

Novel partial Fourier reconstruction technique using FOCUSS

H. Moriguchi^{1,2}, S-I. Urayama³, Y. Imai¹, M. Honda⁴, and T. Hanakawa^{4,5}

¹Radiology, Tokai University, Isehara, Kanagawa, Japan, ²Radiology, Hiratsuka municipal hospital, Hiratsuka, Kanagawa, Japan, ³Human Brain Research Center, Kyoto University, Kyoto, Kyoto, Japan, ⁴Functional Brain Research, National Center of Neurology and Psychiatry, Kodaira, Tokyo, Japan, ⁵Precursory Research for Embryonic Science and Technology, Japan Science and Technology Agency, Japan

Introduction: Partial Fourier (PF) imaging is one of the most widely used fast data acquisition methods in MRI. In PF imaging, data are acquired in only a limited part of the target k-space to reduce the scan time. The missing data are estimated using sophisticated reconstruction techniques. To date, various kinds of PF reconstruction algorithms have been developed [1-5]. Most of the algorithms use image phase information that is estimated from the low resolution image [1-4]. A recently proposed k-space convolution method does not extract image phase in advance but still implicitly estimates phase information through data fitting [5]. In these PF reconstruction algorithms, image quality depends on the estimated phase information. However, it is often difficult to estimate accurate phase from the low spatial frequency k-space data. In this work, we show a novel PF reconstruction technique that does not require phase estimation. Although the new method usually acquires 50~70% data of the target k-space, it is possible to further reduce the acquired data even below 50%. In the image reconstruction, the focal underdetermined system solver (FOCUSS) recently proposed for under-sampled projection reconstruction has been modified to rectilinear acquisition [6]. Therefore, this new method is referred to as 'PF-FOCUSS'. Images reconstructed using PF-FOCUSS are generally of quite high quality.

Methods: K-space data acquisition scheme of PF-FOCUSS is shown in Fig.1. In Fig.1, a dashed line indicates the center of the target k-space, and the colored regions or lines are locations where data are acquired. In this acquisition method, phase encoding (PE) data in the central regions A (indicated as green in Fig.1) and B (yellow in Fig.1) are acquired with no gaps while those in the peripheral regions are acquired at every $m \Delta ky$ (blue lines in Fig.1), where Δky is $1/\text{FOV}_y$ and $m \geq 2$. Regions A and B are usually 20~30% and 10~20% of the whole target k-space, respectively. A flow chart of PF-FOCUSS is shown in Fig.2. A high pass filter along y direction is applied to data A before inverse Fourier Transform (FT) to create an estimated edge map. Data sampled at every $m \Delta ky$ are also high pass filtered along y direction. A high resolution edge map is then reconstructed from these high pass filtered data using FOCUSS. In this step, the edge map created from data A is used as an 'estimate'. Note that FOCUSS can reconstruct images from reduced data using an L1 minimization algorithm when an initial estimate is given. This edge map reconstructed using FOCUSS shows high resolution and no apparent aliasing artifacts. K-space data of the reconstructed edge map are obtained via FT. Inverse filtering is applied to these k-space data. In this step, the data are multiplied by an inverse of the previously applied high-pass filter to restore the whole k-space data. However, since the central k-space data usually contain non-negligible errors, they are replaced by the data A+B. These data are inverse FT-ed to reconstruct an image.

MR experiments were performed to test PF-FOCUSS using a 3.0 Tesla Siemens Trio Scanner. Both phantom and *in-vivo* images were acquired. In the phantom experiments, a resolution phantom was scanned using a FLASH sequence with TE/TR=10.0/20.0ms and FOV 250mm. In *in-vivo* experiments, axial brain image were acquired from an asymptomatic volunteer using a fast spin echo (FSE) sequence. In the FSE sequence, TR/TE 3000/130ms, FOV 230mm, and ETL 16. 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, data A and B consisted of 64 and 22 PEs, respectively, and $m=4$. Therefore, only 128 PEs were acquired, i.e., the scan time was reduced to 50%.

Results: Figure 3 shows reconstructed images: (a) the phantom image reconstructed from 50% data using PF-FOCUSS, (b) the phantom image reconstructed from 100% data using 2DFT, (c) the brain image reconstructed from 50% data using PF-FOCUSS, (d) the brain image reconstructed from 100% data using 2DFT. As observed in (a) and (c), there are no apparent aliasing artifacts in the images reconstructed using PF-FOCUSS. In image (a), although some ghost-like artifacts consisting of high frequency components are observed, they are quite insignificant. Furthermore, when pegs observed in image (a) are compared with those in image (b), the resolution of image (a) is almost comparable with that of (b). In *in-vivo* imaging, there are almost no perceptible difference between (c) and (d).

