Iterative Tuning of System Delay and Phase Correction for Echo-Planar Imaging

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Introduction

Echo-planar imaging (EPI) suffers from ghosting artifacts if the sample positions in *k*-space are not accurately known. Many effects lead to a distortion of the ideal gradient waveforms and cause differences in the sample positions for echoes acquired with positive and negative readout gradient polarity. Various methods have been developed to compensate for them, which rely on either additional calibration data or on heuristic criteria in image space [1]. In this work, a new, iterative method of the first kind is presented to improve tolerance to a badly adjusted system delay.

Methods

It is assumed that data from two acquisitions of the central *k*-space line with opposite readout gradient polarity are available as calibration data. To achieve a joint tuning of the system delay and the phase correction, the following procedure is proposed:

1. The estimate of the system delay is initially set to zero.
2. The sample positions in *k*-space are predicted using the current estimate of the system delay, a description of the ideal gradient waveforms, and a model of the gradient system.
3. Taking these sample positions into account, the calibration data are gridded and transformed in readout direction.
4. Using the resulting data, the system delay is refined by estimating the difference in linear phase between the two acquisitions.
5. If the change in system delay exceeds a given threshold and the number of iterations has not yet reached a given maximum, the procedure continues with step 2.
6. Otherwise, a nonlinear phase correction is derived from the two acquisitions in hybrid space.

The performance of this approach was compared to using no correction, a magnitude-weighted linear phase estimation and correction [2], and a nonlinear phase correction [3].

Phantom data were acquired on a Philips 3.0 T Achieva scanner, once after manual tuning of the system delay to ±0.5 µs, and once after deliberate detuning. They were reconstructed with all four methods, and the artifact level in the resulting images was measured by calculating the ratio of the maximum signal intensities in areas defined in the background and in the phantom.

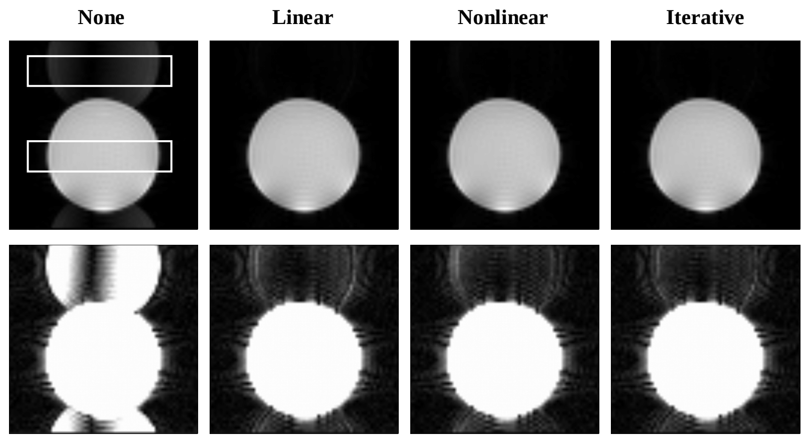

Fig. 1. Results obtained with a manually tuned system delay using four different correction strategies. The images in the lower row are rescaled copies of the images in the upper row. The maximum actual and ghost signal was quantified in the area indicated by the lower and upper rectangle, respectively.

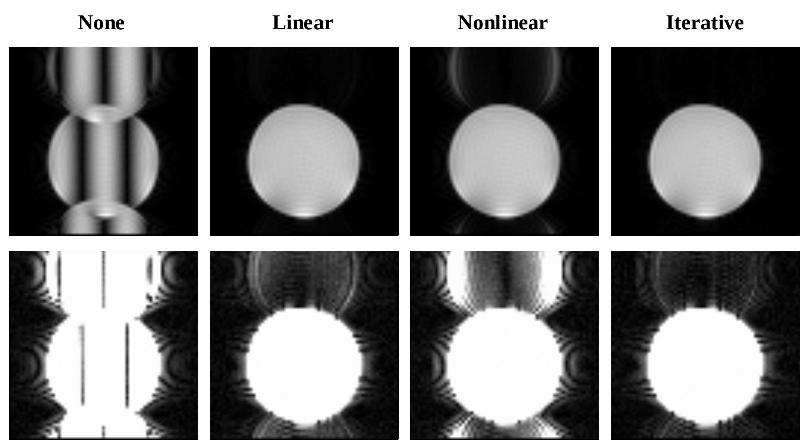

Fig. 2. Corresponding results obtained with a manually by 10 µs detuned system delay.

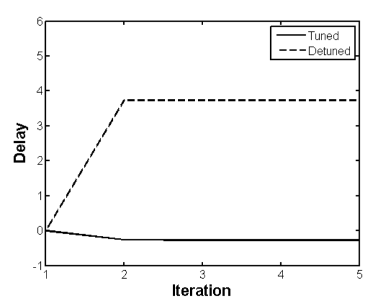

Fig. 3. Evolution of the estimated system delay during the iteration of the proposed correction strategy in the tuned and the detuned case.

Results

Two selected sets of images are shown in Figs. 1 and 2. With the four described approaches, the ghosting levels were 25%, 6%, 6%, and 5% in the tuned case, and 87%, 7%, 40%, and 4% in the detuned case. The estimate of the system delay, measured in units of dwell time, is plotted as function of the number of iterations of the new approach in Fig. 3.

Conclusions

The presented results demonstrate that especially the nonlinear phase correction is susceptible to a badly adjusted system delay. The occurring strong ghosting artifacts are efficiently suppressed by the proposed iterative procedure for a joint tuning of the system delay and the phase correction. It provides comparable image quality irrespective of the accuracy of the tuning of the system delay, and it usually converges sufficiently in only two iterations.

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References

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