Residual reordering for motion compensated compressed sensing cardiac perfusion MR imaging

Huisu Yoon[1], Ganesh Adluru[2], Edward DiBella[2], and Jong Chul Ye[1]

[1]Department of Bio and Brain Engineering, KAIST, Daejeon, Korea, [2]Utah Center for Advanced Imaging Research, Department of Radiology, University of Utah, Salt Lake City, UT, United States

Introduction

k-t FOCUSS with motion estimation and compensation (ME/MC) has been used for various dynamic MR imaging applications including cardiac cine[1], tagging[2], T2 mapping[3], etc to accelerate the acquisition time. However, one of the limitations of k-t FOCUSS with ME/MC is that the motion residual signals are often contaminated with background noises, so the reconstruction of the residual signal using standard l_1 sparsity constraint are often inefficient in capturing the physiological features such as edges and resulting in blurry reconstruction. In this work, we exploit the reordering algorithm[4,5] to make the residual reconstruction more efficient. Using a cardiac perfusion data set, we demonstrate that the proposed method provides more accurate reconstruction compared to the original FOCUSS reconstruction of the motion residual.

Theory

A forward model for dynamic MR image is represented as $y = Fx + w$, where y denotes k-space measurement, x denotes the unknown image, and w denotes measurement noise. F represents undersampled Fourier matrix. Here, x can be decomposed as $x = \Sigma\theta$, where Σ is sparsifying transform and θ is its corresponding coefficients. In this research, we assume that $x = \bar{m} + d$, where $\bar{m}$ is a prediction part and d is an unknown residual to be estimated. To get prediction term $\bar{m}$, initial reconstruction is obtained by k-t FOCUSS[1]. Then, $\bar{m}$ is predicted by applying ME/MC to initial reconstruction image. Taking the temporal average image from predefined phase range generates a reference frame for ME/MC. After the motion prediction and compensation, we adopt the reordering scheme[4,5] to reconstruct the residual signal. More specifically, the cost function for d can be represented as :

$$C = ||y - F\bar{m} - Fd||_2^2 + \alpha_1||\sqrt{\nabla_t(P_t d)^2 + \varepsilon}\,||_1 + \alpha_2||\sqrt{\nabla_x(P_x d)^2 + \nabla_y(P_y d)^2 + \varepsilon}\,||_1,$$ where P represent reordering operator based on signal magnitude and ∇ represents gradient operator. The cost function is referred to as a spatio-temporal constrained reconstruction (STCR)[4,5] for residual encoding. The solution is updated iteratively according to $d^{n+1} = d^n - \lambda C'(d^n)$, where C' is the Euler Lagrange derivative of C.

Experimental results

Short-axis slices were acquired for every heartbeat in each patient on a Siemens 3T scanner using an eight-channel cardiac coil at Univ. of Utah. Gd dose was 0.05 mmol/kg. A turbo fast low-angle shot (TurboFLASH) saturation recovery sequence with scan parameters TR ~2.5ms, TE 1.1 ms, and slice thickness 7–8 mm was used. The acquisition matrix was 144x108 and the acquired pixel size was 2x2.5mm^2. Figure 1 shows the reconstruction results from a single coil with acceleration factor $\cong$ 4. We have compared reordering, k-t FOCUSS, and the proposed algorithm. From the first row, we can see that reordering (STCR) reconstructs moving edges of motion residual images. However, when combined with motion compensated image, as shown in the second row, reordering results in blurring near cardiac wall boundaries, and aliasing artifacts remain. k-t FOCUSS is effective in removing most of the aliasing artifacts, but the cardiac walls are somewhat blurry. The proposed algorithm shows the cardiac wall boundary more clearly than k-t FOCUSS. In the third row, temporal slice profiles are compared. Reordering alone did not catch the cardiac motion effectively, and k-t FOCUSS showed temporal blurring artifacts. However, the proposed algorithm provided the most clear temporal profile without any blurring edge information.

Conclusion

For cardiac perfusion imaging, the spatio-temporal constrained reconstruction using reordering was found effective for reconstruction of the motion residuals in k-t FOCUSS with ME/MC. The results indicated that spatio-temporal reordering favored the reconstruction of clinical important edge information rather than reconstructing background noise.

References

1. Jung et al, Magn Reson Med 61:103-116 (2009). 2. Jung et al, Magn Reson Med 63:68-78 (2010). 3. Li et al, Magn Reson Med 65: 1661-1669 (2011). 4. Adluru et al, Magn Reson Med, 57:1027–1036 (2007) 5. Adluru et al, IJBI,:1-12 (2008)
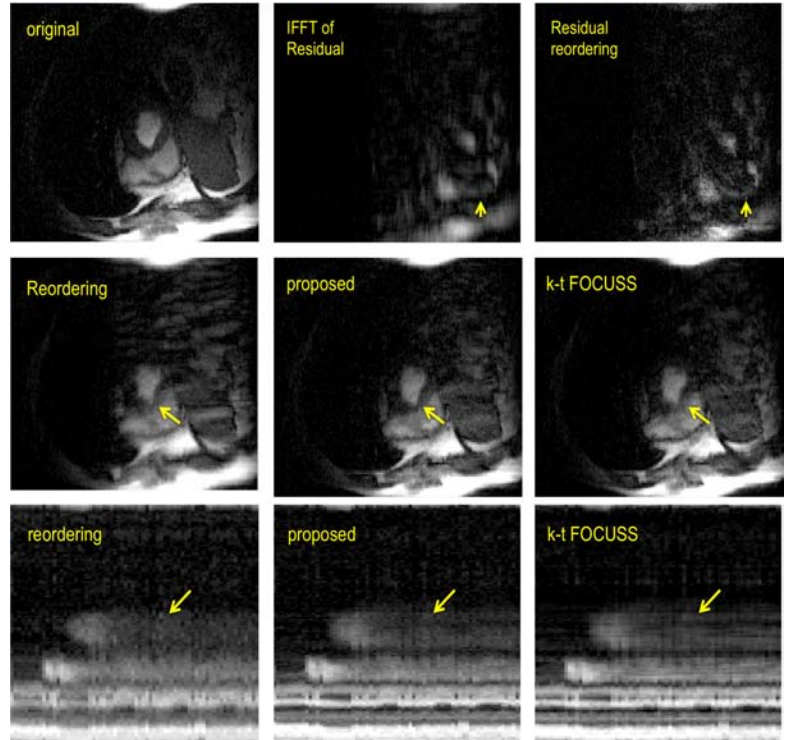
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Figure 1. Reconstruction results of reordering, proposed algorithm, and k-t FOCUSS. The first row represents original image, IFFT of residual, and reconstructed residual by STCR. The second row represents resultant FOVs of STCR(reordering), proposed algorithm, and k-t FOCUSS. The third row represents temporal slice image of STCR, proposed algorithm, and k-t FOCUSS, respectively.