Discussion and Conclusions: Most of the previously proposed PF reconstruction algorithms usually acquire the entire half region of the k-space and small low-frequency portion in the other half region of the k-space. Therefore, at least 65~70% of k-space data must be acquired. In PF-FOCUSS, as shown in Fig.1, while 30~50% data need to be acquired in the central k-space region, the rest of the data are acquired at skipped PE in the peripheral k-space region. Therefore, it is possible to reduce the total data to 50% or even lower than 50%. In each of our reduced acquisition experiments, only 50% of the k-space data were acquired. In the previously proposed PF methods, they extract a-priori phase information from the central k-space data and use it as a constraint when reconstructing the images. However, phase information estimated from the low frequency k-space region is often inaccurate. In PF-FOCUSS, as shown in Fig.2, an edge map is first estimated from the central k-space data. An unaliased edge map is then reconstructed from the high frequency data acquired at skipped PEs with the given estimated edge map. The reconstructed edge map is usually of high resolution and shows no apparent aliasing artifacts. Therefore, as seen in Fig.3, images reconstructed using PF-FOCUSS are of high quality. The newly proposed PF-FOCUSS is a quite useful algorithm for PF imaging that can achieve faster acquisition than existing PF methods while reconstructing images of excellent quality.

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References: [1] McGibney G, et al. MRM 1993;30:51-59. [2] Haacke EM, et al. JMR 1991;92:126-145. [3] Noll DC, et al. IEEE TMI 1991;10:154-163. [4] Liang ZP, et al. IEEE Press. 2000;416p. [5] Huang F, et al. MRM 2009;62:1261-1269. [6] Ye JC, et al. MRM 2007;57:764-775.

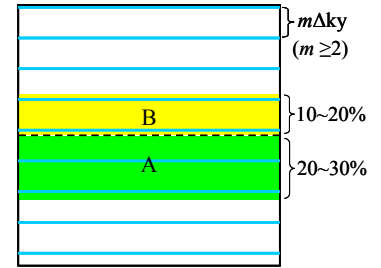


Fig.1. k-space acquisition of PF-FOCUSS

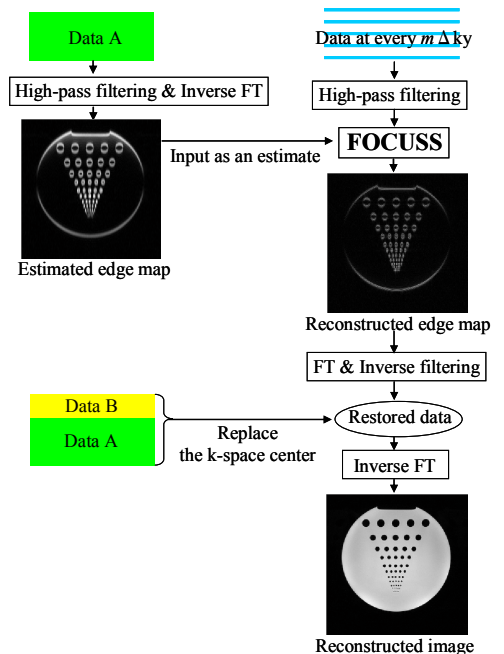


Fig.2. Flow chart of PF-FOCUSS

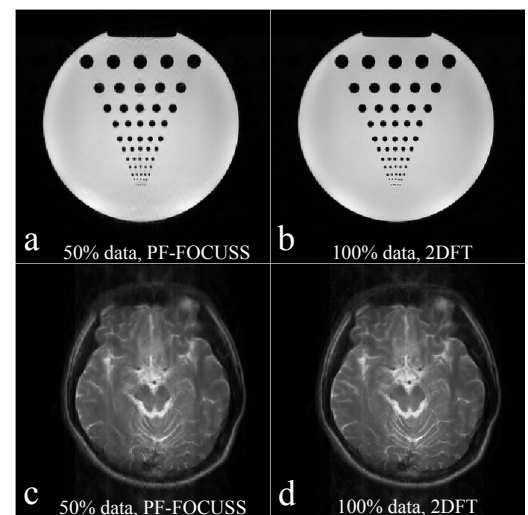


Fig.3. Images reconstructed using PF-FOCUSS and 2DFT