Reduction of Remained Artifacts in Alias-free Reconstruction of MR Images

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Introduction: When the size of the object is larger than the field of view (FOV) or the object is located outside the FOV, wraparound artifacts (aliasing artifacts) will occur because the sampling theorem is not satisfied. We have proposed a new image reconstruction technique in which images of an optional scale can be obtained and hence alias-free images can be reproduced from a single piece of data by applying a quadratic phase modulation to a Fourier imaging technique[1,2]. Almost all the aliasing artifacts are removed, however, small aliasing artifacts that comes from the higher frequency components contained in the signal but not contribute to the down-scaled image are remained. In this paper, we propose a new alias-free reconstruction technique in which remaining aliasing artifact are reduced using SENSE-like algorithm.

Theory: Alias-free reconstruction uses a phase-scrambling Fourier Imaging technique[3] in which a quadratic field gradient for the phase scrambling is added to the pulse sequence of conventional FT imaging in synchronization with the field gradient for phase encoding.

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

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

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 $y' = -k_y/2\gamma b\tau$ [1]. Alias-free image can be reconstructed by appropriately shrinking the image (expanding the field-of-view). Since signal distribution described in Eq.(2) is a Fresnel diffraction equation of the object and is also considered as the blurred image of the object, application of weighting function to the PSFT signal can provide the similar weighting function to the reconstructed objects[4]. Figure 1 shows the principle of our method. PSFT signal (a) multiplied by numerical weighting function (b) reconstructs image having similar weighting function on the image as shown in Fig.1(d) and Fig.2(d). These feature hold for the under-sampled PSFT signal, if the distribution of the diffraction pattern cover the whole area of the object. However the higher spatial frequency components that do not contribute to the down-scaled alias-free images appear as small aliasing artifacts on those images. It can be thought that those aliasing artifacts also reflect the weighting function given on the PSFT signal, and those weighting function hold over in the image space as shown in Fig.2(d). Let the main image component be ρ_{main} and aliasing component be i_{alias}, alias-free image ρ_a can be written as $\rho_a=\rho_{\mathrm{main}} + i_{\mathrm{alias}}$ and the alias-free image with weighting function ρ_{aw} can be approximately described as $\rho_{aw} = S_{01}\rho_{\mathrm{main}} + S_{10}\, i_{\mathrm{alias}}$. By solving the linear parallel equation of Eq.(3), we can obtain main image component ρ_{main} like SENSE algorithm. In Eq.(3), S_{01} and S_{10} are the part of fold-over weighting function shown in Fig.2(e), (f).

$$\begin{pmatrix}\rho_a\\ \rho_{aw}\end{pmatrix}=\begin{pmatrix}1 & 1\\ S_{01} & S_{10}\end{pmatrix}\begin{pmatrix}\rho_{main}\\ i_{alias}\end{pmatrix} \quad (3)$$

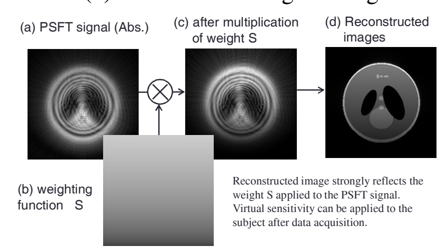

Fig.1 Application of weighting function to the PSFT signal give rise to similar weight on the reconstructed image.

Results and Discussion: Figure 3 shows the results using the numerical phantom. In the reconstruction procedure, linear weighting function varying in the phase-encoding direction S_{01} and S_{10} were used. Imaging parameters are as follows; image matrix 128x256, sampling step in x' coordinate $\Delta x'$ is 0.2 cm (=2 Δx), $\gamma b\tau$=1.227 rad/cm^2. Reconstructed images are scaled to have the same FOV as fully scanned image. Fig.3(a) is the fully scanned (256x256) image and Fig.(b) shows the standard reconstruction, occurring aliasing artifact. Figs. (c) and (d) are the images by alias-free reconstruction and proposed improved alias-free reconstruction, respectively. Experiments were performed using a low-field MRI scanner (0.2T), with Δx=Δy=0.035 cm, image matrix =125x256, and $\gamma b\tau$=10 rad/cm^2. Figure 4 shows the result imaging an orange. Since the weighting functions actually given on the reconstructed images are not the same as that applied to the PSFT signal, there are still remain artifact on the reconstructed image. However, proposed method can effectively remove the edge-like aliasing artifacts as shown in pointed out region in Figs. 3 and 4.

Conclusion: An improved alias-free reconstruction technique that uses only a single signal from the phase-scrambling Fourier imaging technique is proposed. It was shown that remaining aliasing artifacts were effectively removed from the reconstructed images.

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References

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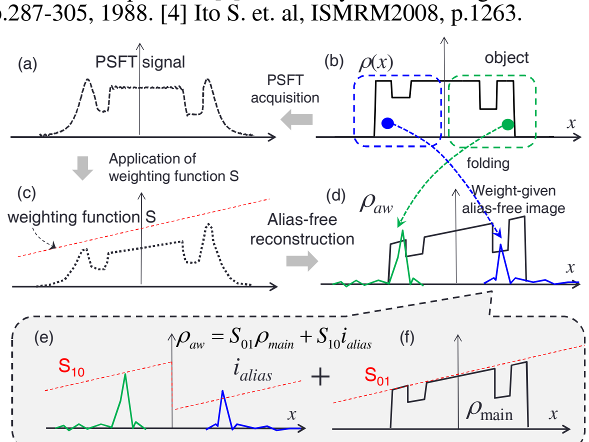

Fig. 2 Difference of weighting function given on the main image ρ_{main} and alias components i_{alias}.

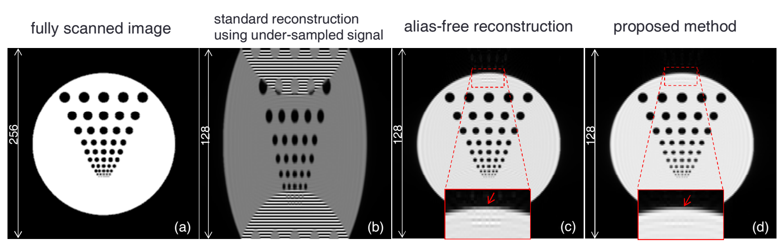

Fig.3 Results of simulation experiments using numerical phantom.

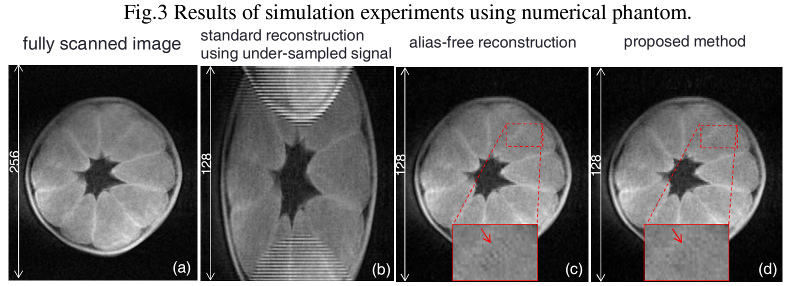

Fig.4 Results of reconstruction using a experimentally acquired data (orange).