Radial MARs for Correction of Motion Artifacts due to Breathing

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Introduction: MR abdominal imaging is especially adversely affected by motion artifact due to breathing. An algorithm called Motion Artifact Removal by Retrospective Resolution Reduction (MARs) for rectilinear trajectories has been previously described [1], which automatically and retrospectively identifies a transition between breath hold to free breathing and subsequently removes the corrupted data for a motion artifact free, yet lower resolution image. Radial trajectories offer many advantages, including inherent relative motion insensitivity due to the oversampling of the center of k-space [2], while achieving a high resolution image with very few projections (at the expense of potential aliasing artifacts). Thus radial trajectories are an attractive alternative to the present clinical standard of Cartesian scanning, in settings where motion is a major problem. While generally more forgiving than the Cartesian case, radial scans are still adversely affected by motion in the form of image degradation due to streaking artifacts and object distortion. Therefore an application of the MARs concept to the radial trajectory, allowing retrospective rejection of corrupted data, is desirable. Here we present such an extension to the MARs method to a radial sequence and demonstrate first results for abdominal scanning in both volunteers and patients.

Theory: For radial MARs, if a transition from uncorrupted to motion corrupted data can be identified, the corrupted lines can be removed prior to reconstruction and motion artifact eliminated. Each projection of a radial trajectory passes through the center of k- space. The center of k-space represents the complex sum of all transverse magnetization in the entire excited volume or the DC value. This value changes with any through-plane motion such as abdominal motion due to breathing, and has previously been used for motion detection [4-6]. In order to detect the transition to motion, the running average over 5 consecutive radial k-space lines and the cumulative standard deviation were calculated for the absolute value of the center of k-space for each projection. The transition from uncorrupted to motion corrupted was defined as the time where the running average of the center magnitude was one standard deviation away from the cumulative standard deviation from five lines earlier. Projections acquired after the detected transition were excluded from the final reconstruction.

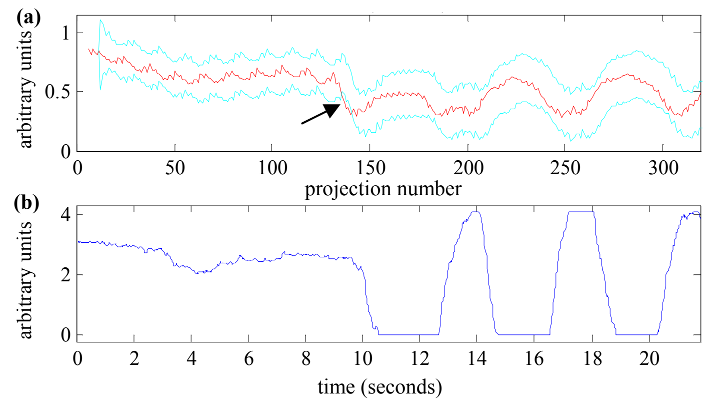

Figure 1: Smoothed magnitude of k-space center over each projection (red) and cumulative standard deviation shifted by 5 projections (cyan) are shown in (a) with corresponding respiratory bellows data in (b) for reference. Arrow depicts transition from breath hold to free breathing.

In such a scheme, the ordering of the projections is critical. If adjacent (in k-space) radial lines are acquired sequentially, retrospectively eliminating lines acquired after commencement of motion would leave wedges of unsampled k- space, and the method would introduce additional artifact. Thus, instead of traditional radial acquisitions, golden angle (GA) radial acquisitions [3] are used. GA radial trajectories are acquired such that there is a constant azimuthal angle of 111.25 degrees between subsequently acquired radial projections, resulting in an almost uniformly sampled radial sequence for any number of projections. The uniformly distributed k-space lines suit our purposes because, once the transition is identified and the corrupted data is removed, the remaining radial k-space lines are still distributed uniformly in k-space regardless of when the transition occurred.

Methods: The study is IRB compliant. Human experiments were performed after informed written consent. Three golden angle 2D FLASH radial data sets were acquired where asymptomatic volunteers (N=1) or patients (N=2) were instructed to hold their breath for the entire scan, for 60% of the scan, and for 30% of the scan. Imaging parameters were TR = 68 ms, TE = 1.8 ms, number of projections = 320, slice thickness = 10 mm, BW = 975 Hz/Px, FA = 15° and base resolution = 256. Respiratory bellows were placed on all subjects for verification that motion detection is accurate.

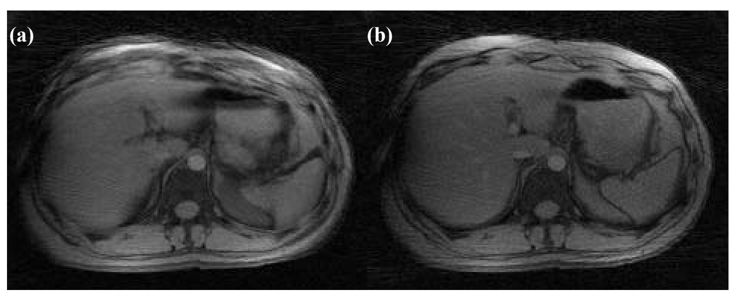

Figure 2: Uncorrected radial image (a) with motion occurring approximately 40% through total acquisition time (320 projections). Corrected image using MARs detected transition with 136/320 projections (b). Both images are reconstructed at 256x256 base resolution.

Results: A running mean (over 5 points) for smoothing and cumulative standard deviation (over time) are shown in Figure 1a as blue and reds lines, respectively. External respiratory monitoring data are shown in (b) for reference. Motion detection by self-navigation corresponds closely to the respiratory bellows data. Figure 2a shows an uncorrected image for approximately 40% breath hold in an asymptomatic volunteer. The MARs corrected image is shown in Figure 2b. Note the distortion of anatomic structures particularly the anterior abdominal wall, the left lobe of the liver, and the stomach in the uncorrected image (Figure 2a). There is improved visualization of several anatomic structures: see, for example, the hepatic veins, which are not seen on the uncorrected exam but are clearly seen on the MARs corrected image, and the splenic contour, which is much better defined on the MARs corrected image.

Discussion: Radial MARs is an algorithm which retrospectively and automatically detects a transition between motion corrupted and motion uncorrupted data using the self-navigating properties of radial trajectories. For the image shown in Figure 2a, the dominating artifact is object distortion from through-plane motion rather than streak artifact. These motion artifacts have been shown to appear more benign compared to rectilinear trajectory artifacts (i.e., no ghosting) [8]. As through-plane motion occurs, the effective slice location changes for each projection causing bulk object averaging over multiple slices and therefore object distortion (shown in Figure 2a). The object distortions are removed with removal of corrupted line with MARs detected transition (Figure 2d). The MARs method serves to further make radial an even more robust alternative to rectilinear sampling. Although not necessary for the example shown, unacceptable streak artifacts due to undersampling could be reduced by decreasing the extent of k-space (i.e., the base resolution) and therefore reducing resolution, or by applying a parallel imaging method.

References: [1] Bookwalter et. al, Proc. of ISMRM 2011, #4603. [2] Glover et. al, MRM; 28(2):275-289, 1992. [3] Winkelmann et. al, IEEE TMI; 26(1):68-76, 2007. [4] Brau et al, MRM; 55(2):263-270, 2006. [5] Larson et al, MRM; 51(1):93-102, 2004. [6] Pipe et. al, MRM; 42(5):963-969, 1999. [7] Peters et. al, MRM; 55(2):396. [8] McKenzie et. al, Radiology; 230(2):589-594, 2004.

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