Improved Partial Fourier Reconstruction Using Two Reverse Polarity Echoes in a Single GRE Acquisition

Ehsan Hamtaei[1,2], Saifeng Liu[3], Yongquan Ye[2], Dongmei Wu[4], and E. Mark Haacke[1,2]

[1]MR Innovations Inc., Detroit, MI, United States, [2]Radiology, Wayne State University, Detroit, MI, United States, [3]MRI Institute of Biomedical Research, Ontario, Canada, [4]East China Normal University, Shanghai, China

Introduction: One approach to saving time in MRI is to use asymmetric echoes. An image is then created using a partial Fourier (PF) reconstruction technique. Depending on the application, asymmetric echoes can be used to achieve short echo time, reduce the scan time or increase the spatial resolution (the data is collected partially in either frequency or phase encoding directions). Theoretically, only half of k-space signal is required for a complete reconstruction of the image. Assuming the desired MR image is a real valued function; the missing half of k-space can be calculated by complex conjugation and reflection of the collected data through the center of k-space. However, due to phase errors from field inhomogeneities, flow, motion, susceptibility effects etc., the MR image is a complex valued function and therefore the conjugate symmetry approach does not hold in k-space signal anymore. Therefore, a few extra lines around the center of k-space are usually collected so the symmetric low spatial frequency k-space signal can be used to get an estimate of the phase image. This phase estimate is then used in different ways to correct for the aforementioned phase errors [1]. The POCS algorithm (Projection Over Convex Sets) [2,3] uses the phase estimate as a constraint in order to drive an iterative algorithm leading to recovery of missing data in k-space and improving the reconstructed image. The crucial point in POCS reconstruction is that if a full resolution phase image were available, the algorithm would converge to the exact recovery of the k-space signal after a finite number of iterations [2]. *This suggests that by collecting more symmetric central k-space information, a better phase estimate can be obtained and eventually a more successful reconstruction can be achieved.*

Method: Instead of collecting more lines in the center of k-space to improve the POCS reconstruction, we are proposing a technique suitable for PF reconstruction of double echo gradient echo acquisitions. In conventional PF reconstruction for multi-echo acquisitions, the k-space for each echo is reconstructed individually by using the POCS algorithm. Therefore the phase estimate for each echo is obtained from the central symmetric part of it's k-space and therefore it only has the low spatial frequency information. The key to our proposed method is to take advantage of having two echoes and obtain a full resolution phase estimate for both of them, eventually improving the reconstruction of both magnitude and phase images.

We consider a simple gradient echo acquisition with an asymmetric echo in echo one mirrored about itself for echo two. This will cause the signal for the second echo to be acquired on the opposite side of the origin of k-space (Fig. 1). For small echo spacings, the T2* decay of magnitude images may be neglected. Assuming that both echoes are fully flow compensated, we have: $\varphi_{TE2} - \varphi_{TE1} = \gamma \Delta B \Delta TE$. This phase difference can be estimated by complex dividing the low resolution image obtained from the symmetric central k-space signal of both echoes: $\Delta\varphi_{sym} = angle(I_{sym_{TE2}}/I_{sym_{TE1}})$. We can correct the phase of each echo to be the same as the other echo by subtracting (or adding) this phase difference estimate from (or to) the zero-filled image in a complex fashion:

$$I_{\varphi 1_{TE2}} = I_{zf_{TE2}}\, e^{-i\,\Delta\varphi_{sym}} \qquad I_{\varphi 2_{TE1}} = I_{zf_{TE1}} e^{i\,\Delta\varphi_{sym}}$$

where $I_{\varphi 1_{TE2}}$ is the zero filled reconstructed complex image of the second echo with its phase corrected to be the same as that of the first echo. With the assumption that the high spatial frequency information of the phase corrected k-space is fairly similar between the two echoes, we can replace the missing side of the original k-space for each echo with the phase corrected k-space of the other echo (Fig. 1). The resultant full pseudo k-space can be used to create a full resolution phase estimate for each echo. The corresponding full resolution phase estimate can be used along with the original zero-filled magnitude image as input to the POCS algorithm to recover the missing data in k-space.

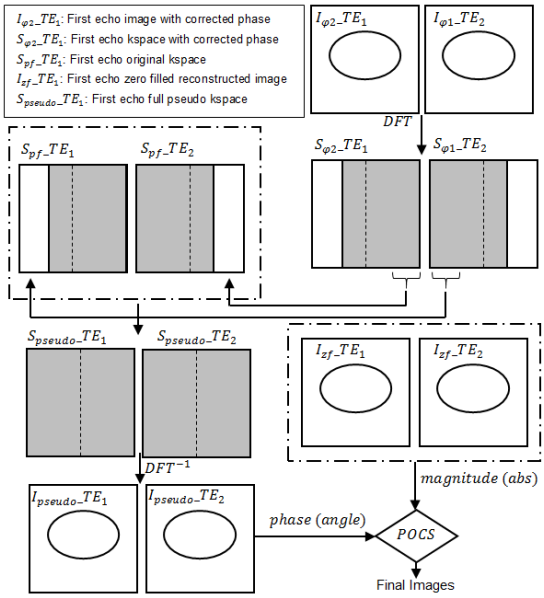

Fig. 1. Schematic view of the proposed reconstruction flow chart. Symbols are defined at the top left corner.

A fully flow compensated double echo GRE sequence was used to image a resolution phantom in a 3T Siemens Verio with the following parameters: TE=5\10ms, TR=20ms, FA=20, BW=501Hz, and a resolution of .87x.87x1 in a matrix size of 256x256 (fully sampled). PF acquisition was simulated by creating masks covering 62% of the k-space on opposite sides for each echo.

Results: Fig. 2a shows the improved phase estimate from our proposed method for both echoes compared with the low resolution phase estimate from 64 symmetric central k-space data used in conventional POCS. The improved detail obtained with the proposed full resolution phase estimate helps POCS converge more efficiently. Fig. 2b compares pixel by pixel error maps for the magnitude images. The normalized total root-mean squared error (RMSE) is qouted for each error map. There is significant improvement in the image quality using our new PF method.

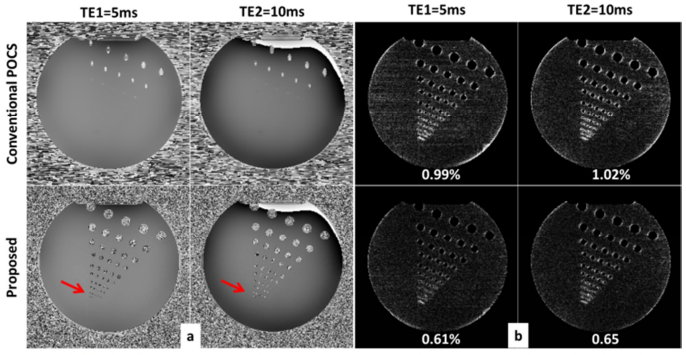

Fig. 2. a) comparing phase estimate used in proposed method and conventional POCS. Red arrow shows the improved structural detail only visible in the proposed phase estimate. b) Comparing normalized RMSE error maps for the reconstructed magnitude images.

Discussion and Conclusion: Using information from both sides of k-space in a double echo GRE sequence, it is possible to obtain improved complex image reconconstructions with a PF reconstruction algorithm. This will make it possible to create better MR angiograms for example without the underlying phase artifacts.

References: [1] Zhi-Pei Liang et.al., MRM1992. [2] E. M. Haacke et.al., JMRI 1991. [3] Yingbiao et.al., JMRI 2001.