A Chaotic K-space Trajectory for CS-MRI

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INTRODUCTION

The objective of compressed sensing MRI (CS-MRI) is to acquire a reduced number of k-space data for image reconstruction, so to speed up the MRI scan time [1]. In general, the CS-MRI process carries out two main operations: undersampling in the k-space, which needs to meet the incoherence condition, and the reconstruction of the image, which usually meets the sparsity or compressibility condition in transformed domain. To meet the incoherence condition, the basic theory of compressed sensing requires acquisition of randomized set of measurements [2]. For MRI scanner, however, random sampling would yield longer sampling trajectory because of the MR hardware constraints, and requires bigger changes in amplitudes and polarity of MR gradients which making physical implementation infeasible. Several attempts by applying random under-sampling patterns along radial and spiral sampling trajectories were reported[3,4]. However, there exist regular artifacts in their reconstructed images because the incoherence requirement is not satisfied well. To solve this problem, we introduce a chaotic k-space trajectory for CS-MRI, which is a good candidate k-space trajectory of incoherent-like sampling scheme since the chaos not only has the characteristic of noise-like, but also it's a deterministic system which is easy to implement. Simulation results demonstrate it has noise-like artifacts which is not diffcult to remove by applying CS algorithms.

METHODS AND MATERIALS

There have been reported a lot of continuous chaos systems since Lorenz firstly discovered the chaos in 1963. Here, we choose the Rössler system [5] to introduce how to generate the k-space trajectory from chaos system. It can be depicted as a third order differential equation in the form of equation (1), with the parameters $a = 0.15$, $b = 0.20$, $c = 10$. When the initial status are chosen as $x_0 = 0$, $y_0 = 0$, $z_0 = 0.01$, by using the Matlab function ODE23 to solve equation (1), we can get the numerical results shown in Figure 1. The overall readout length of this trajectory needs an unacceptably long scan time. In order to physically implement the trajectory, the entire pattern is acquired in multi shots. Here, we cut off a section from the chaotic trajectory based on the requirement of scan coverage of k-space, and rotating the trajectory around the origin. Then, we optimize the chaotic trajectory by use of the tOptGrad V0.2 tool box [6] to satisfy the MRI hardware constraints. The practical chaotic trajectory is showed in Figure 2, where the variable density spiral trajectory is demonstrated for comparison.

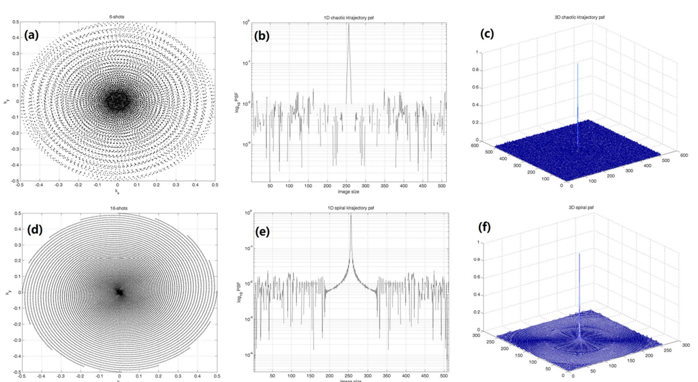

Figure 2: The k-space trajectories and their PSFs of chaotic which in the first row of figure 2, and spiral which in the second row. Acquisition parameters are gradients capable of 40mT/m, slew-rate of 150mT/m/ms,FOV=16cm,image size=[160 160]. For chaotic trajectory, there is 6-shot trajectory with 2326 points per arm, the traversal time is about 55.8ms. For variable density spiral, it takes 16-shot with 930 points per arm, the traversal time is about 59.5ms.

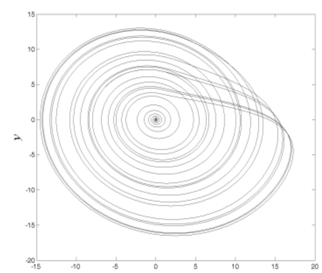

Figure 1 : The x-y plane of Rössler system.

$$\begin{cases} \dfrac{dx}{d\tau} = -y - z \\ \dfrac{dy}{d\tau} = x + ay \\ \dfrac{dz}{d\tau} = b + z(x - c) \end{cases} \qquad (1)$$

RESULTS and DISCUSSTION

Figure 3(a), (b) demonstrate the reconstructions respectively by use of variable density spiral and the chaotic trajectory under the same number of sampling points and reconstruction algorithm. Simulations show that the chaotic trajectory has higher SNR than spiral. The good fidelity should be attributed to the incoherent sampling scheme. Figure 2 shows that the locations of chaotic sampling points are more irregular than spiral. Comparing the zero-filling reconstructed images of Figure 3 (a) with (b), it can be found that their artifacts are different. For spiral, the artifact looks like more regular, however, it is noise-like for chaotic trajectory.

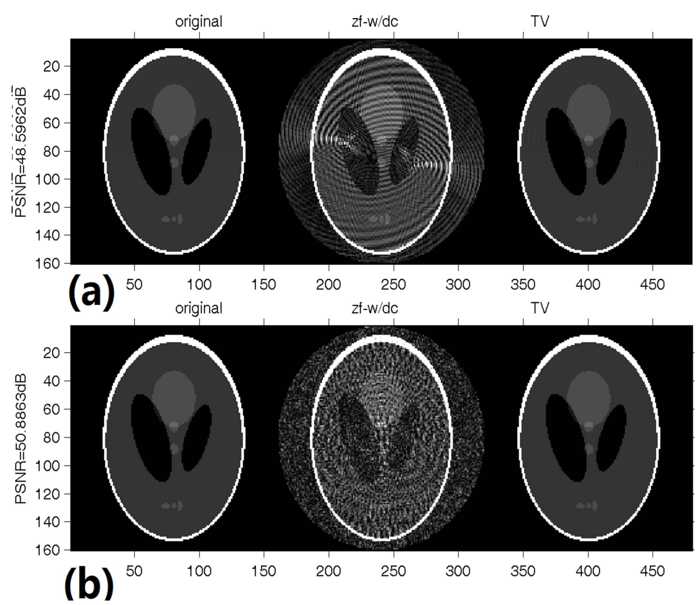

Figure 3: Reconstructions by use SparseMRI V0.2 tool box[6]. a).variable density spiral with 16-shot, 930 sampling points per shot. The PSNR of reconstructed image is 48.6dB. (b).The proposed chaotic trajectory with 6-shot, 2326 sampling points per shot. The PSNR of reconstructed image is 50.9dB.

CONCLUTION

The proposed chaotic k-space trajectory is a smooth, random-like variable density trajectory. Simulations show that its sampling scheme is more incoherent than spiral sampling, it is a good candidate for CS-MRI.

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