Single Coil PILS Imaging Using Phase-Scrambling Fourier Transform Technique

S. Ito[1], and Y. Yamada[1]

[1]Research Division of Intelligence and Information Sciences, Utsunomiya University, Utsunomiya, Tochigi, Japan

Introduction Parallel image reconstruction using local sensitivities (PILS)[1] accelerate MR scan time by using multiple receiver coil in parallel scan time. We propose a novel imaging technique which is based on the PILS, but uses only a single set of signals. The signal obtained in the phase-scrambling Fourier Transform imaging (PSFT)[2] can be transformed into the signal described by the Fresnel transform of the objects, in which alias-less images can be obtained by optionally scaling the object images[3]. The reconstructed alias-less image has lower resolution than the original image which has aliasing artifact since aliasing is avoided by shrinking the image to fit in the given data size. In this paper, we propose PILS like reconstruction method (PSFT-PILS) which can improve the resolution of images by using the up-scaling of alias-less reconstruction and signal band extrapolation technique of PSFT signal[4].

Theory: Phase-scrambling Fourier transform (PSFT) imaging[2] is a technique whereby a quadratic field gradient is added to the pulse sequence of conventional FT imaging in synchronization with the field gradient for phase encoding. The signal obtained in PSFT is given by Eq. (1):

$$v(k_x,k_y)=\int\int_{-\infty}^{\infty}\rho(x,y)e^{-j\gamma b\tau\left(x^2+y^2\right)}e^{-j\left(k_x x+k_y y\right)}dxdy, \quad (1)$$

$$v(x',y')e^{-j\gamma b\tau\left(x'^2+y'^2\right)}=\int\int_{-\infty}^{\infty}\rho(x,y)e^{-j\gamma b\tau\left[(x'-x)^2+(y'-y)^2\right]}dxdy. \quad (2)$$

where $\rho(x,y)$ represents the spin density distribution in the subject, γ is the gyromagnetic ratio, and b and τ are the coefficient and impressing time, respectively, of the quadratic field gradient. Equation (1) can be rewritten as the Fresnel transform equation, as shown in Eq. (2), by using the variable substitutions $x' = -k_x/2\gamma b\tau$ and $y' = -k_y/2\gamma b\tau$ [3]. Fresnel signal is known as the diffraction equation of object illuminated by coherent light wave. The distribution of the Eq.(1) and (2) strongly reflects the distribution of the objects, therefore, in case when the half of PSFT signal is filled with zero in *k*-space, almost half of the imaging object is disappeared. So, superimpose of image to on the other part image do not occur, even if fold-over artifact appeared on the image space. Propose method utilize this feature and avoid the fold-over artifact in the image space.

Theoretically spatial resolution is reduced to 1/2 when band width of signal is narrowed by 1/2 compared to the full band-width. To avoid the reduction of spatial resolution, PSFT band-extrapolation technique[4] is adopted, in which PSFT signal band can be extrapolated and the spatial resolution is improved 2.0 times at maximum by the iterative technique similar to the super-resolution algorithm. Figure 1 shows the schematic of proposed PSFT-PILS algorithm. Obtained PSFT signal is split into 2 segments, upper part and lower part of signal and then those signal are are zero-padded ((b) and (c)) to keep the signal data size. Iterative band-extrapolation is applied to these segmented signals in the reconstruction algorithm. The obtained images (c), (f), in which almost half of the object is reconstructed are combined to construct a whole image.

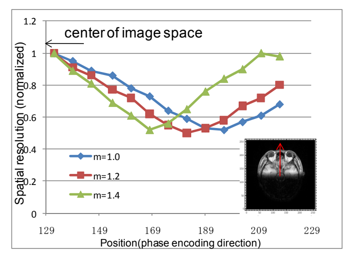

Fig.2 Spatial resolution for the phase encoding direction after PSFT band extrapolation technique.

