Reconstruction Exploiting Phase-Correlation Motion Estimation and Motion Compensation Methods for Cine Cardiac Imaging

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Introduction
Motion estimation (ME) and motion compensation (MC) are both essential to video compression [1], which have also been successfully applied to dynamic MRI with reduced k-space acquisition as baseline estimation adjunct for enhancing image reconstruction. [2] However, ME and MC have not been exploited as a standalone approach for direct dynamic MRI reconstruction. The current main challenges come from the absence of full-resolution frames. To address this issue, this work proposes a reconstruction technique based solely on the phase-correlation ME method [3] to estimate the motion vectors (MVs) needed for reconstruction, without incorporating extra computational routines as in previous works. [2,4] The experimental results show that the proposed method successfully reconstructs full-resolution dynamic MRI at substantially reduced acquisition time without incurring aliasing artifacts and loss of object motion information. The performance is competitive even with acquisition of only the central k-space for most of the frames.

Theory

The proposed method for cine cardiac imaging employs a phase-correlation based motion estimation technique. The motion estimation is based on a cross-power spectrum between two frames that is used to calculate the motion vectors (MVs) using a phase correlation method. The motion compensation is then performed using these MVs to interpolate the missing data in the undersampled k-space.

Methods

With a given accelerating factor, the sampling pattern in k-t domain is depicted in Fig.1. Down-sampled image frames at low spatial resolution are used as training data (called the P frames). Several full-sampled frames are used as reference frames (called the I frames). In our testing series containing 30 time frames, 5 reference frames are picked up. Typical implementation, divides each P frame into small blocks 4x4 pixels in size, with the blocks extended to 8x8 pixels centered around them for estimating MVs because increased overlapping area leads to better estimation. A 2-D Hanning window is applied to each 8x8 block to increase the weight of the formerly defined 4x4 region, to which an MV will be assigned. Phase-correlation ME is then performed between corresponding 8x8 blocks on two P frames. In general, the motion is not purely translational, which results in multiple peaks in cross-power spectrum as shown in Fig.2. While the highest peak in correlation map usually provides the best displacement match between the 8x8 blocks, it may not necessarily be the best for the 4x4 block. Therefore, several candidates are selected instead of just one highest peak. The candidate with highest image correlation [4,5] would best represent the MV for the 4x4 block. The reconstruction employs MC by applying MVs on the blocks of each I frame to obtain the compensated frames, with the residue compensated as well. Results from different acceleration factors are compared with their counter-part using k-t BLAST [4], k-t FOCUSS[2], and BM for benchmarking.

Results and Discussion

Four sets of cine cardiac images have been tested with the proposed method. Short-axis 2D TrueFISP with ECG gating was performed on a Philips Achieva 3T scanner with matrix size 256x256, 32 cardiac phases, 35° flip angle, and 10mm slice thickness. The reconstructed images are illustrated in Fig.3. Images reconstructed by BM suffered from lost details and blurring, and variations in x-t space were not largely preserved. Other reconstruction methods revealed slight blurring in the myocardium in the systolic phase. As for the temporal change for myocardium, the dynamics of myocardium reconstructed by k-t BLAST were somewhat weakened (x-t space at bottom of Fig.3), while our method and k-t FOCUSS preserved the dynamics as indicated by the arrows. In addition, k-t BLAST and k-t FOCUSS led to temporal smoothing in x-t space, while temporal variation is largely preserved with the proposed method.

Conclusion

A robust method for directly reconstructing dynamic images by ME and MC without incorporating extra reconstruction routine was presented in this study. The experimental results indicate that the proposed method can achieve improved temporal resolution and leads to reduced artifacts even from substantially undersampled k-space data. The principle can theoretically be extended to other dynamic imaging, such as functional MRI or contrast-enhanced MRI and is not restricted to cardiac applications.

References