Real-time concomitant gradient field correction.

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Target Audience:

Scientists using non-Cartesian pulse sequences at low to moderate field strengths.

Introduction:

One source of artifacts in spiral scans is concomitant gradient fields (CGFs), which are higher order field terms that accompany linear gradients[1]. The magnitude of such CGFs is derived from the Maxwell equations and is therefore predictable given complete knowledge of the gradients. The simplest case of CGF errors is the homogeneous frequency-offset which is manifest in axial slices. This can adequately be corrected with negligible computation time by applying a time-dependent frequency demodulation to the acquired data[2]. However, simple demodulation is largely ineffective at correcting the more intricate errors exhibited in oblique slices. Multi-frequency binning allows for a pixel by pixel reconstruction using multiple frequency bins, significantly improving non-axial CGF correction but with serious reconstruction time penalties[2]. We propose an intermediate solution that retains the non-axial correction capabilities of the multifrequency approach along with the speed of simple demodulation correction.

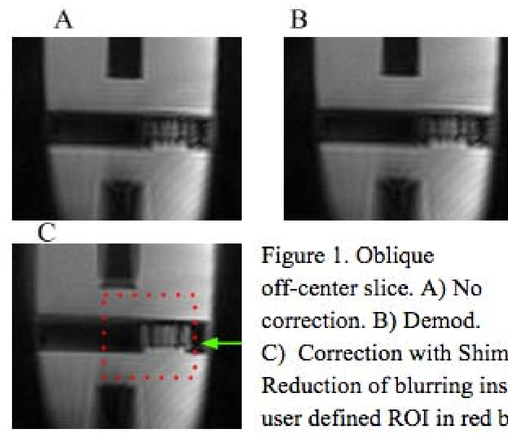

Figure 1. Oblique off-center slice. A) No correction. B) Demod. C) Correction with Shims. Reduction of blurring inside user defined ROI in red box.

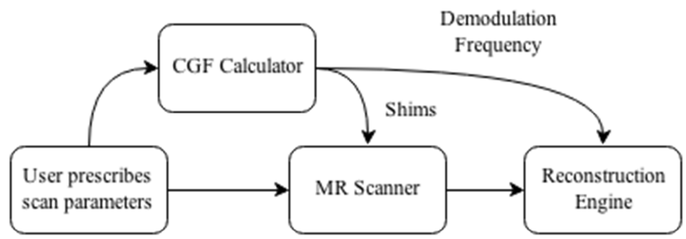

Figure 2. Block Diagram of CGF correction built into real-time pipeline. Correction is performed immediately after slice prescription.

Methods:

The proposed method is to be implemented in real-time MR imaging, so speed is essential. The following procedure was implemented and tested in RTHawk, a real-time cardiac evaluation platform created by HeartVista (Menlo Park, Ca). The second-order value of the CGF is taken from the equation derived by Bernstein et al.[3] The computation can be separated into two parts: a gradient dependent weight and a spatially dependent field map. The gradient weight is precomputed by linearizing the integrated gradient amplitude squared curve; this value is updated whenever the user changes the readout gradients. After the slice is prescribed, a spatially dependent field map is computed by looping over a range of points that lie within a user supplied region of interest and multiplying the gradient weight. A linear fit is performed on the field map to estimate the off-resonance to a first degree. When rotated into scanner coordinates the output of the linear fit provides x, y, and z shim values along with a shim offset frequency and demodulation frequency. The shims are set prospectively, and the demodulation is retrospective. The CGF correction was built into and tested on a real-time spiral GRE pulse sequence. Phantom images were acquired using RTHawk on a 1.5 T GE scanner. Axial scans were prescribed with a z-offset of 6 cm from isocenter. An oblique slice was prescribed at a rotation of 30 degrees from the sagittal plane along the z-axis with a 5 cm Y offset and a 9 cm Z offset from isocenter. A qualitative analysis of image blurring was used to compare images.

Results:

The proposed first order correction performs just as well as the demodulation correction in the axial case and outperforms the demodulation correction within the ROI, shown in red, in the oblique case (see Figure 1c).

Discussion:

The proposed solution for real-time CGF correction does not eliminate all of the artifacts in non-axial images, and improvement in image quality in one area of the image comes at the cost of increased blurring in other areas. It is well known that uncorrected CGFs have no effect at isocenter and that blurring increases along the radial direction. CGF corrected images are similarly blurred outside of the ROI. Consequently, the application of shims can be thought of as effectively shifting isocenter. In cardiac MRI this is acceptable because the region of interest, the heart, is relatively small when compared to the entire image FOV.

References:

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3. M. A. Bernstein, X. J. Zhou, J. A. Polzin, K. F. King, A. Ganin, N. J. Pelc, and G. H. Glover, "Concomitant gradient terms in phase contrast MR: Analysis and correction", Magn. Reson. Med., vol. 39, pp.300 -308 1998