Fast, Robust and Self-Navigated 3D Cylindrical Imaging: MP-RAGE and FLAIR

Wei Lin[1], Qin Qin[2,3], Stewart H Mostofsky[4,5], and Randy Duensing[1]

[1]Invivo Corporation, Philips Healthcare, Gainesville, Florida, United States, [2]Radiology, The Johns Hopkins University, Baltimore, Maryland, United States, [3]F.M. Kirby Research Center, Kennedy Krieger Institute, Baltimore, Maryland, United States, [4]Neurology and Psychiatry, The Johns Hopkins University, Baltimore, Maryland, United States, [5]Kennedy Krieger Institute, Baltimore, Maryland, United States

Introduction

In many MRI applications, 3D imaging provides better volume coverage and thinner slices than 2D multi-slice imaging, often allowing arbitrary post-scan reformatting. However, rigid-body motion artifacts present a major challenge for 3D scans due to the longer scan time. Existing motion correction techniques require either marker(s) to be attached to the subject [1-2] or additional navigators [3-4]. In this work, a self-navigated 3D imaging method is proposed based on sampling k-space with successive pairs of orthogonal view-planes forming a cylinder. Rotation around the main axis of the cylinder is detected and corrected in real-time, while all other motion are detected and corrected retrospectively. The method achieves the same off-resonance behavior and reconstruction speed as the conventional 3D Cartesian imaging. When array coil is used, significant acceleration can be achieved by reducing the number of acquired view-planes. The efficacy of the proposed technique is demonstrated in healthy volunteers using a T_1-weighted magnetization-prepared rapid gradient echo (MP-RAGE) sequence and a T_2-weighted fluid attenuated inversion recovery (FLAIR) sequence.

Methods

The 3D cylindrical k-space is sampled with successive pairs of orthogonal view-planes sharing a common axis k_0 (Fig. 1). The readout is always along the k_0 direction, which makes the technique immune to off-resonance artifacts. Motion is detected using image correlation. A rotation around the k_0 axis introduces k-space undersampling, therefore it is detected and corrected in real-time by correlating a projection image, which is derived by sampling a small central circle in the $k_0 = 0$ plane. The remaining five degrees of freedom are detected and corrected retrospectively using imaging data on each view-plane and a central reference cylinder acquired at the beginning of the scan. Translation is corrected by applying appropriate linear phase. Rotation within each view-plane is corrected by a shearing method [5]. After motion correction, Cartesian grid data points on each k_0 plane is computed by combining nearby acquired non-Cartesian data points [6] prior to the final FFT.

Two healthy volunteers were scanned on a clinical 3.0T scanner (Achieva, Philips, the Netherlands) using an 8-channel head coil (Invivo, Gainesville). Each subject was asked to make a combined nodding and shaking head rotation midway through the scan. A Cartesian MP-RAGE sequence was modified into the proposed cylindrical acquisition with following scan parameters: FOV = 230×230×230 mm^3, matrix size = 256 (readout) × 256 (phase-encode) × 64 (view planes), TI/TR/TE = 1000/9.5/4.2 ms, inversion pulse interval = 2800 ms, flip angle = 8 degree, total scan time = 3 mins. A 3D FLAIR sequence was modified into the proposed cylindrical acquisition with following scan parameters: FOV = 256×256×256 mm^3, matrix size = 256 (readout) × 256 (phase-encode) × 64 (view planes), TR/TE = 4800/372 ms, inversion delay = 1650 ms, total scan time = 2 mins 40 secs.

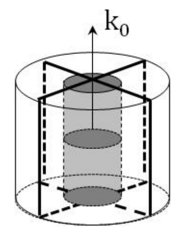

Figure 1 Data acquisition and motion detection scheme in 3D cylindrical imaging. Successive pairs of orthogonal view-planes form a cylinder in k-space. A small central circle on the $k_0 = 0$ plane is acquired repetitively for real-time correction of rotation around the k_0 axis. A central reference cylinder is acquired at the beginning of the scan for retrospective correction of other motion. All motion parameters are detected using image correlation.

