Multiple Overlapping k-space Junctions for Investigating Translating Objects (MOJITO)

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Introduction: Motion artifacts in MR images often appear as ghosting or streaking artifacts. Many correction methods require the collection of extra data (e.g. navigator echoes or averaging) which increase acquisition time. BOWTIE continuous sampling acquisitions (Figure 1) have previously been used to increase SNR without significantly increasing acquisition time [1]. BOWTIE trajectories collect k-space data along both a radial and rectilinear path. This unique traversal of k-space allows correction of translational motion using Multiple Overlapping k-space Junctions for Investigating Translating Objects (MOJITO), described below.

Theory: The phase (φ) of any MRI data point can be described by $\varphi = 2\pi(k_y y + k_x x)$. If two points are collected at the same k-space location after a relative motion of the object, the phase difference ($\Delta\varphi$) can be described by

$$\Delta\varphi = 2\pi(k_y \Delta y + k_x \Delta x) \qquad (1)$$

where Δx and Δy are the object shifts. Two sets of overlapping points (e.g. the solid black circles in Figure 1) and a measured trajectory [2] will give Δx and Δy for each PE line. With the exception of the center three PE lines, the BOWTIE trajectory exhibits at least two overlapping junctions per PE line (shown by the solid circles in Figure 1) thus allowing translational motion detection (Δx and Δy) by solving Equation 1 for the object shifts. Additionally, the over-determined case (i.e. using more than two trajectory intersections per PE line depicted by the open circles Figure 1) can be solved using matrix pseudo-inverse.

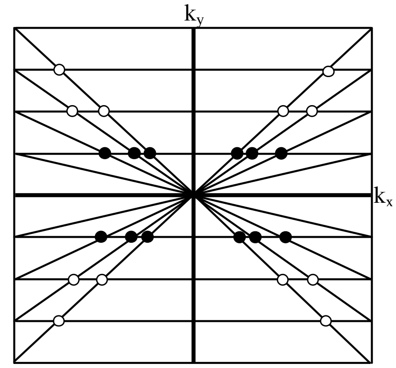
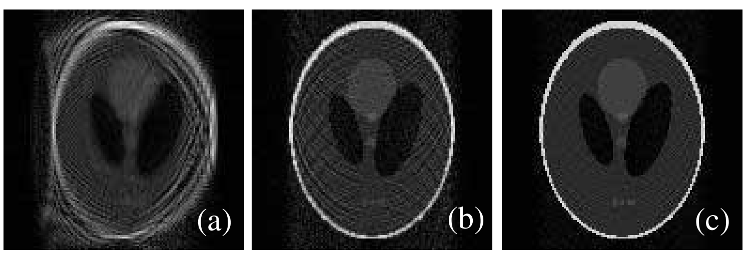


Figure 1: BOWTIE trajectory. The solid black dots represent the intersection of the radial and Cartesian lines that will be used for motion correction.

Methods: To validate Equation 1, simulated Cartesian sampled k-space data from a Shepp-Logan phantom was corrupted by noise and by known sinusoidal motion (in readout-direction). Phase differences between corrupted Cartesian k-space and stationary Cartesian k-space at k_x=1 and -1 for each PE line were used to compute the object shifts and correct the simulated image. The over-determined case was also tested in simulation using a total of eight phase differences per PE line. To test MOJITO with actual BOWTIE data, three stationary BOWTIE k-space data sets (doped water phantom at different x-locations) were combined to simulate periodic motion. Two $\Delta\varphi$ near the center of k-space were found using GRAPPA Operator Gridding (GROG) [3] for each BOWTIE PE line. Only the Cartesian portion of the BOWTIE data was corrected.



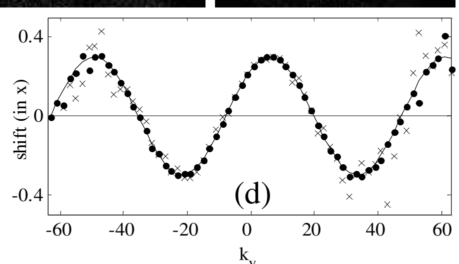
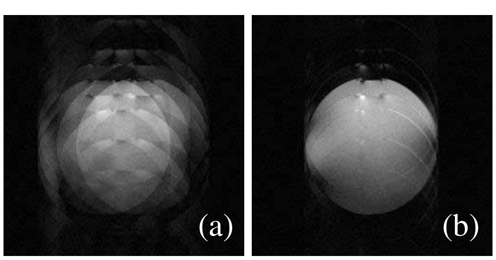


Figure 2: MOJITO simulation results. Image (a) shows a motion corrupted Shepp-Logan phantom, (b) shows a MOJITO corrected image using two intersections and (c) eight intersections. The graph (d) depicts detected shifts in RO-direction using 2 intersections (x's) and 8 intersections (dots).

Results: Image simulation results are shown in Figure 2a-c (using two and eight intersections). Simulated shifts (solid line) and detected motion (symbols) are shown in Figure 2d. Note that the residual error is reduced when eight intersections (x's, Figure 2d) versus two (dots, Figure 2d) are used to fit the motion. In the absence of noise, simulated motion is detected perfectly (not shown). For actual BOWTIE data, using only two GROGed intersections per BOWTIE PE line, the detected motion in the readout direction corrects the image and fits expected shifts (Figure 3). The current MRI implementation does not yet reliably detect motion in the PE-direction (x's, Figure 3c).

Discussion and Conclusions: The MOJITO algorithm has been shown to successfully detect in-plane, translational motion both in simulation and using the BOWTIE trajectory. One of the advantages of this time efficient method is that it may be performed on-the-fly with centric reordering. Additionally, the entire BOWTIE data set may be corrected for a final image.



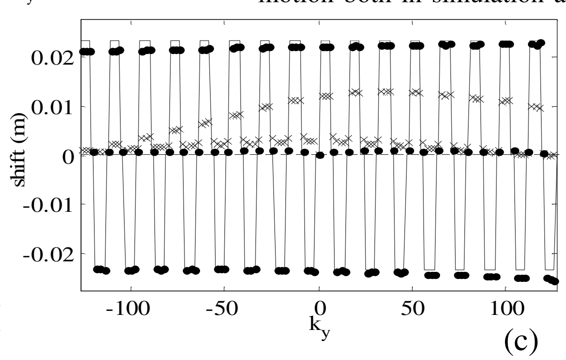


Figure 3: MOJITO phantom results. Image (a) shows the motion corrupted image and (b) the MOJITO corrected image. Graph (c) shows the actual (lines) and the detected motion (x's) in readout and (dots) in PE direction.

References: [1] Bookwalter et. al., ISMRM 2006, Abstract 2439. [2] Duyn et. al., JMRI, 132, 150-153, 1998. [3] Seiberlich et.al., ESMRMB 2006, #300.