Random Delayed Spirals for Compressive Sensing cine MRI

Giuseppe Valvano[1,2], Nicola Martini[2], Dante Chiappino[2], Luigi Landini[1,2], and Maria Filomena Santarelli[2,3]

[1]*Department of Information Engineering, University of Pisa, Pisa, PI, Italy,* [2]*Fondazione G. Monasterio CNR-Regione Toscana, Massa, MS, Italy,* [3]*Institute of Clinical Physiology, CNR, Pisa, PI, Italy*

Purpose: Variable Density Spirals (VDS) are good candidate for Compressive Sensing (CS) MRI [1]. They generate less coherent aliasing artefacts than a standard undersampled spiral and allow for a variable density sampling that accounts for the energy distribution in the K-Space [2]. A lower coherence can be achieved with a randomized sampling pattern, but the design of a randomized spiral is difficult [3]. The purpose of this work is to develop a less challenging randomization for 2D cardiac cine MRI, in order to achieve a higher acceleration with a good reconstruction quality.

Methods: CS Reconstruction in cine MRI typically enforces the sparsity in the temporal frequency domain [4]. For this reason we evaluated the coherence of the acquisition by means of the Transform Point Spread Function (TPSF) in the *x-f* domain [4]. A good randomization can be obtained by rotating the interleaves of the VDS with random angles, but the resulting sampling pattern does not account for the information distribution in the K-space. In fact a randomization of the angles of the interleaves generates a less dense sampling pattern in the center of the K-space (Fig. 1c). In our opinion the randomization should occur only in the undersampled region, far from the center of the K-space. With this purpose, for each interleave, we picked a random point on the gradient waveforms holding then the gradients for few micro-seconds (Fig. 1a) in correspondence to the undersampled region of the K-space. The resulting *random delayed spirals* are shown in Fig.1d. To further reduce the coherence of the acquisition we rotated each entire VDS (with all its interleaves) with random angles respect to the other spirals (Fig. 1e). The TPSF (green lines in Fig.1f and Fig.1g) shows how the proposed approach achieves a lower coherence than the one obtained by changing at random the angles of the interleaves, without undersampling the center of the K-Space. We tested this approach by means of off-line resampling and reconstruction of a fully sampled 2D cine dataset of a heart in short axis (25 cardiac phases, FOV 548x548 mm, 2mm in-plane resolution) for various acceleration factors. The dataset was acquired on a 3T Philips Ingenia scanner. All the spirals were designed with the same readout duration (5 ms) and the acceleration was given by the ratio between the number of interleaves of a fully sampled spiral (48 interleaves) and the number of interleaves used for the VDS. For completeness we compared the results with the reconstructions obtained with the standard VDS and with the VDS obtained by changing at random the angles between the interleaves. Furthermore we tested the efficacy of random delays alone and with the random rotations. The reconstructions were performed solving the following optimization problem: $min.\, 0.5\left||Ax-y\right||_2^2+\tau\left||\Psi x|\right|_1+\lambda TV_a(x)$. Here A represents the Non Uniform Fourier Operator, Ψ is the wavelet 2D - frequency transform (Daubachies 6, 6 levels), and TV_a is the anisotropic Total Variation. All the reconstructions were performed with the same values of the algorithm parameters, i.e. τ=2e-3, λ=5e-4.

