IMAGE BASED CORRECTION OF RADIAL TRAJECTORY SHIFTS

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Target Audience – Researchers working with radial trajectories.

Purpose – Radial acquisition of *k*-space is becoming a highly important acquisition strategy for robust dynamic imaging and real-time MRI. In contrast to Cartesian readout of *k*-space, gradient delays and timing errors have to be precisely corrected in order to avoid artifacts in the reconstructed images. Delay induced shifts of the acquired radial data along the readout directions can cause especially severe signal drop outs and smearing artifacts in the reconstructed images. Although research has been performed on correcting these errors, most solutions require either additional hardware for monitoring the true gradient trajectory during data acquisition or additional calibration or template measurements, which often work only for a particular set of acquisition parameters or homogeneous phantoms[1,2,3]. In this work we introduce a method to correct shifts of the data along the readout direction without performing any additional measurements.

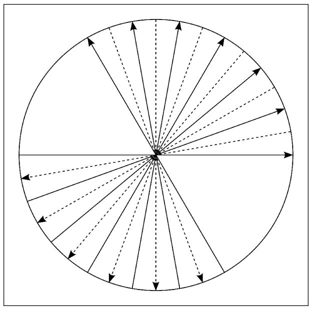

Fig. 1. In the shown radial *k*-space sampling scheme, every second readout is inverted (dashed arrows). Since two adjacent readouts are nearly opposite delay shifts are evenly distributed in the *k*-space center.

Methods – Phantom and *in vivo* volunteer measurements were performed on a clinical 3 T system (TIM Trio, Siemens Healthcare) using a radial 2D FLASH sequence with the following parameters: acquisition matrix 144 x 144, FOV = 220 x 220 mm², TR = 5.30 ms, TE = 2.76 ms, flip angle FA = 8° (phantom data) and FA = 10° (*in vivo* data), number of radial readouts N = 233, acquisition bandwidth BW = 102.04 kHz. Readout polarity of every other spoke was inverted to obtain opposing delay effects evenly distributed at the center of *k*-space (Fig. 1). During image reconstruction acquired raw data were shifted along the readout direction with 80 linearly spaced shifts Δr in the range from -4 to 4 readout points. This was implemented using the Fourier Shift Theorem to achieve sub dwell time accuracy. For each readout shift we reconstructed the image using 2D-gridding with iterative grid weights estimation[4] followed by a 2D-FFT. The optimal shift Δr_{opt} yielding images free of delay artifacts was obtained by analyzing the magnitude of all data voxels. For this purpose the sum over the magnitude of all data voxels I_{sum} was calculated as a function of Δr. The optimal shift Δr_{opt} was then estimated from the local maximum of $I_{sum}(\Delta r)$.

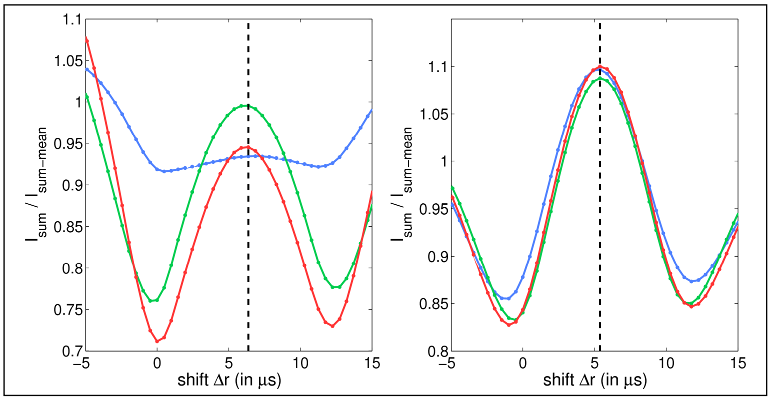

Fig. 2. The sum over the magnitude of all voxels normalized to its mean is plotted against the shift Δr in µs for (a) phantom data and (b) *in vivo* data. The dashed line delineates the observed local maximum at Δr_{opt}. (blue – slice 1, green – slice 2, red – slice 3)

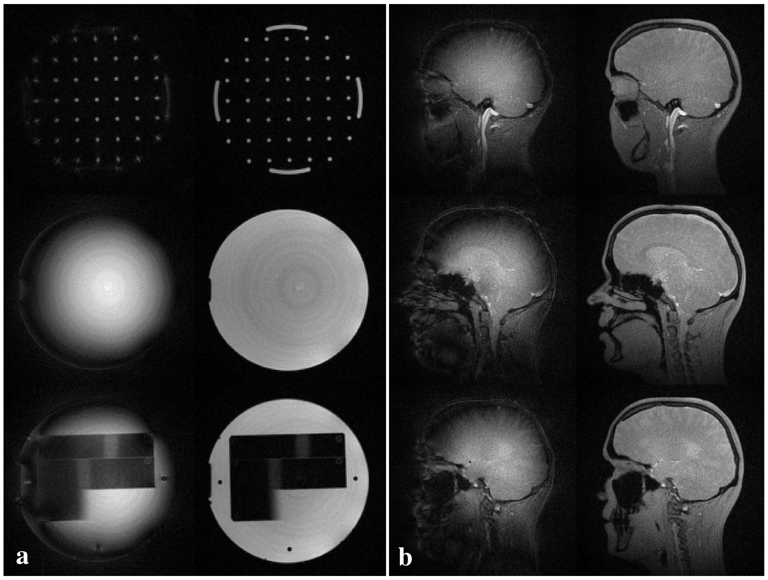

Fig. 3. Three different slices of (a) phantom data and (b) *in vivo* data are shown from top to bottom. Quality of the uncorrected images (left columns) is highly degraded by radial delay artifacts. These artifacts were fully corrected for the right images, respectively.

Results – The sum over the magnitude of all data voxels as a function of Δr is shown in Figure 2 for both the phantom (2a) and the *in vivo* (2b) measurement. Optimal shifts Δr_{opt} were 1.3 and 1.1 readout points (corresponding to 6.37 µs and 5.39 µs time delay) for the phantom and *in vivo* data, respectively. The results were obtained for different slices with different object structures. Even in slices with low overall signal intensity (slice 1, phantom data) the optimal shift was successfully determined. Uncorrected radial readouts resulted in images that were highly degraded by artifacts, whereas correction with the identified optimal shift yielded highly improved, artifact free images (Fig. 3).

Discussion & Conclusion – The presented method was implemented fully automated without further user interaction. It proved to be reliable for correcting the radial shifts along readout direction in phantom and *in vivo* measurements. Since an image has to be reconstructed for each modulated shift computation time can be optimized by undersampling input data or by applying fewer shift values and fitting an appropriate function to the resulting curve. For reconstruction of larger data sets it should be sufficient to perform the described modulation and analysis for data of a single slice, since readout shifts are supposed to remain constant throughout the measurement.

References – [1] Block KT, et al. Proc Intl Soc Mag Reson Med. 2011;19:2816. [2] Peters DC, et al. Magn Reson Med. 2003;50(1):1-6. [3] Moussavi A, et al. Magn Reson Med. 2013;Epub ahead of print. [4] Zwart NR, et al. Magn Reson Med. 2012;67(3):701-10.