Motion Compensation with Floating Navigator and GRAPPA Operators

W. Lin[1], F. Huang[1], Y. Li[1], C. Saylor[1], and A. Reykowski[1]

[1]Invivo Corp., Philips Healthcare, Gainesville, FL, United States

Introduction

Recent developments in partially parallel imaging (PPI) techniques provide new opportunities for motion artifact reduction [1-2]. One PPI technique that exhibits great potentials in many motion detection and correction scenarios is the GRAPPA operator [3], as the GRAPPA kernels can be flexibly positioned for k-space interpolation and extrapolation in any direction. This work proposes a new motion detection and correction method for applications using multiple channel coil arrays. The method uses the image-space correlation of floating navigators for detection of translational, rotational and non-consistent (e.g. through-plane and non-rigid body) motion. GRAPPA operators are then used to correct the k-space data, and hence suppressing motion artifacts.

Theory

Floating navigator (FNAV) was previously proposed to detect translation along both x (readout) and y (phase-encode) directions with a single navigator readout [4]. Unlike the traditional navigator technique which involves acquiring signal along the $k_y = 0$ line, FNAV samples along $k_y = k_f \neq 0$, where k_f is typically small to ensure a sufficient SNR and to avoid phase-wrapping.

In this work, FNAV data is also used to detect rotation and non-consistent motion in addition to translation, based on a correlation method [5]. Translational motion introduces a linear phase shift to the k-space data, while image rotation causes the same amount of rotation in k-space. In our method, a set of motion-free reference k-space lines near the FNAV line is rotated to various angles for rotational motion detection (**Fig. 1a**). In the next step, for each rotation angle the 2D image-space correlation is computed between the reference and FNAV data. The positions of the maximal correlation will yield an estimate of in-plane translation and rotation (Δx, Δy, Δθ). In addition, a low maximal correlation value indicates inconsistent data, which may be caused by through-plane or non-rigid body motion. Following the motion detection, GRAPPA operator is applied to either correct or substitute the motion corrupted data. First, a GRAPPA extrapolation operator is used to fill in the missing “pie-slice” of k-space caused by rotational motion (**Fig. 1b**). Second, a GRAPPA interpolation operator is used to regenerate the full k-space data from a reduced dataset, which allows subsequent rotational correction or the replacement of inconsistent data (**Fig. 1c**).

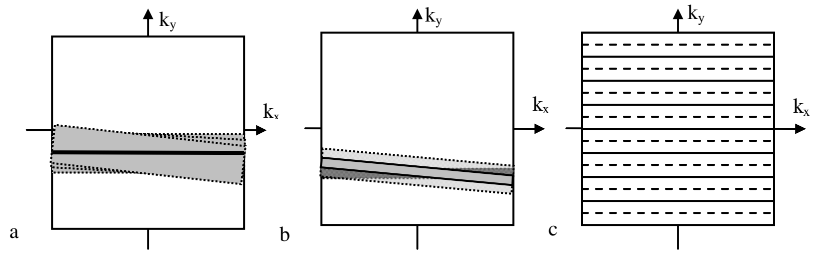

Fig. 1 (a) Image-space correlations are computed between FNAV (thick line) and motion-free reference segment (gray), rotated to different angles. (b) GRAPPA extrapolation operators generate missing “pie-slice” of k-space (darkest regions) due to rotation. (c) GRAPPA interpolation operators generate k-space (dashed) lines to replace inconsistent data.

Methods

The feasibility of motion compensation using floating navigators and GRAPPA operators was examined using a turbo spin echo (TSE) sequence. In this case, each echo train naturally provides a FNAV line near k_y=0. In addition, the sequence was modified to allow either linear or interleaved ordering of different echo trains. Two i*n vivo* brain imaging experiments were carried out on a 3.0T Achieva scanner (Philips, Best, Netherland), using an 8-element head coil (Invivo, Gainesville, FL), with following scan parameters: FOV 230x230 mm^2, matrix size 224x224, Echo train length (ETL) = 16. The first experiment used a linear echo-train order with TR/TE=2000/20 ms. The second experiment used an interleaved (factor = 4) echo-train order with TR/TE = 1500/60 ms. The k_y values of FNAV lines for the 14 echo-trains span the range of 5/FOV to 18/FOV. GRAPPA extrapolation operators used a 5 (readout) x 1 (phase-encode) kernel with an extrapolation factor of 5, while GRAPPA interpolation operators used a 5 (readout) x 4 (phase-encode) kernel with a reduction factor R = 4. A motion-free reference scan was first acquired and a motion-corrupted scan followed by requesting the volunteer to randomly move inside the scanner. Central 24 phase-encode lines from the motion-free reference scans were used for both GRAPPA calibration and FNAV reference, but were not used for final reconstruction of motion-corrected images.

Results and Discussions

Figure 2 shows experimental results for both linear (a-c) and interleaved (d-f) phase encoding orders. Motion introduced severe ghosting, which was significantly reduced after motion correction with the proposed method. Similar improvements in image qualities were observed in all 10 slices. The maximal correlation values between corrupted FNAV lines and reference lines remained high (ranging from 0.96 – 0.99) during 14 echo trains, indicating that motion is mostly in-plane. The maximal value of translation was (Δx, Δy) = (1.9, 5.5) pixels and the maximal value of rotation was Δθ =5.0^0. The entire motion detection and correction process took less than 5 seconds for each slice on a 2.2GHz PC.

Due to noise amplification introduced by GRAPPA extrapolation, the motion corrected image (**Fig. 2c**) does appear to have more noise than the original motion-free image (**Fig. 2a**). Future work will study the optimal method to weight k-space data points with various artifact/noise levels.

The proposed technique can be easily incorporated into sequences other than TSE, provided that a FNAV line is acquired at the desired temporal resolution for motion detection. When compared with previous PPI-based motion correction techniques [1-2], our method corrects for both translational and rotational motion. In addition, the correlation value can be used to detect and reject data with inconsistent motion (e.g. through-plane motion).

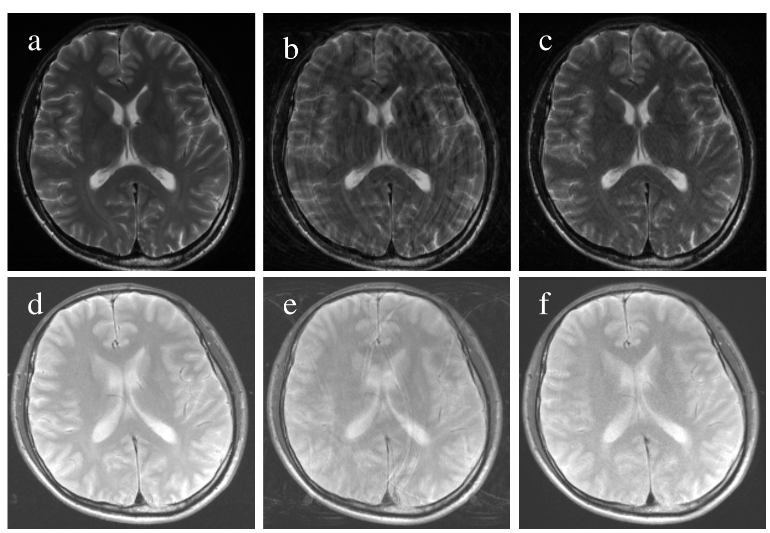

Fig. 2 Motion-free (a), corrupted (b) and corrected (c) images from a TSE brain imaging experiment with a linear echo-train ordering. (d)-(f): Corresponding images using an interleaved echo-train ordering.

References

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