High Temporal Resolution 3D Motion Correction of MP-RAGE with Cylindrical Sampling and Parallel Reconstruction

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Introduction

In many MRI applications, 3D imaging provides an advantage over 2D multi-slice imaging due to its high SNR efficiency and isotropic resolution, which allows arbitrary post-scan reformatting. However, due to the longer scan time associated with a 3D scan, voluntary patient motion artifacts present a major challenge, particularly for pediatric imaging. Existing 3D motion correction techniques require either additional hardware [1-2], or long navigator and real-time motion detection module [3] which is incompatible with short-TR sequences. In this work, a self-navigated method to achieve high temporal resolution 3D rigid-body motion correction is proposed. The k-space data is collected using multiple pairs of orthogonal planes forming a cylinder. A rapid self-calibrated parallel imaging method, generalized **GR**APPA **O**perator for **W**ider readout **L**ines (GROWL) [4], facilitates both motion detection and image reconstruction. Full 3D rigid-body motion detection is achieved at a temporal resolution of every two consecutive view planes (2-6 seconds). The efficacy of the proposed technique is demonstrated in healthy volunteers using a magnetization-prepared rapid gradient echo (MP-RAGE) sequence.

Methods

The proposed data acquisition and motion detection scheme is shown in Fig. 1. The 3D cylindrical k-space is sampled in successive pairs of orthogonal view planes, all sharing a common axis (k_0), which could be either readout or a phase-encode direction. The angle of view planes follows a bit-reversed order previously proposed for radial imaging [5]. Through-plane rotation/translation is detected by image correlation using a central cylinder in k-space (shown gray in Fig. 1a-b) as the motion-free reference. This reference cylinder comes from the GROWL reconstruction of a subset of the acquired data with the least amount of motion, as determined by minimum image entropy. For in-plane rotation/translation, the $k_0 = 0$ plane is sampled rapidly using an interleaved radial trajectory after a single inversion pulse. GROWL operator is used to expand $k_0 = 0$ line on each acquired view plane into a wider band (Fig. 1c), prior to motion detection using signal and image correlation. During the image reconstruction, GROWL operator is used to fill in k-space gaps introduced by rotation and data rejection (e.g. due to non-rigid motion), as determined when the correlation value is less than a threshold.

A healthy volunteer was scanned on a clinical 3.0T scanner (Achieva, Philips, the Netherlands) using an 8-channel head coil (Invivo, Gainesville). A 3D Cartesian MP-RAGE sequence was modified into the proposed cylindrical acquisition by removing slice-encoding gradients, while rotating different view planes with a bit-reverse angle ordering scheme. Scan parameters are FOV = 230×230×230 mm^3, matrix size = 256(readout) ×128(phase-encode) ×128(view planes), TI/TR/TE= 1000/9.5/4.2 ms, inversion pulse interval = 2800 ms, flip angle = 8 degree, total scan time = 6 mins. The subject was asked to make a combined nodding and shaking head rotation midway through the scan.

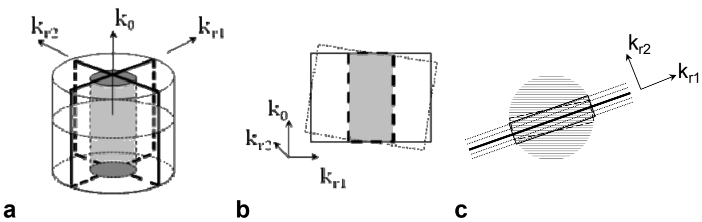

Figure 1 Data acquisition and motion detection scheme. (**a**) Data is acquired using successive pairs of orthogonal view planes forming a cylinder in k-space. One subset of data provides a motion-free central cylinder (gray). In addition, $k_0 = 0$ plane is acquired rapidly. **(b)** Through-plane motion is detected by data correlation within the central rectangle (gray) for each view plane. **(c)** In-plane motion is detected by correlation using the k_0=0 plane reference and GROWL operators.

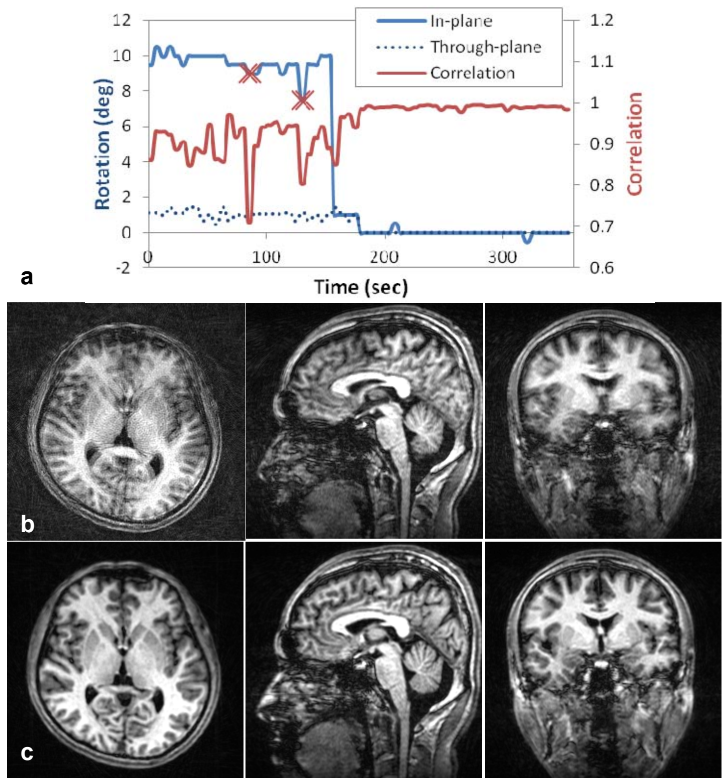

Figure 2 3D brain motion correction results using a modified MP-RAGE sequence. **(a)** Rotation detected within and across the axial plane. Four view planes (indicated by × in red) were rejected due to low correlation values. **(b)** Motion corrupted images. **(c)** Motion corrected images.

Results

Results from the volunteer study are shown in Fig. 2. Full 3D rigid body motion was detected at a temporal resolution of every 5.6 seconds. Four out of 128 view planes (indicated by red × on the in-plane rotation curve) were rejected due to low correlation values. The range of in-plane and through-plane rotation was 10.5 and 1.5 degree, respectively (Fig. 2a). The maximum errors in in-plane and through-plane rotation are 0.75 and 0.5 degree, respectively. Motion introduces severe image ghosts, blurring and streaking artifacts (Fig. 2b). After motion correction, artifact was removed and image sharpness was restored (Fig. 2c). The entire off-line motion detection and correction procedure takes about 5 minutes.

Discussions

The proposed data acquisition method bears some similarity to Cartesian Projection Reconstruction-like (CAPR) technique [6]. However, with our technique, acquired k-space samples are not shifted from radial lines to neighboring Cartesian grid points to facilitate motion detection. When the readout is applied along the k_0 axis, potential off-resonance artifacts associated with the conventional radial imaging can be avoided. Compared to navigator based methods, the proposed self-navigation strategy does not prolong the scan time or introduce additional constraints on the sequence. The reconstruction time of our method can be further reduced to less than 1 minute with directGROWL [7]. The proposed method can be extended to other 3D imaging sequences such as turbo spin echo (TSE).

References

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