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Fast Multi-Patch System Matrix Calibration in MPI Using Reference Patch Data

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Abstract

In multi-patch magnetic particle imaging (MPI), optimal reconstruction performance using the joint reconstruction approach requires acquiring a complete system matrix (SM) for each patch, which leads to a substantial calibration burden. To address this issue, this study proposed a reference-based multi-patch SM fast calibration method. Leveraging the inherent correlations among SMs corresponding to different patches, we fully measure the complete SM only one reference patch, while for the other patches, data are measured at a limited number of positions. The complete SMs of the remaining patches are then reconstructed by referencing the complete SM of reference patch. Experimental results demonstrate that the proposed method significantly reduces the calibration time while achieving high-quality reconstruction of SMs for the other patches.

I. Introduction

In Magnetic particle imaging (MPI), physiological constraints and the power loss limitations typically restrict the field of view (FOV) to a small region [1]. Multi-patch imaging sequences can be employed to overcome these limitations to achieve a larger effective FOV. However, to ensure optimal reconstruction performance using joint reconstruction, a complete system matrix (SM) must be acquired for each patch. This process is extremely time-consuming, making the conventional approach impractical for large three-dimensional measurements. Szwargulski et al. [2] assumed an ideal magnetic field and used translational invariance to replace the SMs of all patches with that of the central patch, significantly reducing calibration time but introducing reconstruction artifacts. Boberg et al. [3] leveraged local translational invariance to propose a generalized MPI multi-patch reconstruction, balancing calibration time and reconstruction quality. Building on the correlations among multi-patch SMs [2, 3], this study proposed a reference-based multi-patch SM calibration method. Specifically, we estimate

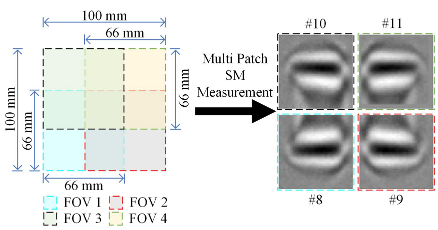

Figure 1: The illustration of the region division of four patches on Open MPI dataset, and visualization of the xy-slice of the real values of the 3961-th SM frequency component for each patch.

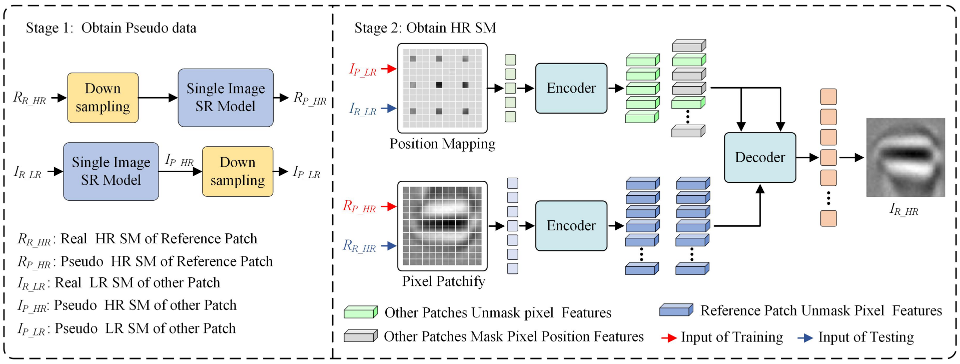

Figure 2: The overall framework of the proposed method.

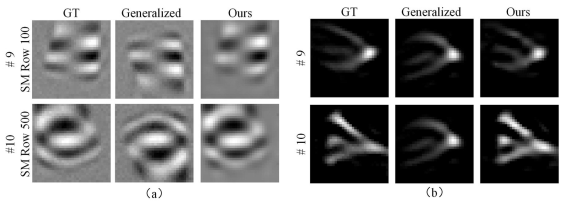

Figure 3: (a) System matrix recovery results. (b) Resolution phantom reconstruction results.

the magnetic field mapping relationship between corresponding patches using their respective pseudo high resolution SM (pseudo-HR SM), which are derived with exiting single-input SM model from limited position data. Then, the complete SMs of the other patches are accurately reconstructed by leveraging the complete SM of the reference patch a small amount of measurement data from the other patches, and the estimated magnetic field correspondence.

II. Methods and materials

II.I. Dataset

The multi-patch SM and phantom data come from the Open MPI dataset [4]. The division of the multi-patch FOV and the visualization of the xy-slice of the read value for the 3961-th SM frequency component of each patch are shown in Figure 1. Notably, #11 was excluded from this study because its spatial size in the xy-plane is 29×29, which differs from that of the other three patches (33×33). We retrained only the SM rows with a signal-to-noise ratio (SNR) > 5 in both training and test datasets, resulting in 2910 samples for the reference patch and other patches. In this study, we performed 4× downsampling on the complete SMs along the xy-plane to obtain low-resolution (LR) SMs for the other patches.

II.II. Model architecture and implementation details

The overall framework of the proposed method is shown in Figure 2 and its workflow is divided into two stages. In stage 1, we utilize the existing single-input SM calibration model (TransSMS [5]) to obtain the pseudo-HR SM of the reference patch and other patches, denoted as R_{P_HR}, and I_{P_HR}, respectively. We then perform 4× downsampling on I_{P_LR} to acquire the pseudo-LR SM of other patches, denoted as I_{P_LR}. In stage 2, for training phase, we use the pseudo data generated in stage 1 to optimize network parameters, where I_{P_LR} and R_{P_HR} as inputs and I_{P_HR}, is treated as the ground truth. For testing phase, the real-HR SM R_{R_HR} and real LR SM I_{R_LR} measured on reference patch and other patches, respectively, are fed into the trained model, ultimately yielding the HR SMs of other patches. The training process adopted the L1 loss function with a batch size of 64 and 50 training epochs. Image reconstructions used the regularized Kaczmarz algorithm (3 iterations, $\lambda = 1 \times 10^{-3}$).

III. Results

III.I. SM calibration results and image reconstruction results

Figure 3 (a) shows the central slices of the recovered HR SM rows for FOV2 and FOV3 using two methods. Our model outperforms the generalized MPI multi-patch reconstruction [3] (we use #8 substitutes #9 and #10 with the assumption that the magnetic fields of FOV2 and FOV3 are similar and can be grouped into a cluster), achieving an average normalized root mean square error (nRMSE) 4.26%. Figure 3 (b) presents the resolution phantom image reconstructions results for FOV2 and FOV3 using the corresponding SMs obtained via the two methods. Notably, the reconstructed images from our method are closest to the ground truth. Furthermore, for a four-patch multi-patch SM, the proposed method reduces the measurement time by approximately fourfold compared with full sampling measurements across all patchers.

IV. Conclusion

This paper proposed a reference-based multi-patch SM calibration method. It establishes inter-patch magnetic field correspondence via pseudo-data, then leverages a complete measured SM of a reference patch to rapidly reconstruct HR SMs for the remaining patches. Open MPI dataset results validate its effectiveness fast multi-patch SM calibration.

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Author's statement

Conflict of interest: Authors state no conflict of interest.

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