International Journal on Magnetic Particle Imaging
Vol 12, No 1, Suppl 1, Article ID 2603041, 3 Pages

Proceedings Article

Domain-weighted Block Coordinate Descent for Quantitative Single-sided MPI Reconstruction

Lingwen Hou[a,b] · Kaixiong Yang[a,b] · Yihan Wang[a,b,*] · Shouping Zhu[a,b,*]

[a]School of Life Science and Technology, Xidian University Engineering Research Center of Molecular and Neuro Imaging, Ministry of Education, Xi'an, Shaanxi 710126, China
[b]Xi'an Key Laboratory of Intelligent Sensing and Regulation of trans-Scale Life Information International Joint Research Center for Advanced Medical Imaging and Intelligent Diagnosis and Treatment, School of Life Science and Technology, Xidian University, Xi'an, Shaanxi 710126, China
*Corresponding author, email: wangyihan@xidian.edu.cn;spzhu@xidian.edu.cn

Abstract

Single-sided Magnetic Particle Imaging (MPI) provides a solution suitable for intraoperative localization. However, asymmetric coil arrangements cause nonuniform magnetic fields and depth-dependent sensitivity decay, leading to biased reconstructions. This paper proposes a domain-weighted Block Coordinate Descent (DW-BCD) algorithm for quantitative single-sided MPI reconstruction. A preliminary reconstruction estimates the signal support domain, from which weighting and regional partitioning are derived. The subsequent reconstruction combines block-wise domain-weighted l_1 and global total variation(TV) regularization. Experiments show that DW-BCD effectively reduces depth-related concentration bias, enabling accurate quantitative reconstruction of magnetic nanoparticle distributions for clinical applications of single-sided MPI.

I. Introduction

In system matrix–based Magnetic Particle Imaging (MPI), reconstruction can be formulated as an inverse problem [1]:

$$S \cdot c = u \tag{1}$$

where $S \in X^{m\times n}$ is system matrix, $c \in \mathbb{R}^n$ is the concentration distribution of magnetic nanoparticles (MNPs), $u \in \mathbb{R}^m$ is the measured signal.

Conventional MPI systems adopt a closed configuration to generate uniform magnetic fields, enabling homogeneous sensitivity and accurate quantification [2]. However, their bulky structure limits portability. Single-sided MPI systems address this limitation by placing all coils on one side, allowing flexible detection and real-time operation. Nevertheless, the asymmetric coil arrangement leads to depth-dependent field decay and variation in system-matrix column norms, causing commonly used reconstruction algorithms to yield biased particle concentration estimates at different depths.

To this end, this paper proposes a reconstruction algorithm based on domain-weighted block coordinate descent for single-sided MPI to accurately quantify particle concentration distribution.

II. Methods

The proposed domain-weighted block coordinate descent (DW-BCD) algorithm for single-sided MPI first performs a Landweber pre-reconstruction to estimate

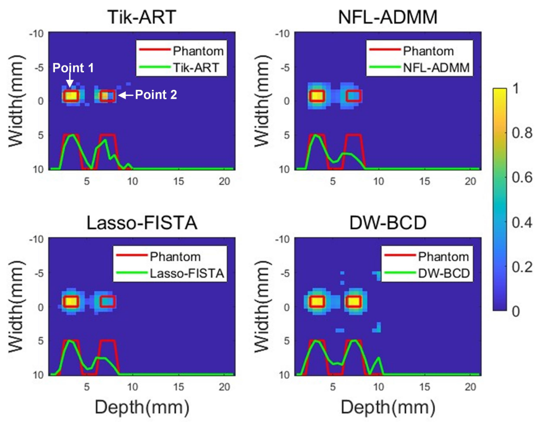

Figure 1: Comparison of quantitative reconstruction performance of different reconstruction methods.

