An efficient reconstruction method for spatially encoded single-scan 2D MRI

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Introduction

Recently, a novel encoding approach called spatial-encoding [1] is put forward to solve various problems induced by field perturbations in ultrafast imaging. It uses a linear frequency-swept pulse and a simultaneous gradient field to sequentially excite the nuclear spins along the direction of the gradient with a quadratic phase profile. The MRI signals can then be acquired in the same way as in traditional linear phase encoding methods. Due to its simplicity and compatibility with existing protocols, spatial-encoding approach has been applied in many studies [1,2]. A revised echo planar imaging (EPI) sequence with the application of spatial-encoding is able to achieve perfect field perturbation immunity. Furthermore, the image quality is not hampered if imaging on oblique planes. However, the inherent spatial resolution of this method is much inferior to its Fourier encoding counterpart if the product of the excitation bandwidth and duration is not large enough [2,3]. Increasing these two parameters may result in an overflow of the gradients values and the excitation power. Therefore, reconstruction is of great importance in this imaging method. In this work, we utilize a generalized Fourier transform algorithm based on local k-space to reconstruct a high-resolution image with acceptable noise level in a faster and memory-saving way.

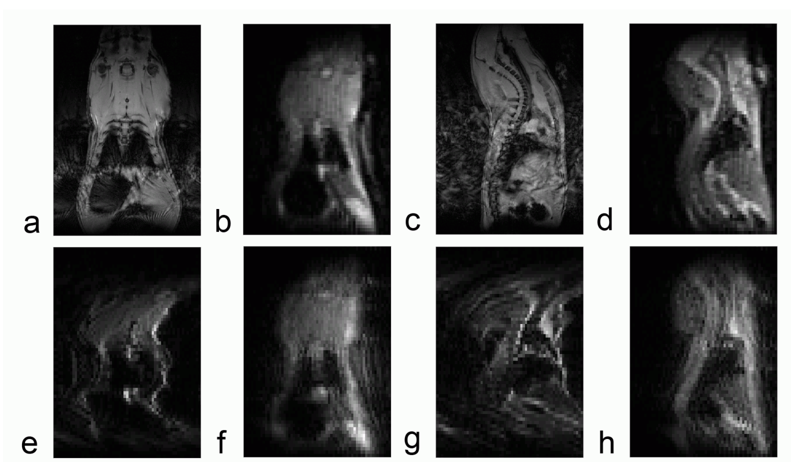
Theory

The quadratic phase profile localizes the magnetizations that contribute to the entire signal to a limited region in the excited body. The center point of this region is the vertex of the instantaneous phase profile. Its location is decided by the zero point of the first spatial derivative of this profile and sequentially shifts along the encoding direction during the acquisition process. If we regard the wave number as the first spatial derivative of the phase distribution, each location has a different k value under the quadratic spatial-encoding. The origin of local k-space corresponds to its vertex instant $t_{a0}(z)$. Therefore, we can retrieve a more accurate magnetization distribution with a formula as Eq. (1) using generalized Fourier decoding calculation. This formula is for 1D spatial-encoding MRI. M_1 refers to the number of signals used to reconstruct a voxel, Δt_a is the acquisition interval, $\varphi_a(t_{a0}(z)+m\Delta t_a, z)$ is the local phase of a signal and g is a window function that is used to improve the signal-to-noise ratio (SNR) level of the resulted image. The formula uses a series of signals around the origin of local k-space to reconstruct each voxel. The maximum number of signals available is restricted by Nyquist theorem as Eq. (2) because when spatial-encoding is applied to single-scan 2DMRI sequence, the local k-space is always undersampled. M is the total number of acquired signals. ΔO_{Hz} and T_e are respectively the bandwidth of the frequency-swept excitation pulse and its duration. The optimum spatial resolution of reconstructed image is identical to that of EPI with a same acquisition number. For 2DMRI, the reconstruction work can be completed in two procedures. Firstly, performing a fast Fourier transform on every echo, or every row of the signal matrix. Secondly, taking each column of the new matrix as a set of one-dimensional spatially-encoded signals and constructing each voxel based on the above-mentioned algorithm.

$$f_{pFT}(z) \propto \sum_{m=-\frac{M_1-1}{2}}^{\frac{M_1-1}{2}} g(m)\cdot S(t_{a0}(z)+m\cdot\Delta t_a)\,e^{-i\varphi_a(t_{a0}(z)+m\cdot\Delta t_a,\,z)} \qquad (1); \qquad M_1^{\max} = \frac{M^2}{\Delta O_{Hz}\cdot T_e} \qquad (2)$$

Experiments and results

In vivo experiments on rat are executed on 7 T/160 mm bore Varian MRI imaging system using a quadrature-coil probe. Single-scan hybrid-encoding sequence [1] is used to validate the effectiveness of this reconstruction algorithm. The excitation bandwidth and duration of the frequency-swept excitation pulse are 96 kHz and 26.1 ms respectively. The duration is set equal to that of the echo train to generate a series of spin echoes and minimize the off-resonance effects. The experiments are performed on the coronal and sagittal planes of rat. Heart beating blurs the gradient echo images. The blurring is reduced in EPI images, but the sharp susceptibility variations around the tissue/air and tissue/bone interfaces lead to serious distortion. In contrast, the images produced by the hybrid-encoding sequence are not blurry and in good shape. The proposed reconstruction algorithm greatly improves the definition of the images while maintaining the excellent field perturbation immunity of the hybrid-encoding sequence.



spin-echo EPI (e,g), and hybrid-encoding sequence (raw (f,h); reconstructed (b,d)).

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References

[1] Ben-Eliezer N, et al. Magn Reson Med 63 (2010) 1594-1600. [2] Chamberlain R, et al. Magn Reson Med 58 (2007) 794-799. [3] Stockmann JP, et al. Proceedings of the 19th Annual Meeting of ISMRM. Montreal, Quebec, Canada; 2011. p 744.