Accelerating MRI by quadratic phase encoding

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Target audience

The target audience is basic scientists and clinical scientists who are interested in fast MRI.

Purpose

Magnetic resonance imaging (MRI) is widely used in clinical diagnosis but limited by its data acquisition speed. Reducing the number of measurements required by Nyquist sampling theorem is one way to accelerate MRI acquisition at the cost of introducing aliasing artifacts. Various approaches have been proposed to eliminate aliasing artifacts caused by under sampling. Parallel imaging uses the sensitivity of multiple receiver coils to encode the aliasing artifacts and recover an aliasing-free image by specific reconstruction algorithm.[1] However, the higher hardware requirement limits its wide application. Variable-density sampling needs to be designed with great skill and the image reconstruction algorithm is also complicated.[2] In this abstract, we propose an MRI approach based on quadratic phase encoding, which can accelerate acquistion with efficient aliasing artifacts suppresion using a single receiver coil and uniform sampling.

Methods

The pulse sequence is shown in Fig. 1. The quadratic phase is introduced by the frequency-swept pulse (termed Chirp pulse).[3] The image is reconstructed by Fourier transform (FT). The point spread function (PSF) is expressed as

$$PSF(y,\varepsilon) = N\sum_{m}\operatorname{sinc}\left[\frac{\gamma G_a T_a}{2}\left(\varepsilon + m\frac{2N}{\gamma G_a T_a}\right)\right]\cdot E(y,\varepsilon) \quad (1)$$

where G_a and T_a are magnitude and duration of the decoding gradient respectively. N is the sampling point along phase encoding dimension. $E(y,\varepsilon)$ is the additional phase term derived from the quadratic phase encoding. According to the PSF, the aliasing artifacts carry a unique phase term, which can distinguish itself from the real signal profile. This characteristic is demonstrated by the spectra shown in Fig. 2(a), where the peaks on both sides indicate the aliasing artifacts and the peaks in the middle stand for real profile. This characteristic is unavailable in conventional k-space encoding methods. Assume that the magnitude of the aliasing artifacts and real signal profile are the same, the relationship between the aliasing image $\boldsymbol{\rho}_\mathbf{a}$ obtained by FT-based reconstruction and the aliasing-free image $\boldsymbol{\rho}$ can be expressed as

$$\mathbf{E}\boldsymbol{\rho} = \boldsymbol{\rho}_\mathbf{a} \quad (2)$$

where $\mathbf{E}$ is related to the additional phase term. The least squares solution can be expressed as

$$\boldsymbol{\rho} = (\mathbf{E}^{+}\mathbf{E})^{-1}\mathbf{E}^{+}\boldsymbol{\rho}_\mathbf{a} \quad (3)$$

The superscripts "+" and "-1" represent the conjugate-transpose and inverse of a matrix, respectively.

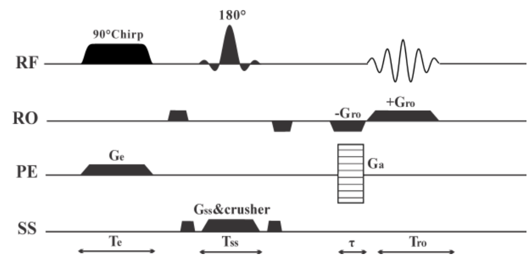

FIG. 1. Pulse sequence

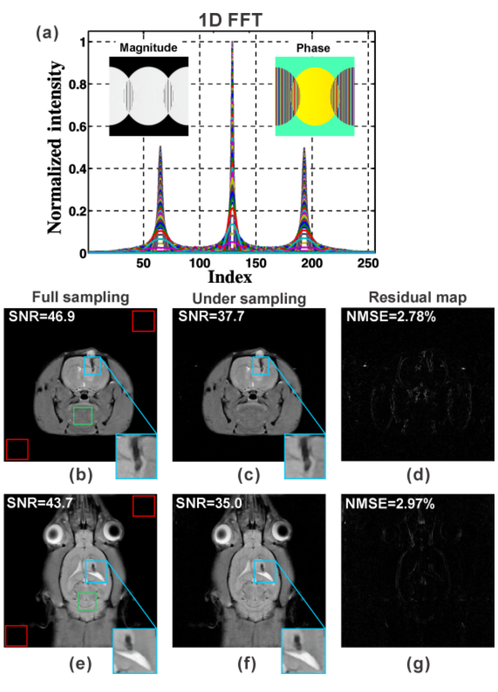

FIG. 2. a. Spectra of different rows along phase encoding dimension. b & e: Images reconstructed from full sampling. c & f: Images reconstructed from under sampling. d & g: Residual maps.

Results

Experiments were performed on a Varian 7.0 T MRI system using a quadrature-coil probe. The sample was a brain injured rat. The FOV was 45 × 45 mm^2. The bandwidth and duration of chirp pulse was 64kHz/4ms. The imaging matrix size was 256 × 256 for full sampling and 128 × 256 for under sampling. The results are shown in Fig. 2. The signal-to-noise ratio (SNR), normalized mean square error (NMSE) and residual map were used to evaluate the performance of proposed method.

Discussion

The NMSE values of axial images and coronal images are 2.78% and 2.97% respectively, which means the images from full sampling and under sampling are very similar to each other. The wound is shown in the zoom-in region in Fig. 2, and we can see that under sampling has negligible impact on the identification. One drawback is that the SNR of under sampling is inferior to that of full sampling, and this problem can be relieved by combining the present method with advanced denoising algorithm.

Conclusion

In this abstract, we make use of the quadratic phase encoding to eliminate the aliasing artifacts caused by under sampling, which is simple and efficient. Moreover, this method can be accomplished in single receiver coil and uniform sampling situation. It may find great clinical application.

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