Further acceleration of Partial Fourier-FOCUSS using Bunched Phase Encoding

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Introduction: Bunched Phase Encoding (BPE) has significant potential for fast data acquisition in MRI [1]. In BPE, k-space data are acquired along zigzag trajectories (Fig.1) using rapidly oscillating gradients along the PE direction. Since BPE acquisition scheme is comparable to acquiring multiple PE lines in a single readout, the total number of TR cycles and hence the scan time can be reduced. In practice, reduction factor of BPE is usually up to around 2. If the reduction factor is increased, there is considerable noise amplification in the reconstructed image [1]. Recently, Partial Fourier-FOCUSS (PF-FOCUSS) has been proposed as a new reconstruction method for PF imaging in standard Cartesian data acquisition [2]. In PF-FOCUSS, an edge image is first estimated from low frequency k-space data. The final image is reconstructed from the data undersampled at PE direction using FOCUSS based on the estimated image. Images reconstructed using PF-FOCUSS are generally of high quality. Furthermore, unlike other PF techniques, PF-FOCUSS can achieve reduction factor that is greater than 2 [2]. In this study, BPE acquisition method is taken advantage of in PF-FOCUSS to further accelerate the data acquisition while quality of the image is maintained. The newly proposed method is referred to as 'BPE-PF-FOCUSS'. As demonstrated below, while no parallel imaging techniques are used, BPE-PF-FOCUSS can usually achieve reduction factor 4 with no significant noise amplification.

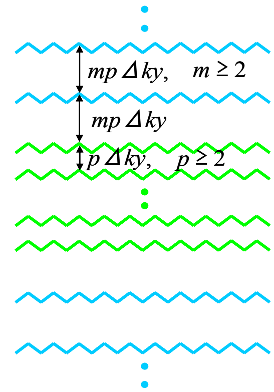

Fig.1. k-space of BPE-PF-FOCUSS

Methods: K-space data acquisition method of BPE-PF-FOCUSS is shown in Fig.1. As seen, all k-space data are acquired along zigzag trajectories. Data in the central k-space are acquired at every $p\Delta ky$ ($p\geq2$) along PE direction (green lines), where Δky is $1/FOV_y$. The rest of k-space data are acquired at every $mp\Delta ky$ ($m\geq2$) (blue lines). A flow chart of the whole procedures of BPE-PF-FOCUSS reconstruction is shown in Fig.2. The central data are first high-pass-filtered along *y* direction and inverse Fourier Transform (FT) is performed on these data. Note that BPE reconstruction is not done in this step but that normal 2D-IFT is performed directly on the data. The reconstructed image will be used as an estimated edge image when FOCUSS reconstruction is done afterwards. Since sampling frequency of BPE is higher than that of normal acquisition, FOV_x of this estimated image is usually larger than the prescribed FOV_x. The whole acquired data are then high-pass-filtered along *y* direction. These data are reconstructed using FOCUSS based on the estimated edge image. The reconstructed edge image shows higher resolution than the estimated image while aliasing artifacts still remain in both *x* and *y* directions. K-space data of the reconstructed edge image are obtained via FT. Inverse filtering is successively applied to these data to restore the data over the entire target k-space. In this inverse filtering, the data are multiplied by an inverse of the previously applied high-pass filter. The originally acquired data are inserted to the corresponding k-space locations in the restored data. BPE reconstruction method using matrix inversion [1] is then applied to these data to reconstruct the final image.

MR experiments were performed to test BPE-PF-FOCUSS using a 3.0 Tesla Siemens Trio Scanner. Both phantom and *in-vivo* images were acquired. In *in-vivo* experiments, axial brain images were acquired from an asymptomatic volunteer. We used the same FSE sequence in each experiment. The sequence parameters are TR/TE 3000/200ms, FOV 270x270mm, and ETL 16. The zigzag trajectory used in these experiments had 128 oscillations with the amplitude $0.6\Delta ky$. All procedures were done under an institutional review board approved protocol for volunteer scanning. The image matrix size was 256 x 256, i.e, there were 256 PEs in the target k-space. In reduced acquisition in each experiment, the total number of TR cycles was 4, i.e, only 64 (=16 ETL x 4) PEs were acquired. Therefore, the reduction factor was 4 (=256/64). In the data acquisition, *p* and *m* were set to 2 and 4, respectively. Note that parallel imaging methods were not used in these experiments.

