

Reconstruction of accelerated dynamic contrast-enhanced Lung MR Imaging using Phase-Correlation Motion Estimation and Motion Compensation

Mei-Lan Chu¹, Jia-Shuo Hsu¹, Hsiao-Wen Chung¹, Shang-Yueh Tsai^{2,3}, and Yi-Ru Li⁴

¹Graduate Institute of Biomedical Electronics and Bioinformatics, National Taiwan University, Taipei, Taiwan, ²Graduate Institute of Applied Physics, National Chengchi University, Taipei, Taiwan, ³Research Center for Mind, Brain and Learning, National Chengchi University, Taipei, Taiwan, ⁴Department of Electronic Engineering, National Taiwan University of Science and Technology, Taipei, Taiwan

Introduction: Phase-correlation motion estimation (ME) and motion compensation (MC), which is an essential part of video compression technique [1], has been successfully applied to reconstructing under-sampled cine cardiac imaging [2]. For dynamic MR imaging outside of the cardiac region, such as dynamic contrast-enhanced (DCE) perfusion lung imaging, higher temporal resolution for wider slice coverage is still highly desirable. Previous works [3,4] have validated the feasibility of k-t BLAST [5] in DCE lung imaging, with a known restriction on temporal-smoothing and baseline overshoot. In this abstract, we demonstrate that these drawbacks can be overcome by using phase-correlation ME / MC with 2-fold to 6-fold acceleration. The experimental results show that the proposed method successfully reconstructs full-resolution dynamic frames at substantially reduced acquisition data without the disadvantages of overshooting in the initial time frames and the undesired smoothing effects in the presence of abrupt temporal variations.

Theory: The phase-correlation ME method [2] measures the translation between two blocks (i.e., sub-regions in the image) from their phases. According to the Fourier shift property, the translation in spatial domain is reflected as a phase change in the spectral domain. Therefore, we can obtain the translation, which is the motion vector (MV), by locating the peaks in the cross correlation corresponding to the phase change. The MVs can then be used to recover full-resolution frames in a block-by-block MC manner. The estimation is robust for capturing translation even with varying contrast since Fourier phases are hardly affected by shift or multiplication of the contrast.

Methods: The sampling pattern for lung imaging with a given accelerating factor is shown in figure 1. Down-sampled image frames with 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 60 time frames, 6 I frames were picked up. Typically, I frames and P frames are divided into 4x4 blocks respectively from which we estimated MVs by phase-correlation ME, and the reconstruction employs MC by applying MVs on the blocks of each I frame to obtain the reconstructed frames with the residue compensated as well. Dynamic contrast-enhanced lung images were obtained using IR-prepared, segmented EPI with TI/TR/TE/ETL=180/6.5/1.2/4, matrix size 256x256, and slice thickness=10~12mm with two coronal slices. Results from different acceleration factors are compared with their counter-part using k-t BLAST [5] for benchmarking.

Results and Discussions: The reconstructed images are illustrated as figure 2, and the RMS errors of individual time frames are shown in figure 3. The dynamics of signal intensity variations reconstructed by k-t BLAST were smoothed, while the temporal variation is largely preserved by our method as shown in latter time frames in figure 4. In addition, images reconstructed by k-t BLAST suffered from overshooting in the initial time frames, while our method accurately estimated the initial intensity (red dashed circle, figure 4). The relative root-mean-square (RMS) reconstruction errors with different accelerating ratios are shown in figure 5. Our proposed method is comparable to k-t BLAST in terms of overall RMS error and provides improved reconstruction.

Conclusion: The potential feasibility of reconstructing DCE lung perfusion images by phase-correlation ME and MC was investigated in this study. The experimental results indicate that the proposed method can achieve accelerated acquisition with improved preservation of temporal dynamics even in the presence of drastic signal variation caused by the wash-in/wash-out of the contrast agent. The proposed method can be extended to other dynamic imaging, such as functional MRI and other contrast-enhanced imaging, and is not restricted to cardiac and pulmonary applications.

References: [1] D. Le Gall, Communications ACM 1991;34:46-58 [2] Chu et al. ISMRM 2010 (3078) [3] Hsu et al. ISMRM 2007 (3040) [4] Hsu et al. ISMRM 2010 (5075) [5] Tsao et al. MRM, 53:1372-1382, 2005

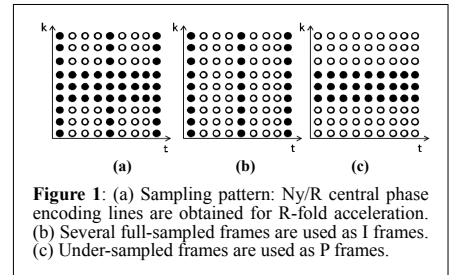


Figure 1: (a) Sampling pattern: Ny/R central phase encoding lines are obtained for R-fold acceleration. (b) Several full-sampled frames are used as I frames. (c) Under-sampled frames are used as P frames.