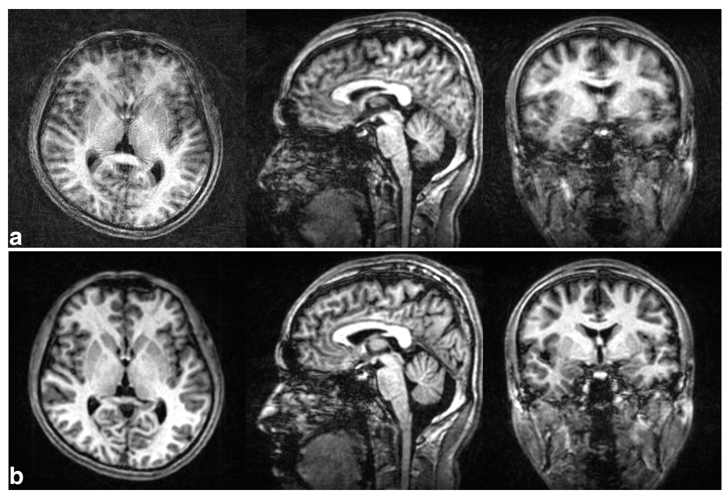

Figure 2 3D motion correction results using a cylindrical MP-RAGE sequence. **(a)** Motion corrupted images. **(b)** Motion corrected images.

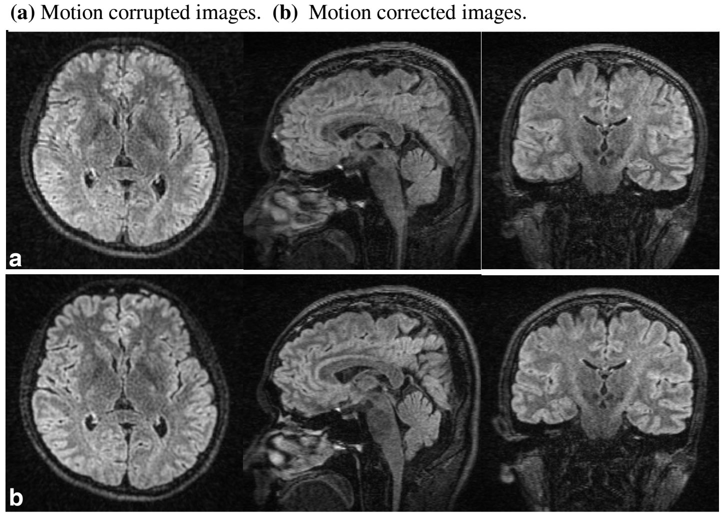

Figure 3 3D motion correction results using a cylindrical FLAIR sequence. **(a)** Motion corrupted images. **(b)** Motion corrected images.

Results and Discussions

Results from the volunteer study are shown in Fig. 2-3. Full 3D rigid body motion was detected for each echo train, resulting in a temporal resolution of about 2 sec and 1 sec, for MP-RAGE and FLAIR scans respectively. Motion introduces image ghosts, blurring and streaks (Fig. 2a, 3a). After motion correction, artifact was removed and image sharpness was restored (Fig. 2b, 3b). The retrospective motion correction and image reconstruction for the entire 3D volume takes about 30 seconds on a PC with a 2.0GHz CPU.

When compared with marker-based approaches [1-2], the proposed method does not introduce additional workflow or increase patient discomfort. When compared to navigator based methods [3-4], the proposed self-navigation strategy does not prolong the scan time or introduce additional constraints on the sequence. When an array coil is present, the acquisition can be significantly accelerated by reducing the number of acquired view planes and applying parallel imaging methods previously proposed for azimuthally undersampled radial acquisitions.

References

[1] Zaitsev M, et al. *Neuroimage* 2006; 31: 1038-1050.
[2] Ooi MB, et al. *MRM* 2009; 62: 943-954.
[3] Van der Kouwe AJW, et al. *MRM* 2006; 56: 1019-1032.
[4]White N, et al. *MRM* 2010; 63: 339-348.
[5] Eddy WF, et al. *MRM* 1996; 36: 923-931.
[6] Lin W, et al. *MRM* 2012; 67: 1097-1105.