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Spatial regularization in 2D multi-color magnetic particle imaging

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Introduction: Multi-color magnetic particle imaging (MPI) enables the differentiation between multiple types of magnetic nanoparticles from one measurement. However, the common reconstruction approach using two or more system matrices (SMs) to map the particle signal to different image channels [1] often results in channel leakage artefacts [2].

Methods: Inspired by the critical offset points leveraged in COMPASS to distinguish bound from unbound nanoparticles [3], we propose to find spatial regions in the SM frequency components where the phase varies significantly between the SMs of different particle types. These regions are then masked and used as a spatial regularization during the common multi-channel Kaczmarz reconstruction [1]. Specifically, we extend the row-based algorithm that iterates over all frequency components, by multiplying each update with the correponding regularization mask for this frequency component to enforce that the regions that differ significantly in phase in the two SMs have the highest importance.

Results and Discussion: In Fig. 1, some phase profiles of two SMs acquired with different types of particles, namely perimag (micromod Partikeltechnologie GmbH, Rostock, Germany) and SHP25 (Ocean NanoTech, San Diego, US), can be seen. Furthermore, the figure shows the absolute difference between the phase profiles and the regularization mask that was created by setting all values in the difference map below 0.5 to 0 and above 0.5 to 1. To test the algorithm, we simulated a measurement of two phantoms, each containing one particle type (Fig. 2, left). For reconstruction, the 200 frequency components with the highest SNR are selected for both SMs, and the algorithm is run for one iteration. The standard Kaczmarz regularization value was set individually for the two algorithms to achieve the best visual results. The middle column of Fig. 2 shows the standard Kaczmarz reconstruction, where the leakage of the SHP25 signal is clearly visible (green box). With our spatial regularization approach, this is prevented. However, our reconstructions are noisier and have more artefacts towards the edge of the field-of-view. The SHP25 channel is generally much noisier due to significantly lower signal of the SHP25 particles compared to perimag.

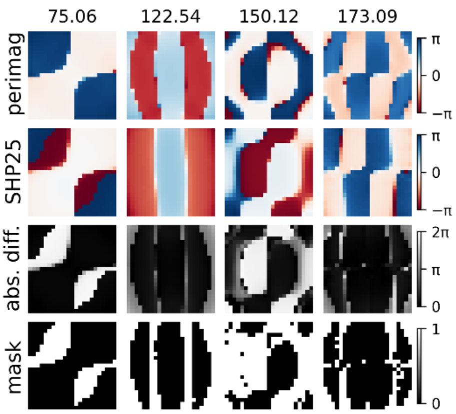

Fig. 1: From top to bottom: Phase of four SM frequency components (frequencies given above in kHz) for perimag and SHP25, absolute difference of the phase and regularization mask.

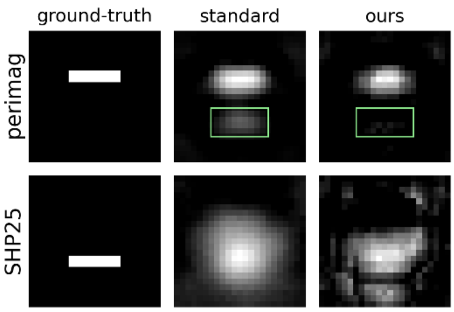

Fig. 2: Ground-truth phantoms and reconstruction result for the perimag (top) and SHP25 (bottom) channel using the standard Kaczmarz algorithm and our extension.

Conclusion: In conclusion, we proposed a spatial regularization approach for multi-color MPI which can prevent channel leakage artefacts. However, further testing and refinement of the method is necessary.

References: [1] Rahmer, Phys. Med. Biol. (2015). [2] Nawwas, Phys. Med. Biol. (2024). [3] Vogel, Nat Commun (2022).