Parallel Image Reconstruction using a Single Signal and PSFT Anti-alias Image Reconstruction

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INTRODUCTION Sensitivity encoding (SENSE)[1] accelerate MR scan time by using multiple receiver coil in parallel scan time. SENSE is based on the fact that receiver sensitivity has an encoding effect complementary to Fourier preparation by linear gradients. Here, we propose a method to reconstruct under-sampled images using 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-free images can be obtained by optionally scaling the object images to fit in the field-of-view (FOV)[3]. By applying a weighting function to the alias-free image corresponding to sensitivity of the receiver coil and then calculating a weighted PSFT signal from the weighted alias-free images, we can obtain two or more signals with different sensitivity distributions. The proposed method is demonstrated using 2-fold under-sampling with *k*-space trajectories.

METHOD 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):

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

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 $y' = -k_y/2\gamma b\tau$ [3]. Image reconstruction by inverse Fresnel transform allows optional scaling of the images by using the appropriate coefficient of the quadratic phase function. This is similar to the phenomena in optical image reconstruction in which the scale of a focused image varies when the power of the refocusing lenses are changed in optical image reconstruction. Therefore alias-free image can be reconstructed by appropriately shrinking the image (expanding the field-of-view) [3]. Since the unfolded images are obtained from the under-sampled signal in PSFT, a weighting function corresponding to the sensitivity of the receiver coil can be applied to the object function by multiplying the alias-free images by the weighting function. After the inverse calculation of the PSFT signal from the weighted alias-free images, we obtain a PSFT signal with weighted functions. Since we have two or more folded images with known weighting function, unfolded image can be obtained by using the SENSE image synthesis algorithm.

Figure 1 shows a schematic of the proposed algorithm. Fig.1(a) shows the PSFT signal and Fig.1(b) is an alias-free image reconstructed by anti-alias image reconstruction[3]. The weighting function (c) is applied numerically to this alias-free image. Fig.1(d) shows the calculated PSFT signal that is encoded with the weighting function. Parts (e) and (f) show the folded images reconstructed by (a) and (d), respectively. Application of SENSE image synthesis algorithm using these folded images and the known sensitivity map (b) gives an unfolded image (g).

EXPERIMENTS Figures 1 and 2 shows the results using the numerical model and experimental data, respectively, corresponding to SENSE factor 2. In the experiments, dummy sensitivity functions were used, which were linear functions varying in the phase-encoding direction. Experiments were performed using an ultra-low-field MRI scanner (0.0187T), with Δx=Δy=0.045 cm, and $\gamma b\tau$=7 rad/cm^2. It was shown that even though the spatial resolution was slightly reduced compared to fully scanned data (d), aliasing was clearly removed from the image created using our proposed algorithm, shown in Fig.2(e). Since the anti-alias image has a small remaining artifact that comes from the higher frequency components contained in the signal but not contribute to the down-scaled image, there are small errors in unfolded images.

CONCLUSION A new unfolding image reconstruction algorithm, based on the anti-alias image reconstruction in phase-scrambling Fourier imaging technique, is proposed. This method uses only one under-sampled signal but can be used to obtain unfolded images. The proposed method could be applied in commercial MRI by simply adding a weak quadratic field gradient to the imaging pulse sequences. In the future, we hope to further improve the image quality and spatial resolution by iteratively correcting the sensitivity function.

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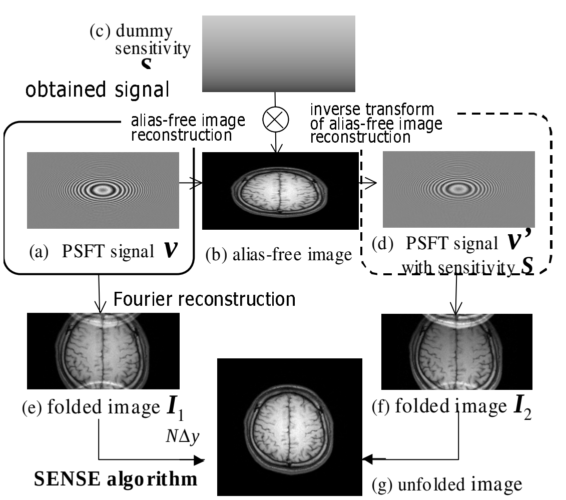

Fig.1 Schematic of parallel imaging using a single set of signals based on the anti-alias image reconstruction.

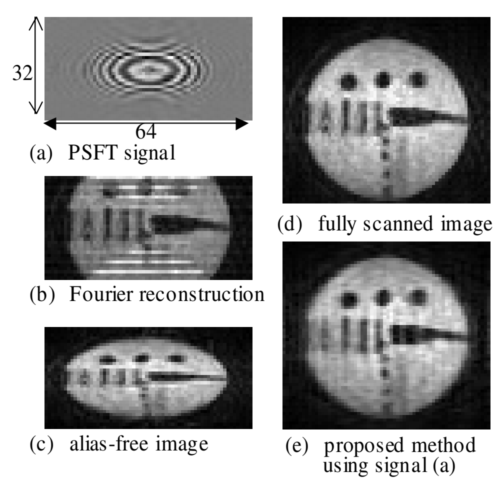

Fig.2 Results of experiment using a water phantom.