Image Based Compensation of Breathing Motion Artifacts in MRI with Continuously Moving Table Acquisitions

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Introduction

MRI with continuously moving table is an efficient method to image arbitrary large body regions within one measurement. However, breathing motion causes problems for this technique, since the acquisition time is usually too long to perform the whole measurement within one breathhold. Synchronization of acquisition and breathing motion is technically difficult to realize and causes discomfort for the patient due to the discontinuous table motion. Finally, retrospective gating is very inefficient since a considerable amount of acquired data must be discarded and its applicability is limited by the lowest possible table speed. In this work a method is introduced which allows the efficient reconstruction of artifact free images from data acquired during free breathing. Snapshots of arbitrary breathing states are acquired and consistently combined using image registration techniques. Typical breathing motion induced artifacts such as ghosting, blurring and signal cancellations are thus eliminated.

Methods

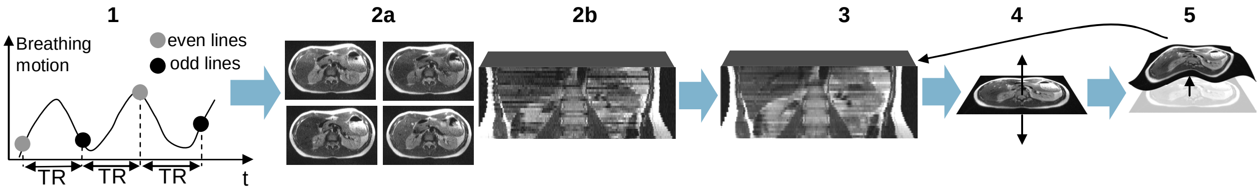

Fig. 1: Processing scheme of the breathing motion compensation method

32 axial slices of a volunteer's abdomen were acquired using a TSE sequence (TR/TE = 1831/122ms, 320x144 matrix, 1.1x1.4x5mm^3 voxel size, 1mm gap between adjacent slices) and the sliding multislice technique [1]. For each slice position four undersampled k-spaces (two times even k-space lines and two times odd k-space lines) were acquired, each with one shot (Fig. 1, step 1). The breathing state of each shot was measured with a breathing cushion. Parallel imaging using GRAPPA [2] was applied to reconstruct artifact free snapshot images from the undersampled k-spaces (Fig. 1, step 2a), each potentially representing a different breathing state. GRAPPA calibration data was obtained by combining even and odd k-space lines from different shots appropriately [3]. Due to breathing state variations, a volume composed of arbitrary snapshot images is usually not consistent (Fig. 1, step 2b). A motion consistent reference volume (Fig. 1, step 3) was obtained by selecting one out of four snapshot images per slice position such that the following two consistency criteria were optimized: (1) The breathing state variation over all selected images should be minimal. (2) Each image should contain little signal cancellation. Since an exhaustive search over all image combinations is computationally too expensive, a heuristic was applied for optimization. Breathing state variations were minimized exactly only for a local neighborhood of slices and dynamic programming [4] was used to efficiently determine the optimal combination of the locally optimal subvolumes. The obtained reference volume suffers from a low signal-to-noise ratio and may still contain signal cancellations. Both shortcomings were eliminated by consistently combining the remaining images with the reference volume using two image registration techniques. First, a rigid translation in cranio-caudal direction was computed for each image (Fig 1, Step 4), since the breathing induced deformation in the abdomen is particularly large in that direction [5]. To refine the breathing motion compensation, a deformable slice-to-volume registration was performed subsequently on the translated images (Fig 1, Step 5). For both registration techniques a mutual information based cost function [6] was used. Deformable registration was based on a B-Spline deformation model with iterative control point grid refinement [7]. To be able to use derivatives of the cost function during optimization, computed transformations for each image deform the reference volume onto a single image. The actually desired inverse deformation was obtained by inverting the deformation field using a technique for interpolation from scattered data [8]. Images were finally resampled using the estimated inverse deformation and combined with the reference volume applying a weighted averaging technique. A global signal cancellation score for each image and local signal intensity were considered in the weighting scheme to obtain combined images with good signal quality.

Results

Figure 2 shows images reconstructed for one slice position with different methods. The snapshot image included in the reference volume (Fig. 2a) contains no breathing induced artifacts such as ghosting or blurring. Averaging over all four snapshot images obtained for the same slice position results in strong blurring (Fig. 2b, solid arrows), but ghosting which typically occurs in conventional reconstructions of free breathing multi-shot acquisitions is avoided. Comparable results were achieved in previous work aiming at artifact reduction in MRI with continuously moving table [9]. Averaging of images after rigid registration (Fig. 2c) reduces blurring. The anatomy of static tissue in the area of the spinal chord is however not correctly represented (Fig. 2c, dashed arrow). After deformable registration and weighted image combination (Fig. 2d) blurring is reduced even more, anatomy is correctly represented and the noise level is decreased compared to the snapshot image from Fig. 2a.

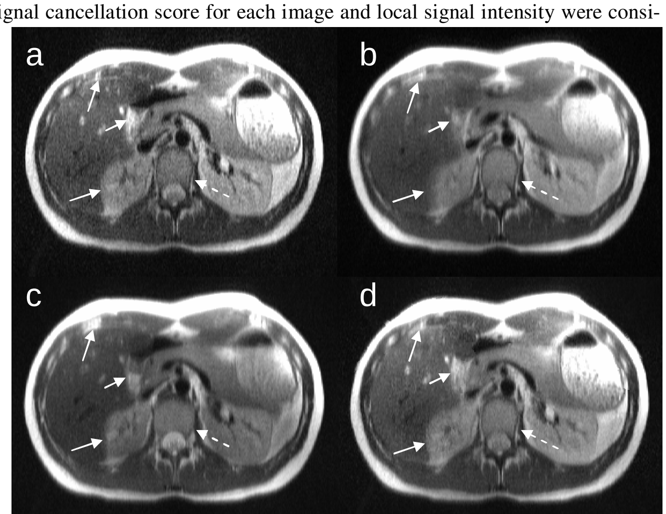

*Fig. 2: **(a)** Snapshot image included in the reference volume, **(b)** Average of all four snapshots for the same slice position, **(c)** Average of snapshots after rigid registration, **(d)** Weighted image combination after deformable registration. Solid arrows indicate blurring in (b) and corresponding positions in the other images. Dashed arrows indicate incorrectly represented anatomy in (c) and corresponding positions in the other images.*

Discussion

The presented method allows the reconstruction of artifact free images from free breathing acquisitions. In contrast to previous work [9] blurring and signal cancellations are eliminated. The applicability of the method is currently limited to multi-shot sequences, where motion consistent snapshots from arbitrary breathing states can be reconstructed from each shot. Future work includes its extension for application to sequences which acquire data continuously along the breathing motion (e.g. steady state gradient echo sequences). Furthermore, registration accuracy shall be improved by incorporating automatically detected landmarks in the registration process. Finally, through-plane resolution shall be increased by acquiring data continuously along the slice direction instead sampling k-space twice at slice positions with relatively large spacing.

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