrid system calibration techniques [2,3,4]. The method can also be adapted to the system level, as system calibration data from one system can be used to reconstruct measurement data of another system. In this paper all receive chains of an MPI scanner are calibrated, which not only makes system matrices exchangeable between the receiver systems [5], but also reduces the total calibration time and data necessary by the number of chains in use. This allows the use of small highly sensitive coils for system matrix determination while preserving the bore size for recording the image data.

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II Material and methods

II.I Hardware

To measure the transfer function of all channels of each receive chain a 3D calibration coil was built on a sphere of 5 mm radius using a 0.2 mm enameled copper wire. The three channels are wound on the same core each with 10 turns. To limit the current through the calibration coil, a total resistance of 576 Ω is added in series to the coil ensuring a stable current over the total frequency range. The coil was driven by a vector network analyzer (DG8SAQ VNWA3, SDR-Kits) featuring a total output resistance of 50 Ω. With the calibration coil on the Tx-port and the receiver output on the Rx-port the transfer function can be measured as the S21 parameter:

$$TF = S21 \cdot \frac{\alpha R}{\pi r^2 N \omega}.$$

Here, α describes a voltage drop that, depending on the output impedance of the amplifier system, can occur because the input impedance of the ADC (100 Ω) unit and the VNWA (50 Ω) differ. R describes the total resistance of the calibration coil circuit ($576\Omega + 50\Omega = 626\Omega$), r is the radius of the calibration coil and N the number of turns. The weighting with the angular velocity ω is caused by the definition of the TF as the ratio between the coil voltage and the ADC voltage, which is in accordance to the MPI data format specification (MDF) [6].

The measured transfer functions are stored on the hard drive of the imaging system. The scanner control software (Paravision, Bruker Biospin) deposits a comment in the parameter file of the current acquisition containing the path to the corresponding transfer function. In the converting script to the MDF format this comment is parsed, and the TF is stored within the MDF file. When loaded, this transfer function is automatically applied to the measurement vector:

$$\hat{u}_{\text{corr}} = \frac{\hat{u}_{\text{meas}}}{TF}$$

This new corrected voltage is now the derivative of the total magnetic moment of the particle sample. Currently, the spatial distribution of the receive coil sensitivity $\mathbf{p}(\mathbf{r})$ is assumed to be sufficiently homogeneous. Thus, for the exchangeability of the data the sensitivity profile is set to 1.

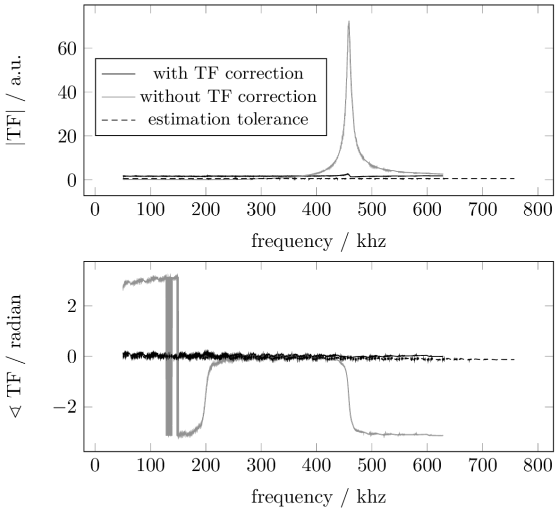

Figure 1: Calculated transfer function before and after the application of the measured transfer function. As the estimated TF is not equal 1 even for the same receiver such a TF is plotted as tolerance for orientation.

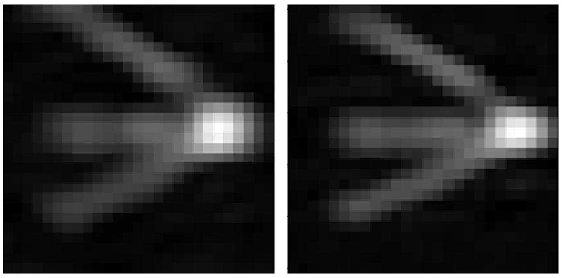

Figure 2: Reconstructed OpenMPIData phantom. The left image shows the original data reconstructed with a corresponding system matrix. On the right side the same measurement data was reconstructed with a system matrix recorded in a dedicated 3D receiver coil. For both settings the same frequencies and parameters were used for reconstruction.

II.II Experiments

To compare the imaging performance of the exchanged system matrix data two experiments are performed. First, two system matrices are recorded featuring the same particle sample but different receive chains and receive coils. Both are corrected using the corresponding transfer-function. Between both corrected matrices a new TF is calculated using a linear regression method proposed in [7]. If the correction is successful the amplitude should be stable at 1 and the phase should be around 0.

Noise and trajectory accuracy also affect the TF estimation. Thus, a second TF is calculated between two system matrices with the same sample and the same receive chain to determine the tolerance of the estimation. As a second experiment we reconstruct data from an in vivo experiment using a specialized mouse head coil. The coil only provides 17 x 16 mm in open space, which does not allow the measurement-based acquisition of a system matrix of the full FOV using a delta sample. By the transfer of one system matrix to this receiver however the reconstruction becomes possible.

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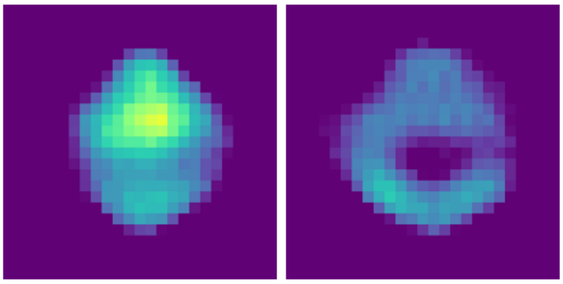

Figure 3: Central slice of a reconstruction of an in vivo experiment using a dedicated mouse head receive coil at two different time points. The system matrix used was recorded using a 1D 40 mm receive coil with different transfer functions.

III Results and discussion

After correction of the TF (see figure 1) for system matrices and measurements the reconstructed images show no obvious artifacts (see figure 2) and a very similar image impression. In addition, an in vivo dataset was reconstructed (see figure 3). In the left picture the inflow of the tracer in the brain tissue of a mouse is shown, while in the right picture the bolus has passed the tissue and is accumulated in the veins surrounding the mouse brain.

IV Conclusions

In this paper, it was shown that by correction of the transfer function the system matrices are exchangeable between different receive units. Thus, the complexity that goes along with system matrix reconstruction is reduced by one set of parameters. Linked with a sensitivity profile correction this allows the determination of quantitative images.

Author's Statement

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