K-SPACE TRAJECTORY CORRECTION IN SPIRAL-IN/OUT BSSFP IMAGING

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Introduction: Spiral-in/out bSSFP differs from spiral-out bSSFP in that it has a symmetric spiral-in gradient in front of a spiral-out gradient. This yields TE=TR/2 and leads to nulling of the 0^{th} and 1^{st} gradient moments via symmetry, which saves time compared to a flow-compensated spiral rewinder [1]. However, eddy currents and other gradient imperfections of the gradient system affect the fidelity of the k-space trajectory and cause blurring and distortion in reconstructed images. In this abstract we compare cardiac spiral-in/out bSSFP images reconstructed using a k-space trajectory calculated using a single gradient delay model to those reconstructed using a model that incorporates gradient delays and eddy currents calibrated for each physical axis. We compare each of these to measured trajectories. In addition, we measured B0 eddy currents and analyzed their effect in spiral-in/out bSSFP imaging.
Methods: A modified Duyn's method described in [2] was used for trajectory measurement. For a double oblique slice, the gradients along each axis of the physical coordinate system were measured separately and then rotated to the logical coordinate system to get the measured trajectory. The deviation of the measured trajectory from a single-delay trajectory is mainly caused by anisotropic gradient delays on each physical axis and linear eddy currents. A model-based trajectory estimation method [2] was used to correct for the two effects. The trajectory component on each physical axis was calculated separately by the equation:

$k(t) = Ak_{delay}(t) + B\int_0^t k_{delay}(\tau)d\tau$ where $k_{delay}(t)$ was calculated with the gradient delay along that axis, which, together with A and B was estimated from a prior calibration scan. We compared the images reconstructed with the measured trajectory to the single-delay trajectory and the estimated trajectory in a cardiac spiral-in/out bSSFP experiment. In addition, the phase due to B0 eddy currents was also measured as a by-product in the trajectory measurement; therefore, images with B0 eddy current correction were also reconstructed and compared.
Results: Figure 1 shows two interleaves of the measured trajectory, single-delay trajectory, and estimated trajectory. The estimated trajectory is much closer to the measured trajectory than the single-delay trajectory. The root mean square difference between the two calculated trajectories and measured trajectory decreases from 0.215 to 0.096. In Fig. 2, the first row, from left to right, shows the images reconstructed with single-delay trajectory, estimated trajectory and measured trajectory, all of which are reconstructed without B0 eddy current correction; the left most image of the bottom row shows the difference image between the single-delay trajectory and the measured trajectory; the center one shows the difference image between the estimated trajectory and the measured trajectory; the right most one shows the difference image between images reconstructed using a measured trajectory with and without B0 eddy current compensation. The blurring in the top right corner of the images is reduced using the measured trajectory and the estimated trajectory. In the difference image of the single-delay trajectory and measured trajectory (bottom left), the brightest part is the chest and the back, reflecting a minor image distortion. By using the estimated trajectory, the distortion is mostly corrected, as shown in the difference image (bottom center). The difference between the B0 eddy current corrected image and uncorrected image is almost invisible (bottom right).
Conclusions: In cardiac spiral-in/out bSSFP imaging, the anisotropic delay along three physical axes and linear eddy current effects will affect the fidelity of the k-space trajectory and cause image blurring and distortion. Using a measured trajectory can correct for these artifacts but requires additional measurement for each slice; however, using the estimated trajectory can give satisfactory results without measuring the trajectory. The effect of B0 eddy currents is very small so that correction for them is unnecessary.
References: [1] Feng X, et al. ISMRM 2010. [2] Tan H, et al. MRM 61: 1396-1404 2009.
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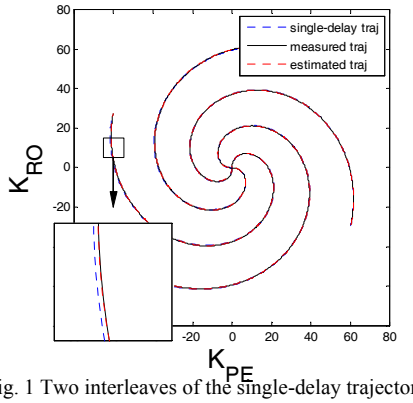

Fig. 1 Two interleaves of the single-delay trajectory (blue), measured trajectory (black) and estimated trajectory (red) and the enlarged area

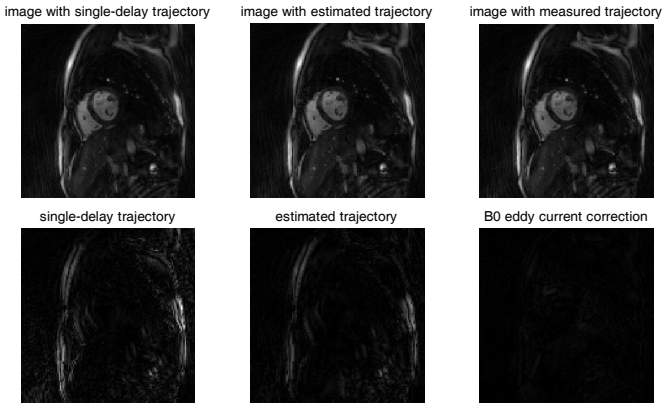

Fig. 2 Spiral-in/out bSSFP short axis cardiac images (top row) and difference images between single-delay trajectory, estimated trajectory and measured trajectory (left two of bottom row), difference image between images of measured trajectory with and without B0 eddy current correction (right most of bottom row)