Variable Density 2D Spiral Excitation with Self Compressed Sensing

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Target audience: MR pulse sequence designer, fast imaging engineers

Purpose: 2D spiral excitation pulses are valuable for bolus tracking and reduced FOV imaging. But 2D excitation pulses are usually long, given *in vivo* FOV and resolution requirements, making them susceptible to off-resonance blurring of the spatial profile. Imaging at high field strengths, near air-tissue interfaces, or short T2 tissues cannot afford a long 2D spiral excitation pulse that meets the Nyquist sampling rate. However, in an analogy to subsampled data acquisitions where variable density spirals generate low incoherent aliasing, a subsampled excitation profile will also have incoherent sidelobes. However, with the excitation profile of spin echoes, the sidelobes shrink considerably since spin-echoes: $Mxy^+ = i\beta^2 M_0$. [1]

In this work, we designed a linear FOV variable density spiral trajectory to make the aliasing incoherent, and then used a spin-echo pulse to suppress the aliasing sidelobes.

Methods: Gradient waveforms were designed to excite a 0.5 cm diameter (=resolution) cylinder and a 16x16 cm^2 FOV, with maximum gradient amplitude of 40 mT/m and maximum gradient slew rate of 150 mT/m. The design criterion for gradient waveforms is that the aliasing sidelobes should be uniformly spread in a noise-like pattern. Based on this motivation, conventional quadratic variable density spiral and linear FOV subsampled spiral trajectories were designed. To begin with, the 1D point spread function (PSF) was computed to evaluate the performance of the different variable density patterns (Fig.1). Then, quadratic and linear FOV spiral gradient waveforms were designed by following a similar pattern to the 1D PSF. The variable density spiral was generated by varying ΔK_r of each turn with interpolating the other points along the whole spiral (Fig.2).

Corresponding RF pulses were designed including density compensation (shown in Fig.3). 1D and 2D profile simulations were performed to evaluate the excitation profiles of variable density spirals. All the simulations were based on the Shinnar-Le Roux method [1] using MATLAB.

Results: From the PSF of 1D variable density sampling patterns, we noticed that linear FOV sampling spreads the aliasing side lobes more uniformly compared with quadratic subsampling. These spiral trajectories were improved by using constant slew rate in order to shorten the duration of pulses. The fully sampled 2D spiral excitation pulse takes 4.226 ms with 8 turns, while quadratic excitation takes 2.388 ms with 6 turns and linear FOV excitation takes 2.256 ms with 6 turns. When used as an excitation and spin-echo pulse, the profiles are almost free from any obvious sidelobes.

Conclusion: 2D RF pulses with variable density spiral trajectories combined with a spin echo acquisition will effectively suppress the aliasing excitation sidelobes resulting from subsampling. A linear FOV subsampling of the spiral resulted in the best suppression of aliasing sidelobes.

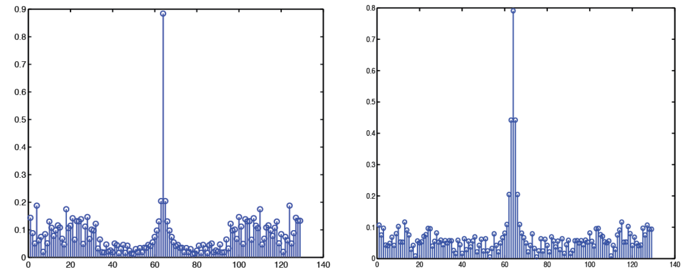
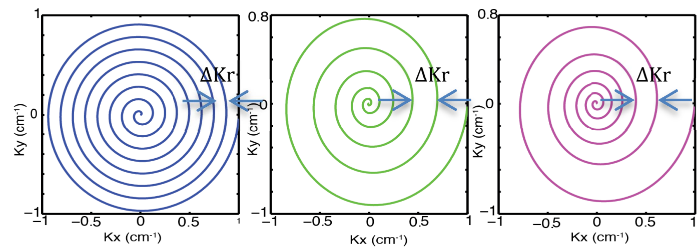


Fig.1. Point spread function of variable density subsampling: (left) quadratic sampling; (right) linear FOV sampling



$$K_r(t) = \frac{N(1-t/T)^2}{FOV} \quad (1) \qquad \Delta K_r(n) = -\frac{N}{nFOV} \quad (2)$$

Eq(1) is the for quadratic spiral, Eq(2) is for linear FOV spiral design: T is the total duration , N is the total number of turns, n is the nth turn

Fig.2. Fully sampled and variable density spirals: (left) fully sampled and uniform density spiral; (middle) quadratic spiral; (right) linear FOV spiral

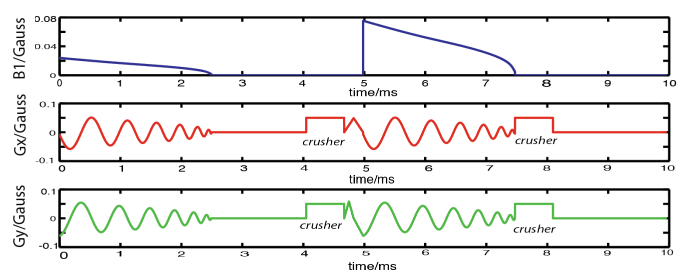


Fig.3. Variable density spiral pulse sequence (spin echo)

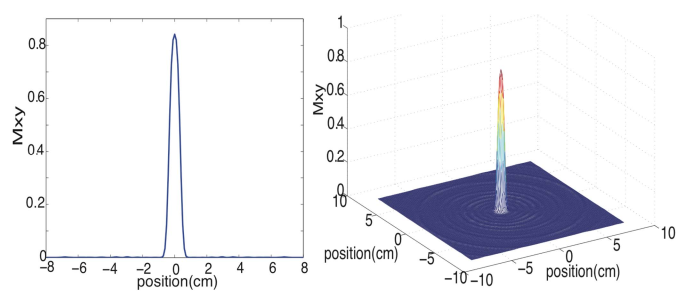


Fig.4. Excitation profile of spin echo pulse with linear FOV spiral: (left) 1D view; (right) 2D view

Reference:

[1] Pauly, J, Roux, L P, Nishimura, D and Marovski A. IEEE Trans 1991: March: VOL.10, NO. 1.