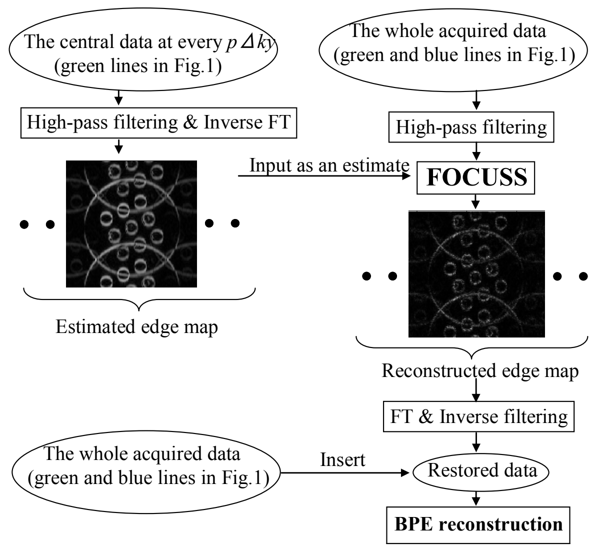

Fig.2. Flow chart of BPE-PF-FOCUSS

Results: Figure 3 shows reconstructed images: (a) the phantom image reconstructed from 25% data using BPE-PF-FOCUSS, (b) the phantom image reconstructed from 100% data using 2DFT, (c) the brain image reconstructed from 25% data using BPE-PF-FOCUSS, (d) the brain image reconstructed from 100% data using 2DFT. In (a) and (c), neither apparent aliasing artifacts nor significant noise amplification can be seen. Although 'aliased edges' can barely be observed at some locations in these images, the artifacts are perceptibly insignificant. The measured SNR's of (a) and (c) are 65.1 % and 70.6 % of those of (b) and (d), respectively.

Discussion and Conclusions: Both BPE and PF-FOCUSS are fascinating fast data acqusition methods of MRI. When the reduction factor is increased, they show different patterns of image degradation: the reconstructed images exhibit amplification of noise and increased levels of aliasing artifacts in BPE and PF-FOCUSS, respectively. In the newly proposed BPE-PF-FOCUSS, these methods are combined and comlement each other, thereby enabling substantially fast data acquisition with quite minor degradation of image quality. In our experiments, reduction factor 4 was achieved in BPE-PF-FOCUSS. Furthermore, as mentioned above, parallel imaging techniques were not used in our experiments. If BPE-PF-FOCUSS is combined with parallel imaging or other fast imaging methods, we can expect even faster data acquisition. In reconstruction of BPE-PF-FOCUSS, as seen in the left column of Fig.2, an estimated image that FOCUSS algoritm starts with shows aliasing artifacts. Therefore, the reconstructed edge map also exhibits aliasing artifacts. However, these aliasing artifacts can be decomposed at the final BPE reconstruction. Thus, in BPE-PF-FOCUSS, no modification is required in reconstruction of PF-FOCUSS except the final BPE reconstruction. The newly proposed BPE-PF-FOCUSS is a considerably fast imaging method that capitalizes on advantages of BPE acquisition and PF-FOCUSS reconstruction.

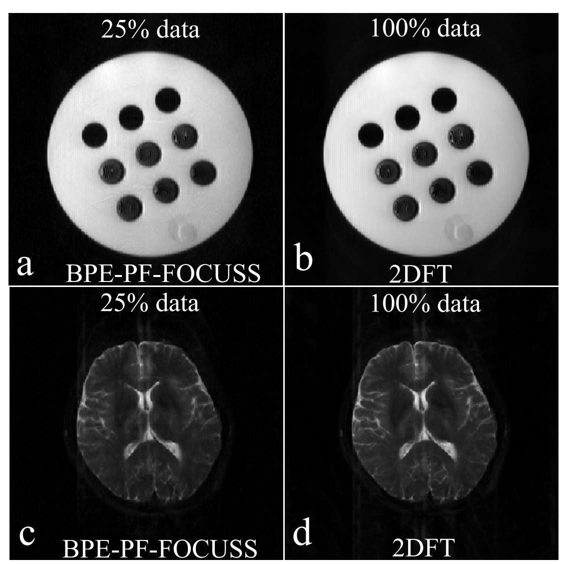

Fig.3. Reconstructed images

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References: [1] Moriguchi H, et al. MRM 2006;55:633-648. [2] Moriguchi H, et al. Proc ISMRM 2011. p2844.