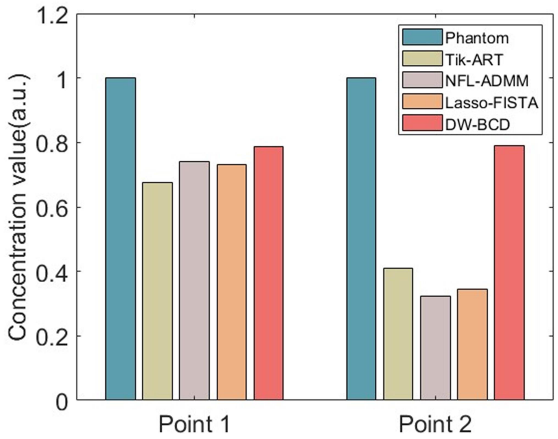

Figure 2: Comparison of mean intensity at different depths using different reconstruction methods

the MNPs distribution, from which the weighting mask $W = [W_1, W_2, \cdots, W_B]$ and block partitioning $c = [c_1^T, c_2^T, \cdots, c_B^T]^T$ (with B blocks) are derived. The reconstruction problem is further formulated as:

$$\min_{c \geq 0} \frac{1}{2} \|Sc - u\|_2^2 + \lambda_1 \|W \odot c\|_1 + \lambda_2 TV(c) \quad (2)$$

Where $\|\cdot\|_2^2$ denotes the Euclidean norm, $\|\cdot\|_1$ denotes the l_1 regularization, $\odot$ represents the Hadamard product, $TV(\cdot)$ denotes the Total variational regularization, λ_1 and λ_2 are the regularization parameters.

According to the block partition obtained from the pre-reconstruction, the corresponding system matrix is denoted as $S = [S_1, S_2, \cdots, S_B]$. The overall objective function is further decomposed into two subproblems for iterative optimization.

The first subproblem corresponds to the within-block optimization, formulated as:

$$c_b^{(k+1)} = \arg\min_{c_b \geq 0} \frac{1}{2} \left\| r_b^{(k)} - S_b c_b \right\|_2^2 + \lambda_1 \|W_b \odot c_b\|_1 \quad (3)$$

The residual $r_b^{(k)}$ is determined based on the current estimates of all other blocks. In each iteration, all other blocks remain unchanged while the current block is updated independently.

The second subproblem involves a global TV regularization constraint across blocks:

$$c^* = \min_{c \geq 0} \frac{1}{2} \|c - \tilde{c}\|_2^2 + \lambda_2 TV(c) \quad (4)$$

where $\tilde{c}$ is an intermediate solution obtained from the block-wise updates $\tilde{c} = [c_1^{(k+1)}; \cdots; c_B^{(k+1)}]$.

III. Results and discussion

Signals of two point-like phantoms at different depths were generated using the simulation framework established in our previous work [3], and were separated by 2 mm. The phantom locations are indicated by red boxes in Figure 1.

Three commonly used reconstruction methods (Tik-ART, NFL-ADMM, Lasso-FISTA) were evaluated. Compared with the shallow phantom (Point 1, Figure 1), all three underestimated the deeper phantom (Point 2), while DW-BCD maintained consistent intensities. Quantitative analysis of mean region intensities (Figure 2) confirms that conventional methods exhibit depth-dependent bias, which is absent in DW-BCD.

IV. Conclusion

The DW-BCD-based method provides a feasible complement to the current SM-based single-sided reconstruction algorithms. It can effectively overcome the bias in estimating particle concentrations at different depths commonly observed in single-sided MPI reconstructions, thereby enhancing the quantitative reconstruction performance of single-sided MPI.

Acknowledgments

This work was supported by the National Key Research and Development Program of China under Grant No. 2022YFB3203803, the National Natural Science Foundation of China under Grant Nos. 62027901, 62471372, 62071362.

Author's statement

Conflict of interest: Authors state no conflict of interest.

10.18416/ijmpi.2026.2603041

References

[1] T. Knopp et al., “Weighted iterative reconstruction for magnetic particle imaging,” Physics in medicine and biology, vol. 55, pp. 1577–89, Feb. 2010, doi: 10.1088/0031-9155/55/6/003.

[2] B. Gleich and J. Weizenecker, “Tomographic imaging using the non-linear response of magnetic particles,” Nature, vol. 435, no. 7046, Art. no. 7046, June 2005, doi: 10.1038/nature03808.

[3] Q. Wang et al., “Single-sided Magnetic Particle Imaging Device with Offset Field based Spatial Encoding,” IEEE Transactions on Medical Imaging, pp. 1–1, 2024, doi: 10.1109/TMI.2024.3522979.

10.18416/ijmpi.2026.2603041