TITLE: Robust volume assembly from real-time free-breathing cardiac 2D acquisitions with edge-preserving smoothing

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Target audience: MR scientists who work on motion correction, especially in the presence of image noise; and MR scientists working in cardiac MR.

PURPOSE: Real-time free-breathing image acquisition is a practical solution for patients, who cannot hold their breath reliably, and overall improves patient comfort. Due to respiratory motion, images acquired in free-breathing exhibit significant misalignment when combined in a 3D volume. When we take a volume stitched together from short axis images and reformat it into long axis MPRs, these long axis images provide little diagnostic value. Registration techniques for motion correction of MRI data have been widely used. Reference [1] applies misalignment correction when assembling a time-resolved 3D cine dataset from a stream of 2D free-breathing images. However, even with the advances of recent compressed sensing based reconstruction methods, real-time acquired images still exhibit significant noise levels, which lead to registration errors and residual misalignment. We propose to integrate an edge-preserving smoothing technique (e.g. a diffusion-based approach) to preserve the anatomical boundaries while suppressing noise in the images. With stronger guidance by the anatomical boundaries, the registration becomes more robust and the misalignment correction improves. The deformation fields obtained through registration are propagated across smoothing levels. Here, we integrate this approach into the workflow of [1], and demonstrate the improvement in the 3D volume assembly step.

METHODS: We acquired free-breathing cardiac images with a fluoroscopic radial bSSFP prototype, at an image rate of 40-50 ms and a resolution of 1.82x1.82x7 mm^3. ECG time-after-trigger was recorded to retrospectively map the images to cardiac phases. Images were reconstructed offline with a compressed sensing based algorithm [3]. Two datasets with approximately orthogonal scan planes were acquired: a short-axis (SX) set covering the heart with steps of 0.05mm, and a long-axis (LX) set, rotating 180° around the left-ventricular long axis in steps of 0.1°. After normalizing the cardiac phases for each cardiac cycle to a frame rate of 30ms, we assembled a series of 3D volumes from SX slices, one for each cardiac phase. Two LX slices are used as image anchors for this assembly. For each cardiac phase, we have a set S consisting of SX images and LX anchors. To evaluate our new method, we applied anisotropic diffusion [2] to obtain a new set S' with images SX' and anchors LX'. Anisotropic diffusion is a non-linear and space-variant transformation of the original image, and a typical technique for edge-preserving smoothing. For each SX' image, we now calculate the normalized correlation scores along the intersection lines with the two LX' anchors. The SX' slices with the "best fit" to the anchors (correlation scores with local maximum) are selected for the subsequent assembly. These selected SX' slices can still show misalignment among each other in the 3D spatial domain because they may have been acquired at slightly different breathing phases. Therefore, a correction process on SX' is performed iteratively by optimizing the line intersection correlation between SX' and anchors LX' while being constrained by neighboring slices (SX') through non-rigid registration. The deformation fields obtained in the correction process are then applied to the respective original images in S to correct those while maintaining the original resolution. Corrected slices are then interpolated to generate a volume on a regular 3D grid or are reformatted to MPRs.

RESULTS & DISCUSSION: We have collected 9 datasets from 6 volunteers and 3 patients, and tested the proposed method. For comparison, we also applied the algorithm described in [1] without edge-preserving smoothing. On each dataset, 3D volumes are reconstructed from the short axis stack of SX images making use of LX anchors. MPRs are then reformatted at an orthogonal orientation to the short axis slices for motion correction evaluation. Examples from two volunteers are provided in Fig. 1. Without edge-preserving smoothing, image noise degraded the registration and the correlation scores at a few slice locations. With the proposed approach, these artifacts in the reconstruction results are significantly reduced.

CONCLUSION: We have demonstrated the effectiveness of edge-preserving smoothing in correcting misalignment of short axis slices introduced by respiratory motion in cardiac MR imaging. The proposed approach was successfully integrated into a fully automated 3D reconstruction from real-time free-breathing 2D acquisitions, resulting in a time-resolved 3D volume sequence. The experimental results show promise for improved motion correction and volume reconstruction.

REFERENCES:

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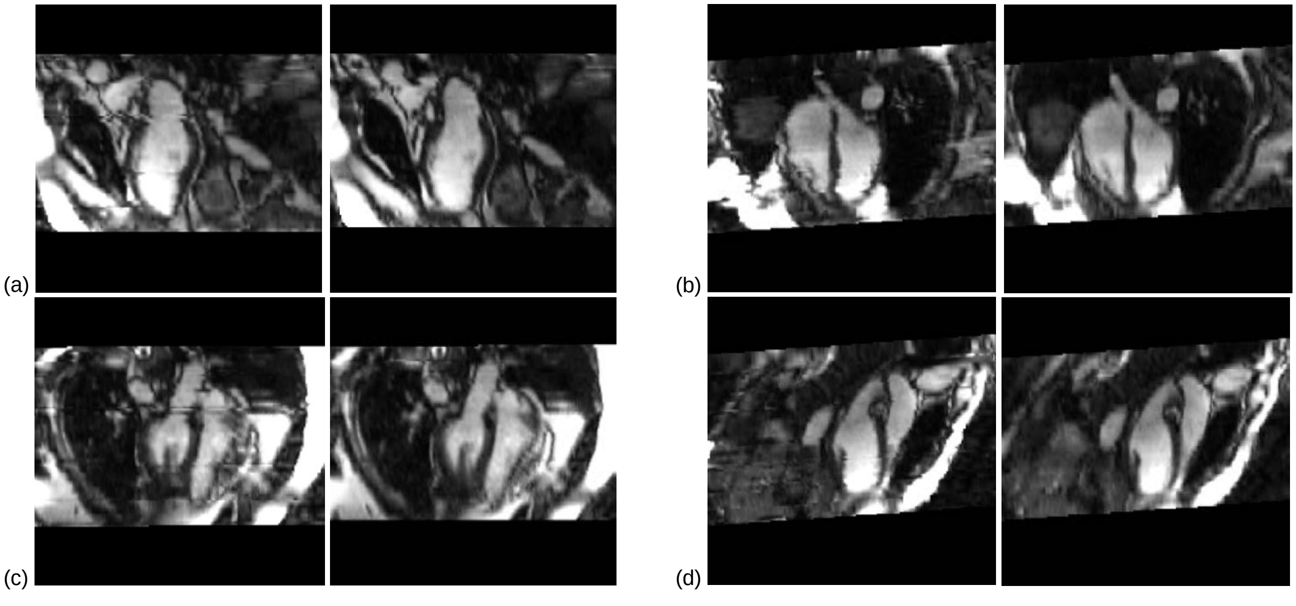

Figure 1. Four pairs of reformatted MPRs (Volunteer 1: a,c; Volunteer 2: b,d). Each MPR is reformatted from a stack of motion corrected slices orthogonal to the MPR orientation. Motion correction was performed with (right) and without (left) edge-preserving smoothing.