Three-Dimensional Overlapping "Rod" acquisition (TORQ): a Novel K-Space Trajectory for 3D Extension of PROPELLER

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Introduction

3D MRI acquisition methods have advantages over 2D counterparts in providing thinner slices and greater Signal to Noise Ratio [1]. However, the associated increased acquisition time and motion artifacts limit the usefulness of 3D methods. Thus, 3D MRI acquisition methods that incorporate intrinsic motion correction and acquisition time reduction are desirable and if successful could replace existing methods.

Periodically Rotated Overlapping Parallel Lines with Enhanced Reconstruction (PROPELLER) [2] is a 2D MRI data acquisition method with intrinsic motion correction that acquires k-space data with rotating "blade" elements. PROPELLER provides oversampling in a center circle of k-space, and the data within that circle is used for the translation and rotation motion correction. When 2D PROPELLER was first introduced by Pipe et. al., also suggested extending the method to 3D [2] by expanding "blade" elements to "rod" elements that rotate in 3D space to form a sphere. The authors envisioned that the oversampled central circle in the 2D case would be replaced by an oversampled inner sphere in the 3D case which would be utilized for 3D motion correction. Also, with spherical k-space sampling with rod elements, the corners of the 3D k-space would not be acquired and thus the trajectory would be more efficient compared to the traditional trajectories that acquire full Cartesian k-space sampling. The current study proposes to extend 2D PROPELLER to 3D by introducing a new non-Cartesian k-space trajectory similar to that originally suggested by Pipe. To our knowledge, the extension of PROPELLER to 3D has not been previously reported.

Methods and Results

Figure 1(a) shows the Cartesian and spherical coordinates in k-space, where ρ is defined as a radius of the sphere (i.e. number of samples away from the center of the radial line), θ is azimuth angle in kx-ky inplane with respect to kx-axis, and ϕ is the elevation angle from kx-ky inplane toward kz-axis. Each "rod" element (represented as a box shown in Figure 1(b)) consists of a set of parallel readouts that are essentially "blade" elements in PROPELLER with length 2ρ, width L_θ and height L_ϕ.

A new trajectory is obtained by rotating the "rod" element in the θ direction for every ϕ angle increment. The rotation angles θ and ϕ are determined from partitioning the first upper quadrant of the k-space ($0 \le \theta \le \pi/2$, $0 \le \phi \le \pi/2$). Let N be the number of inplane "rod" elements in the upper quadrant (equivalent to half of the total # of "blades" in PROPELLER). The θ inplane rotations about the kz axis are completed at each of the N-partitioned ϕ elevation angles. The number of partitions in ϕ remains N. The number of partitions of the θ direction initially start at N, and then decrease by 1 at every ϕ increment. This rule for reduction in the number of partitions is extended for the other 3 upper quadrants to complete the upper half hemisphere. Since the "rod" elements are symmetric about the origin of k-space, the entire lower hemisphere is automatically covered by this partition of the upper hemisphere. The resulting k-space trajectory is shown on Figure 2.

The implementation of this specific 3D "rod" trajectory with the associated image reconstruction will be referred to as the *Three-dimensional Overlapping "Rod" acQuisition (TORQ)* method. The TORQ method inherits many of the advantages of the PROPELLER method, the most important being the motion correction from central k-space oversampling which will improve the quality of the images from the 3D dataset. The TORQ method can also utilize scan time reduction strategies previously applied to the PROPELLER methods, such as undersampling [3] and "data-sharing" reconstructions (e.g. "keyhole" and RIGR reconstructions) [4].

References

1. Bernstein et al, 2004.
2. Pipe et al, MRM, 1999.
3. Arfanakis et al., MRM,2005.
4. Natsuaki et al, Proc. ISMRM, 2005

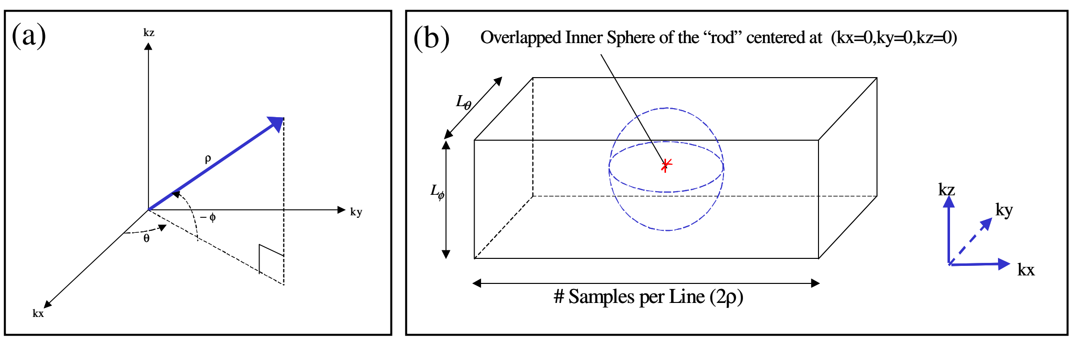

Figure 1: (a) Spherical coordinates in k-space (b) diagram of basic "rod" element used in the acquisition

Figure 2: Proposed k-space trajectory for the TORQ method using "rod" elements, with number of inplane rod elements =12 (thus N=6), length 2ρ = 128 samples, width L_θ = height L_ϕ = 16 lines each. The resulting spherical data set is equivalent to 128 x 128 x 128 3D k-space data. Different ϕ angles are represented with different colors. Figure on left has filled in with color to clarify the rods. The figure on the right is the actual look using schematic "rods" in Figure 1(b).