A New K-space Trajectory for Compressed Sensing MRI

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INTRODUCTION

A new k-space trajectory for compressed sensing MRI (CS-MRI) is proposed in this paper. Our approach is motived by the CS theory[1] which shows that random sampling pattern is preferred for better signal reconstruction performances. For MRI scanner, however, random sampling would yield longer sampling trajectory than spiral trajectory because of the hardware constraints. Several attempts by applying random under-sampling patterns along radial and spiral sampling trajectories were reported[2,3]. However, there is a difference between CS and MRI is often neglected, That is CS aims to reduce the number of sampling points, while the scanning time of MRI not only depends on the number of sampling points but also on the length and curvature of k-space trajectory. Inspired by this viewpoint, we introduce a new k-space trajectory for CS-MRI, which is a smooth, short, random-like and with variable density. Simulation results demonstrate its good image reconstruction performance from under-sampled k-space data by using CS algorithms..

METHODS

The new trajectory named as four leaved rose curve (FLRC), is defined by $r=a\sin 2\varphi$, where (r,φ) denotes the standard polar coordinates. It can be described in (k_x,k_y) plane as $k_x=a/2(\sin 3\varphi+\sin\varphi)$, $k_y=a/2(\cos 3\varphi-\cos\varphi)$. The gradient waveforms of this trajectory can be expressed as $g_x=a/(2\gamma)(3\cos 3\varphi+\cos\varphi)$, $g_y=a/(2\gamma)(\sin\varphi-3\sin 3\varphi)$. This trajectory is periodic with a period of 2π , where $a=1/2\delta_r$ depends on the image resolution and the FOV, δ_r is the image resolution, γ is the gyromagnetic ratio. When the hardware constraints is applied to the gradient design—peak gradient amplitude and its slew rate, we can get a practical trajectory for MRI scanner. The tOptGrad V0.2 tool box[4] is good at solving this problem. For simplicity, we use this tool box to optimize the the proposed trajectory. Figure 1(a) is the single shot trajectory after optimized by tOptGrad V0.2, and the traverse time along the trajectory is about 3.91ms. To get multi-shot trajectories, just rotating the trajectory around the origin, it can be described as: $ktraj=k'.*\exp(pi/2*i*[1:N]/N)$, where $k=k_x+i*k_y$ is the single shot trajectory, N is the number of multi-shots. Figure 1(b) shows the 15-shot trajectories. Figure 1(c) is the point spread function (PSF) of this15-shot trajectories, the maximum of the side-lobe is only 0.2347 which is smaller than the variable density spiral with the same number of sampling points.

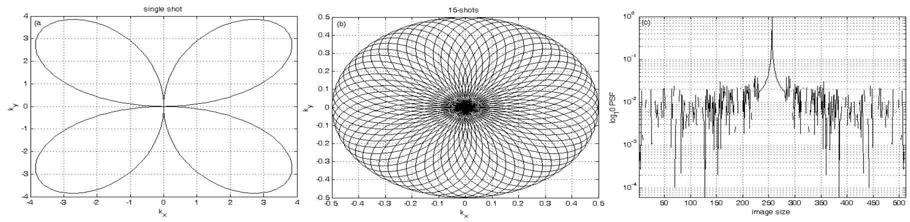

Figure 1: The FLRC k-space trajectory and its PSF. Acquisition parameters are FOV=20cm, ,image size=[160 160], gradients capable of 40mT/m, slew-rate of 150mT/m/ms. Figure 1(b) is the 15-shot trajectory with 979 points per arm(scan time about 3.91ms) with a 4us time between samples , figure 1(a) is the one arm of 15-shot. The largest off-diagonal element of PSF (shows in figure 1(c)) is 0.2347.

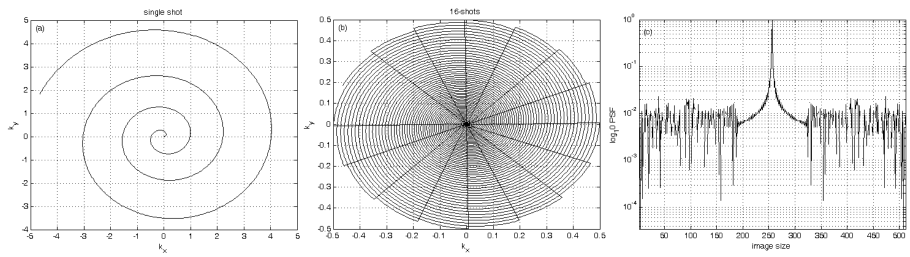

Figure 2: The variable density spiral k-space trajectory and its PSF. The acquisition parameters are at the same with figure 1. Figure 2(b) is the the 16-shot variable density spiral with 930 points per arm(scan time about 3.71ms)with a 4us time between samples , figure 2(a) is the one arm of 16-shot. The largest off-diagonal element of PSF (shows in figure 2(c)) is 0.4107..

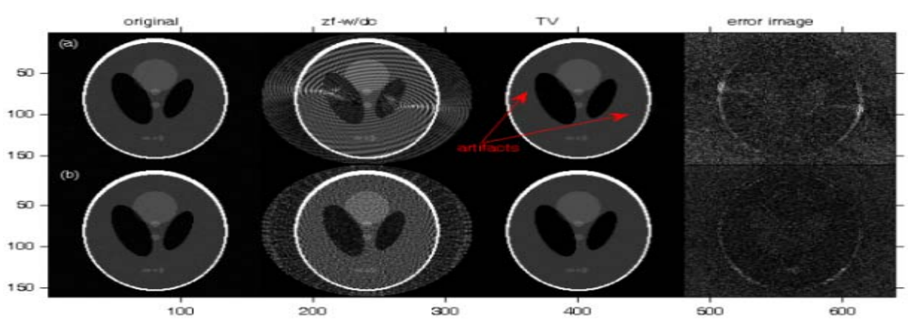

Figure 3: Reconstructions by use SparseMRI V0.2 tool box[4]. a).variable density spiral with 16-shot, 930 sampling points per shot. (b).FLRC trajectory with 15-shot, 979 sampling points per shot. The red arrows present the difference between original and reconstruction by CS, it is shown obviously in the error image.

RESULTS and DISCUSSTION

Figure 3(a), (b) demonstrated the reconstructions respectively from variable density spiral and FLRC under the same number of sampling points and reconstruction algorithm. Simulations show that FLRC trajectory has better fidelity than spiral. There is existing artifacts which indicated by the red arrows in figure 3(a), in contrast, there is no obvious artifacts in figure 3(b). The good fidelity should be attributed to the following two aspects: 1).The locations of FLRC sampling points are more irregular than spiral. Comparing the second column of figure 3 (a) with (b), we can find that these artifacts are different. For spiral, the artifact looks like more regular, however, it is noise-like for FLRC. 2).The FLRC trajectory has much smaller side-lobe of PSF than spiral trajectory . That means a incoherence which is the very important requirement for CS

CONCLUTION

The FLRC is a short, smooth, variable density and random-like trajectory, simulations show it is well-suited to CS-MRI. However, it has two disadvantages: firstly, there is oversampling in the periphery of the k-space. Secondly, it exists a few cross-points, which would reduce the sampling efficient.

REFERENCES

[1] Candès et al. IEEE Information theory.52:5425,2006.[2] Block et al. MRM.57:1086,2007.[3] Santos et al. MRM.55.371,2007.[4]Lustig's homepage, http://www.eecs.berkeley.edu/~mlustig/index.html