An efficient de-convolution reconstruction method for spatiotemporally-encoded single-scan 2D MRI

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Introduction

Accelerating the acquisition process, or equivalently increasing the achievable resolution with a fixed acquisition time, is of major interest for magnetic resonance image (MRI) [1]. Echo-planar imaging (EPI) has been a commonly used single-scan MRI technique for a long time. However, EPI is very sensitive to field inhomogeneity. A single-scan MRI method recently proposed by Frydman and co-workers relies on local signal contributions progressively along the encoding direction [2-4]. This method is based on spatiotemporal encoding (SPEN) of MR spin interactions and can cope efficiently with field inhomogeneities [5]. SPEN MRI method introduces a quadratic phase to the spin signal, therefore images acquired from spatiotemporally-encoded MRI without super-resolved (SR) reconstruction have low resolution. Conjugate gradient (CG) method has been proposed to reconstruct SR images. Its effectiveness depends on the small condition number of the coefficient matrix, which may not always be satisfied. In this paper, a new de-convolution method is proposed to reconstruct the SR images in a simpler and more efficient way.

Theory

The signal for the sequence shown in Fig. 1(b) can be expressed as follows:

$$s(t) \propto \int_{-L/2}^{L/2} \rho(y) e^{i\left(-\frac{O_i^2}{2R}-\frac{\gamma^2 G_e^2 y^2}{2R}+\frac{\gamma G_e T_e y}{2}+\gamma G_a y t\right)} dy . \qquad (1)$$

For simplicity, G_a is assumed to be constantly applied over an acquisition time In Eq. (1), O_i is the initial sweep frequency of 90° chirp pulse (in, e.g., rad/s), γ is the gyromagnetic ratio of inspected nucleus; G_e is the encoding gradient amplitude and T_e is its duration; G_a is the decoding gradient amplitude; R is the sweep rate of the chirp pulse; $\rho(y)$ is the spin density at position y, and t varies from 0 to T_a. After the coordinate transformation, Eq. (1) can be simplified into:

$$l(y') \propto \int_{-L/2}^{L/2} \rho(y) m(y-y') dy , \qquad (2)$$

where $m(y) = e^{i\frac{A}{2}y^2}$, and $A = \gamma G_a T_a / L$. $l(y')$ was obtained from the original signal $s(t)$ by removing the quadratic phase modulation ($e^{-i\frac{A}{2}y^2}$). This treatment can help to reduce the complexity of the original signal, and make the signal post-processing much easier. The blurred or low-definition image obtained by magnitude processing can be expressed as a convolution of the SR image and its point spread function. According to the convolution theory, SR image information $\rho(y)$ can be reconstructed from Eq. (2) by de-convolution method.

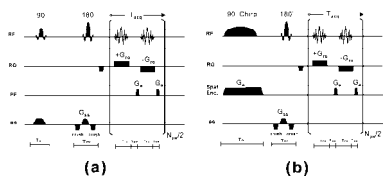

Fig. 1. MRI sequences. (a) EPI sequence; (b) SPEN sequence.

Experiments and results

To evaluate the algorithms described above, the SR results from the de-convolution reconstruction method were compared with those from the CG reconstruction method. *In vivo* experiments on rat brain were executed on 7 T/160 mm bore Varian MRI system using a quadrature-coil probe. The sequences shown in Fig. 1 were applied. The excitation bandwidth and duration of the frequency-swept excitation pulse were 64 or 32 kHz and 4 ms respectively. Comparing the SR reconstructed images from spatiotemporally-encoded MRI with EPI images shown in Fig. 2, we can see that the spatiotemporally-encoded MRI can provide images with less distortion caused by susceptibility heterogeneities. It can also be seen that for the spatiotemporally-encoded MR images, the SR reconstructed images from de-convolution method have higher quality than those from CG method. The new method is simpler, more efficient, and more precise.

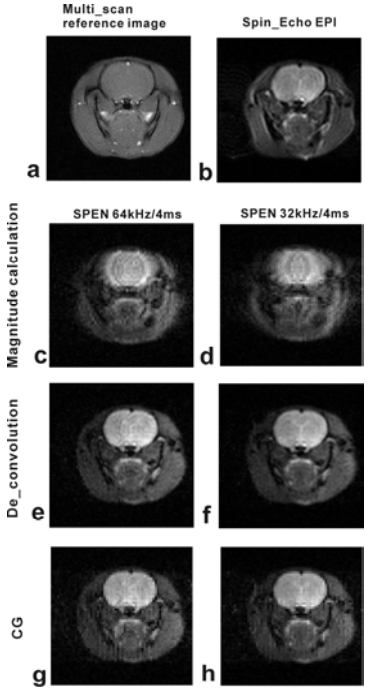

Fig. 2. Single-scan *in vivo* images of a rat brain (FOV = 4 × 4 cm^2, 2 mm slice thickness, image matrix size = 64 × 64), *sw* = 250 kHz. (a) Multi-scan image; (b) EPI image; (c,d) magnitude-processed SPEN MR images: (c) SPEN image, R = 64kHz/4ms; (d) SPEN image, R = 32kHz/4ms; (e,f) reconstructed images of (c,d) using de-convolution method; (g,h) reconstructed images of (c,d) using CG method.

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