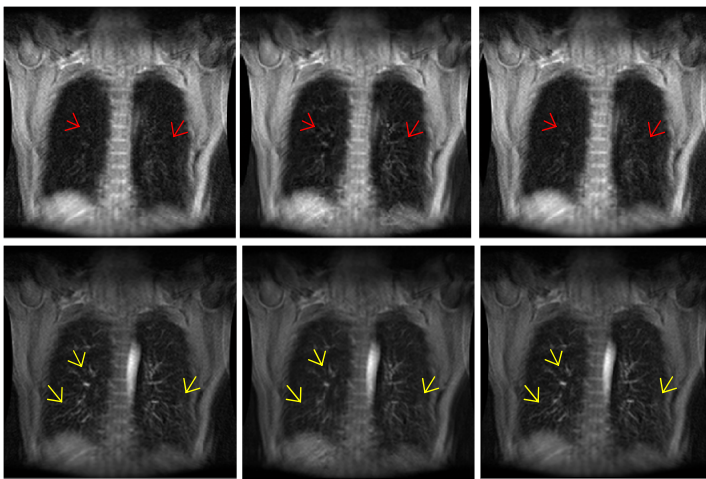


Figure 2: Time frame 11 (top row) and 22 (bottom row) of slice 1 reconstructed by the proposed method (right column), k-t BLAST (middle column), and non-accelerated reference (left column). Some finer vessels were properly enhanced by k-t BLAST as indicated by red arrows and some were blurred and partially lost as yellow arrows indicated, while our method largely preserves their morphological details and contrast variations.

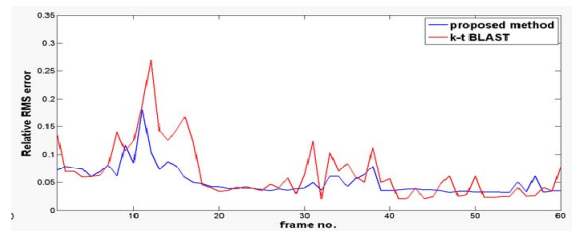
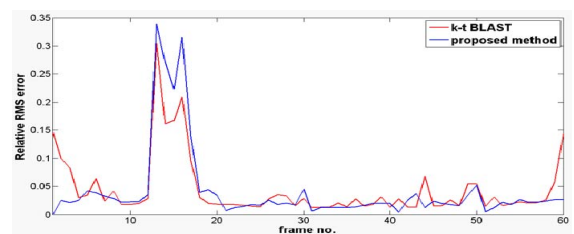


Figure 3: RMS error of each time frames of slice 1 (top) and slice 2 (bottom) reconstructed by k-t BLAST (red) and the proposed method (blue) under 6-fold acceleration. The results reveal that the relative RMS error is particularly larger at frames 10 to 20 due to the steep change of image contrast with contrast agent wash-in.

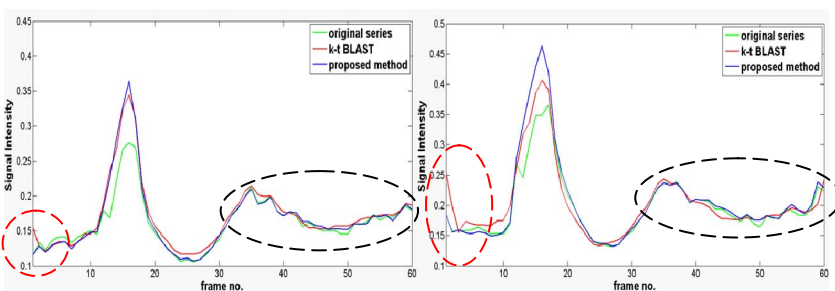


Figure 4: Time-intensity curve of left lung (left) and right lung (right) from slice 1 reconstructed by k-t BLAST (red), the proposed method (blue), and non-accelerated reference (green).

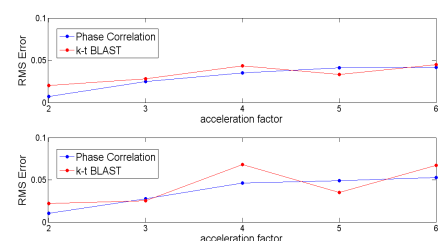


Figure 5: RMS error within entire FOV of slice 1 (top) and slice 2 (bottom) from 2 to 6-fold acceleration using k-t BLAST (red) versus the proposed method (blue).