

Multi-voxel excitation using sparse pulse on significantly undersampled k-space

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Introduction: 2D spatial selective RF pulse [1] is able to generate arbitrarily shaped excitation pattern, while parallel transmission [2] offers additional degrees of freedom to shorten the pulse width and reduce SAR. Both techniques have benefited the single and multi-voxel MR-spectroscopy [3, 4]. Recent years, sparse pulses [5, 6] have been developed to shorten the excitation duration by using a significantly undersampled k -space trajectory. In this work, an example of multi-voxel excitation using sparse pulse is presented. The k -trajectory is designed on an undersampled k -space and represented as a Fourier Transform (FT) matrix. The RF pulse can then be designed using nonlinear Conjugated Gradient (CG) algorithm. Bloch simulation of a multi-voxel excitation is performed to demonstrate the feasibility of this method.

Theory and method: To design an incoherent undersampled k -space, we used the Monto-Carlo sampling strategy to choose the k -space samples. Then an optimized k -space trajectory through all these k -space samples could be designed using the simulated annealing algorithm and discretized to N_t time samples. Also, the desired excitation pattern was discretized and rearranged to N_s spatial samples. Thus the FT matrix is expressed by a $N_s \times N_t$ system matrix \mathbf{A} where each element $a_{i,j}$ is [7]:

$$a_{i,j} = i\gamma M_0 e^{ik(t_j)\mathbf{x}_i + i\Delta\omega(\mathbf{x}_i)[t_j - T]}\Delta t \quad (1)$$

where t_j and \mathbf{x}_i denote the time and spatial samples respectively. γ and M_0 are the gyromagnetic ratio and equilibrium magnetization respectively. $\mathbf{k}(t_j)$ denotes the optimized sparse k -space trajectory samples and $\Delta\omega(\mathbf{x}_i)$ represents resonance frequency offsets. Then the magnetization after RF excitation can be expressed as:

$$\mathbf{m} = \mathbf{A}\mathbf{b} \quad (2)$$

where $\mathbf{b} = [b(t_1), b(t_2), \dots, b(t_{N_t})]^T$ denotes the sparse RF pulse vector corresponding to N_t time samples. Assuming that the desired magnetization after excitation is \mathbf{m}_d , then the RF pulse can be designed by solving the following optimization problem:

$$\mathbf{b}_{opt} = \arg \min (\|\mathbf{A}\mathbf{b} - \mathbf{m}_d\|_2) \quad (3)$$

which can be solved using the nonlinear CG optimization.

The gradient waveforms were designed using the time-optimal gradient method [8] which can be used to design gradients under the limitation of maximum gradient strength and slew rate for arbitrary trajectory. The design procedure of the sparse pulse for multi-voxel excitation is shown in Figure 1.

Results: Bloch simulation was used to demonstrate the feasibility of this method and all the calculation was performed using Matlab7.6 (Mathworks Co.). A 90° sparse pulse is designed to excite a multi-voxel pattern shown in Figure 2a. The FOV is 5cm by 5cm and the desired voxel is with 8mm diameter. The simulated excitation pattern in 2D view is drawn in Figure 2b. To show the profile more clearly, the 1D profile across the blue line indicated in the 2D image is also plotted. The ripples appear in the in-slice and out-of-slice regions are below 5% and 8% respectively. The gradient waveforms and the sparse RF pulse corresponding to the sparse k -space trajectory are plotted in Figure 3a and 3b respectively.

Conclusion and discussion: This work has demonstrated that sparse pulse designed on significantly undersampled excitation k -space is feasible for multi-voxel excitation. Simulation results have shown that each voxel can be well localized. However, there are some small ripples on the out-of-slice region and the transition is not very sharp, these are due to imperfection of the undersampled k -space and RF pulse. Both excitation k -space sampling strategy and RF pulses design method need to be improved for better excitation accuracy.

References: [1] Pauly J, et al, J Magn Res 1989; 81: 43-56. [2] Zhu Y, Magn Reson Med 2004; 51: 775-784. [3] Ullmann P, et al, ISMRM 2009: p2602. [4] Busch MG, et al, ISMRM 2009: p2603. [5] Zelinski AC, et al, IEEE Trans Med Imaging 2008; 27: 1213-1229. [6] Chen D, et al, ISMRM 2009: p2569. [7] Yip C, et al, Magn Reson Med 2005; 54: 908-917. [8] Lustig M, et al, IEEE Trans Med Imag 2008; 27: 866-873.

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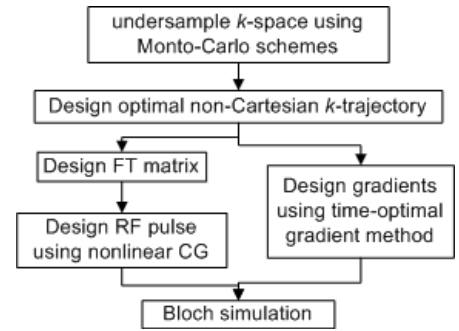


Fig. 1 Flowchart of sparse pulse design for multi-voxel excitation.

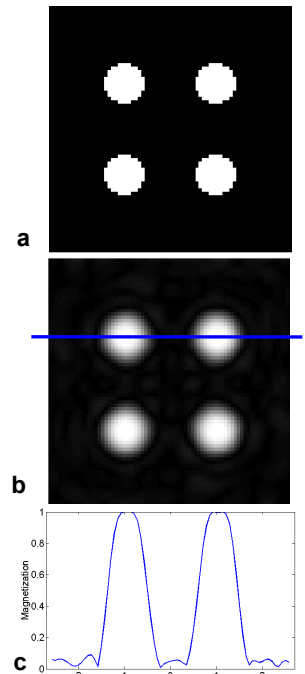


Fig. 2 (a) desired excitation pattern; (b, c) simulated excitation profiles in 2D and 1D views.

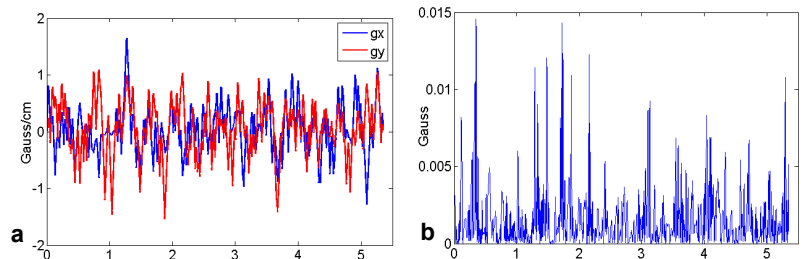


Fig. 3 (a) gradient waveforms and (b) sparse RF pulse corresponding to the sparse k -space trajectory.