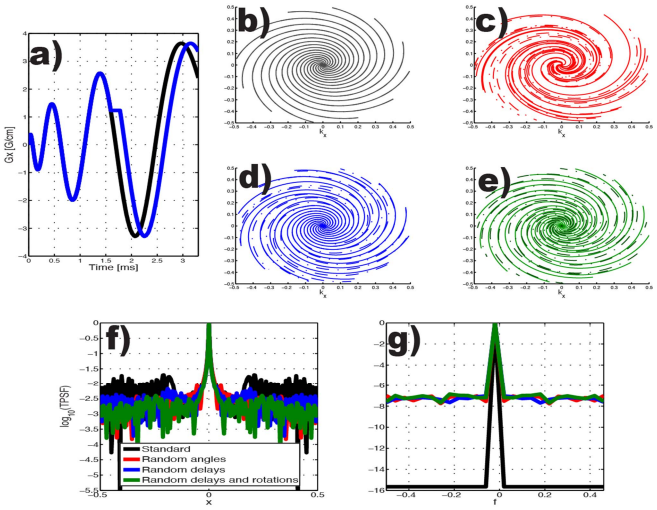

Fig. 1: a) Gradient waveforms for a standard VDS (black) and a random delayed VDS (blue) and corresponding spirals for a cine acquisition in b) and d). c) VDS with random angles between the interleaves. e) Random delayed spirals with rotations. Dashed lines in c-e) indicate the spiral used in the successive cardiac phases. f-g) TPSF for a 5-fold acceleration along *x* and *f* direction in logarithmic scale .

Results and Discussion: Fig. 2a shows the reconstruction errors for various acceleration factors. Although a randomization of the angles generates a low coherence in the TPSF, the results of the reconstructions showed a consistent error due to the high undersampling in the center of the K-Space [2] (Fig. 2a green line). In fact the use of standard VDS achieved a better reconstruction for all the acceleration factors (blue line). The use of random delays alone combined the variable density design of the standard VDS with the low coherence of the randomization (Fig.1) and for this reason it gave better results respect to the standard VDS in the reconstructions (Fig. 2a red line). A better degree of randomization was achieved adding the random rotations to the random delayed VDS and for this reason the proposed approach gave the best results (Fig. 2a black line). Fig. 2b and Fig. 2c show the results of the reconstructions and their relative error maps for a 5-fold acceleration. It is possible to note how, also for high acceleration factors, the reconstruction relative to the random delayed VDS with random rotations shows a very good image quality without noticeable residual aliasing artefacts.

Conclusion: This study demonstrates the feasibility of a fast acquisition for 2D cine MRI without sacrificing the image quality by the use of *random delayed spirals*. Further work is needed for the optimization of the trajectories and for the determination of the maximum achievable acceleration.

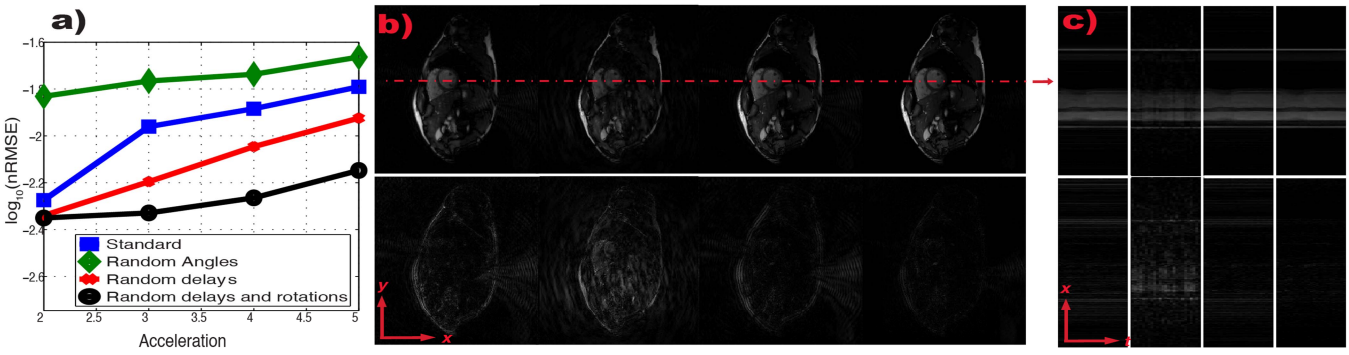

Fig. 2: a) Reconstruction errors for various acceleration factors. b) Results of the reconstructions for a 5-fold acceleration. c) Temporal evolution along the red dashed line. From left to right: standard VDS, VDS with random angles, random delayed VDS, random delayed VDS with random rotations. Upper row: reconstructions. Bottom Row: error maps (the scale of the error maps is 50% of the scale of the reconstructions).

References: [1] Zhao et al. Mag. Reson. Med. 22 (2014) 1543. [2] Adcock et al. arXiv:1302.0561. [3] Lustig et al. IEEE transactions on medical imaging (2008) 27(6), 866–73. doi:10.1109/TMI.2008.922699. [4] Lustig et al. MRM 2007;58:1182.