On the Optimization of Parallel Imaging for Ghost Reduction: A Blood Flow Example

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Introduction

A data COnvolution and Combination OperAtion (COCOA) [1], has been recently proposed to deal with random and non-rigid motion, which is common in clinical imaging. It has been demonstrated that the ghosts due to swallowing and breathing can be significantly suppressed by COCOA with a minimum impact on the reconstruction time and the image signal-to-noise ratio (SNR). In this work, we further optimized COCOA for the specific application of blood-flow artifact reduction. .

Theory

There are two steps in COCOA: the convolution step and the combination step. In the convolution step, an extra synthetic *k*-space dataset is generated using the convolution kernel obtained from the calibration data near the *k*-space center. It is expected that the error in the original *k*-space data will be attenuated after the data convolution. Therefore, the convolution kernel should be large enough to contain sufficient motion-free data or data with incoherent motion. Moreover, the kernel should not contain data acquired in the same or adjacent repetition times (TR) since they are prone to similar coherent motion artifacts. If one phase encoding (PE) is contaminated by flow artifact, it is likely that the immediate adjacent phase encoding (PE) lines are also corrupted. Hence, the convolution kernel is designed as shown in Fig. 1. Immediate adjacent PE lines are not used in the convolution. In the combination step, it is expected that the corrupted data can be detected by using the *k*-space difference before and after convolution. Using a set of abdominal data as an example, the black line in Fig. 2 plots the difference between the original and the synthetic *k*-space. Periodic local maxima introduced by inflow can be seen on the plot of *k*-space difference. By smoothing the difference signal along the PE direction, these local maxima can be easily identified. The red line in Fig. 2 shows the plot of the smoothed difference. At locations with errors, the black line has higher value than the red line and the data from the synthetic *k*-space will be used. At other locations, the original acquired *k*-space data will be used.

Methods

A non-ECG synchronized abdominal breath hold data set was acquired on a 3.0T Achieva scanner (Philips, Best, The Netherlands), using a 32-element cardiac coil (Invivo Corp, Gainesville, FL). A dual echo gradient echo imaging sequence (FOV 375 × 375 mm2, matrix size 204×256, TR 90 ms, TE1/TE2 2.3/5.8 ms, flip angle 80°, Slice thickness 7 mm) was used for data acquisition. PE direction was anterior-posterior. COCOA was used with the convolution kernel defined by Fig. 1 and the combination scheme defined by Fig.2. The central 64 PE lines of the corrupted data set were used for convolution kernel calibration.

Results and Discussion

Fig. 3 shows the results of the abdomen images corrupted by blood flow. In Fig. 3a, multiple copies of vessel can be clearly seen due to flow artifacts. Fig. 3c shows the result after the application of optimized COCOA. It can be seen that the ghosts were significantly reduced. The removed ghosts are shown in Fig. 3d, which is the difference between Figs. 3a and 3c. When comparing image quality before and after correction, it can be seen that the change in SNR was insignificant. Fig. 3b shows the result using immediate adjacent PE lines in the convolution. Some residual ghosts can be observed, as shown by the arrows. This is because the convolution contains data with coherent errors due to the same inflow.

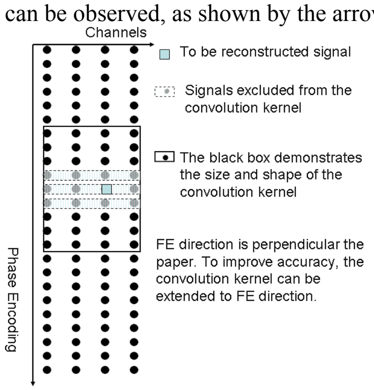

Fig. 1 The optimized convolution kernel for ghosts due to blood flow

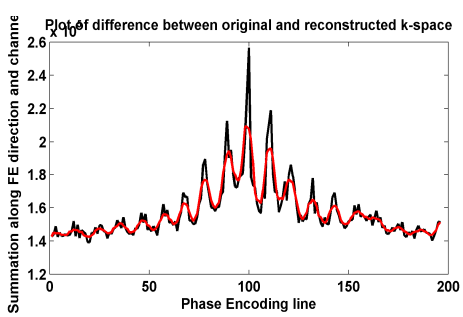

Fig. 2 Black Line: the plot of the difference between original and the synthetic *k*-space. The absolute value was added along FE direction and channels. The red line: smoothed version of the black line through local average

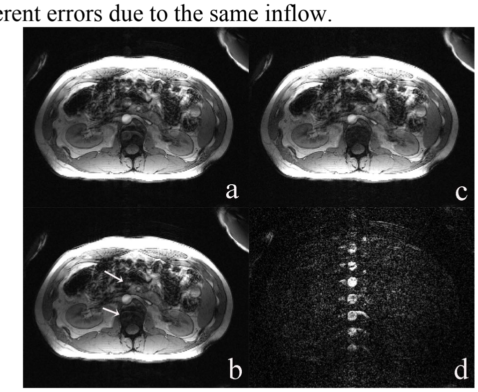

Fig. 3. a) The image before COCOA. b) Result of COCOA with non-optimized convolution kernel, which uses the immediate adjacent PE lines. c) Result of optimized COCOA. d) The removed ghosts, which is the difference between a) and c).

Conclusion

The convolution kernel can be optimized by avoiding coherent error in COCOA method. The ghosts due to blood flow in the corrupted data demonstrate themselves as peaks in the *k*-space difference. Hence the corrupted data can be easily identified using the smoothed difference. The computation cost of COCOA is similar to GRAPPA, which is a few seconds for most data sets. In summary, ghosts due to blood flow can be significantly suppressed in seconds with minimal impacts on SNR using COCOA.

References

[1] Huang F, et al. 2009; the 3rd International Workshop on Parallel MRI, Santa Cruz, CA, USA. [2] Griswold M. A., et. al. Magn Reson Med 2002;47:1202-1210