Results and Discussion: Fig.2 shows the distribution of the spatial resolution compared to the fully scanned image. The phase scrambling parameter $\gamma b\tau$ is set as $m\gamma b\tau_0$ where $\gamma b\tau_0$ gives the condition Δy=$\Delta y'$(=$\Delta k_y/2\gamma b\tau_0$). It was shown that the comparative resolution is obtained at the center and the end of the image for the phase encoding direction. Figure 3 shows the results of experiments using a low-field 0.02T MRI. The imaging parameters are as follows; number of signal is 256x256, $\gamma b\tau$=10 rad/cm, m=1.0, Δy=$\Delta y'$=0.03 cm. Fully scanned PSFT signal is acquired at first and then he signal is interleaved to obtain a data that abrupt sampling theorem. Figure 1(a) shows the standard Fourier transformed image, in which aliasing artifacts appeared in phase encoding direction. Part (b) shows the image by alias-less reconstruction using the same signal as (a). Part (c) show the fully scanned image and part (d) shows the PSFT-PILS image (proposed). In the band extrapolation of PSFT signal to improve the spatial resolution, the phase distribution on the image is required to obtain a real image. Since *k*-space sampling trajectory is symmetry for the center of the *k*-space in our data acquisition scheme, phase distribution can be calculated easily by the alias-less image (b). Almost no aliasing artifacts are seen in the image (d).

Conclusion: A new unfolding image reconstruction algorithm that uses only a single signal from the phase-scrambling Fourier imaging technique PSFT-PILS is proposed. PSFT-PILS avoids the aliasing artifact using the feature of local image reconstruction of PSFT signal. could be applied to commercial MRI simply adding a weak quadratic field gradient to the imaging pulse sequences.

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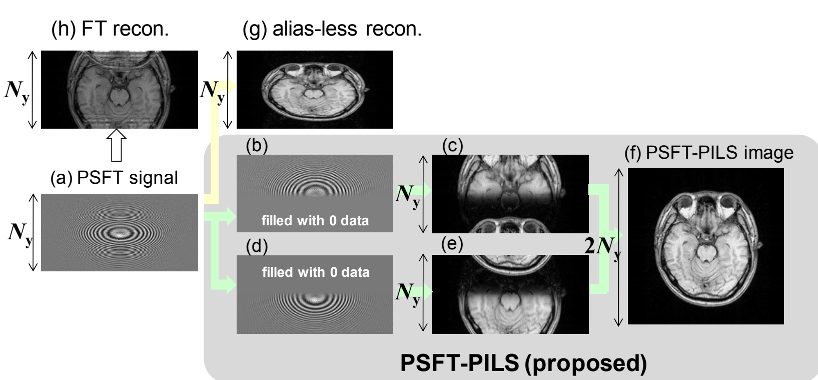

Fig.2 Schematic of PSFT-PILS. The obtained PSFT signal is split into the 2 part of signals with zero-padding, and then Fourier transformed. The obtained half part of images are combined to construct whole image.

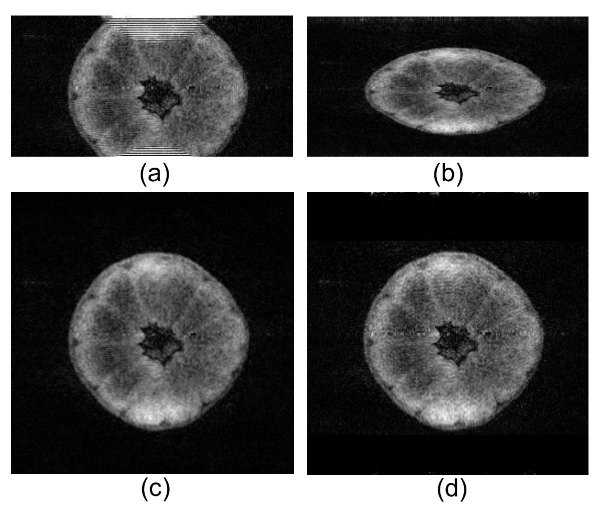

Fig.3 Results of experiments; (a) Fourier recon. , (b) alias-less recon. , (c) fully scanned, (d) PSFT-PILS (proposed).