Self Calibration for Relaxation- and System-Induced Delays in X-space MPI

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INTRODUCTION Both system and relaxation induced time delays complicate image reconstruction in x-space magnetic particle imaging (MPI). Relaxation reduces the signal-to-noise ratio (SNR) and blurs the image along the scan direction [1-4]. System delays, on the other hand, introduce unwanted image artifacts. Hence, determining the delays accurately is crucial for obtaining artifact-free images. Here, we propose a method to estimate the effective time delay for relaxation- and system-induced sources, without any a priori knowledge.

MATERIAL AND METHODS X-space image reconstruction in the presence of time delays can be represented as:

$$\mathrm{IMG}\big(x_s(t)\big) = \frac{s(t + \Delta t_r - \Delta t_s)}{\dot{x}_s(t)}$$

Here, IMG is the reconstructed image, s(t) is the received signal, Δt_r is the effective relaxation-induced delay, Δt_s is the delay in the system, $x_s(t)$ is the instantaneous position of the field-free point (FFP). Typically, Δt_s is measured through a prior phase calibration. A reasonable value for Δt_r was suggested as $\tau/2$, where τ is the relaxation time constant of the nanoparticle [1], which can be measured on a relaxometer setup. Here, we lump both delays into one estimated delay, Δt_{est}, which we calculate *directly* from the MPI signal.

We developed a custom x-space MPI simulation toolbox in MATLAB. Simulation parameters were as follows: 25 nm nanoparticle diameter, τ = 2.9µs, 20 kHz and 25 mT-pp drive field, 2.3 T/m selection field (similar to values as in [1]). Scan axis was partitioned into 80% overlapping partial field-of-views (pFOVs). The first harmonic of the signal was filtered out [5] and noise added. 1D cross-sections of images were analyzed.

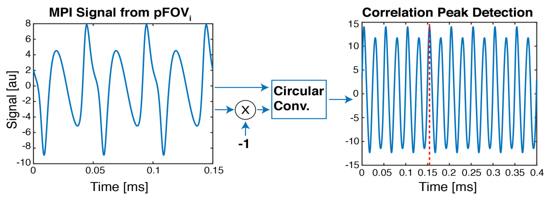

Figure 1: Phase shift estimation for one partial field-of-view.

As outlined in Fig. 1, to determine Δt_{est}, the signal from each pFOV was circularly convolved with its mirror symmetric version. A subsequent peak detection yields twice the value of Δt_{est} (after some further processing). From this time delay, the phase shift of the signal can be computed.

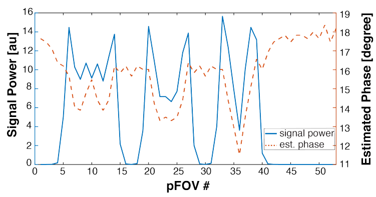

Figure 2: Signal power and estimated phase shift for each pFOV.

Finally, an overall phase shift was computed via weighted mean of the estimated shifts from all pFOVs. The weight for each pFOV was its total signal power, effectively penalizing low signal regions of the image. Fig. 2 shows both the corresponding signal power and estimated phase shifts for each pFOV.

RESULTS Figure 3 compares the proposed technique with calibration-based methods. As seen in Fig. 3a, 45° phase error causes significant artifacts in the image. With prior system phase calibration (Fig. 3b), artifacts are not fully alleviated. If τ of the nanoparticle is known (Fig. 3c), applying an additional $\tau/2$ time shift further improves the image. Finally, Fig. 3d shows the results of the proposed method. Even though our method does not require any calibration or a priori knowledge, it provides results closest to the ideal image.

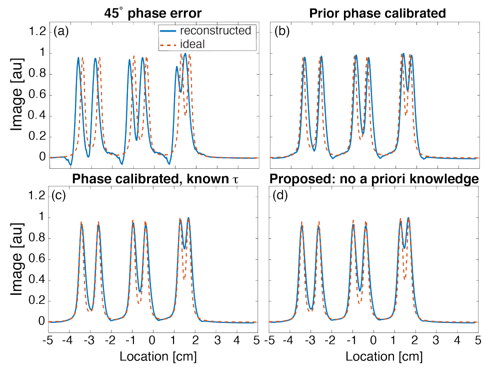

Figure 3: Comparison of the proposed method with calibration-based techniques. In each plots, dashed line is the ideal image without relaxation, solid line is the reconstructed MPI image.

CONCLUSION In this work, we propose a new method to estimate the effective system- and relaxation-induced time delays in MPI. This method does not require any a priori knowledge about the system or the nanoparticle. Our results showed that this practical approach outperforms calibration-based methods. Experimental validation of this technique remains as future work.

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