RESIDUAL DISTORTIONS IN MRI AFTER GRADIENT CORRECTION ALGORITHMS

Richard Mallozzi, Ph.D.
Phantom Laboratory, Inc.
Image Owl, Inc.

Summary
Manufacturers’ gradient distortion correction algorithms correct much of the distortion due to nonlinearity inherent in gradient coil fields. However, two sources of gradient distortion remain:

- residual distortion from imprecise gradient calibration
- distortion in the slice direction on 2D pulse sequences

Together, these sources of distortion commonly leave 1-3 mm of gradient-induced distortion in scanners that are within operating specifications.

Details
Normal tolerance on gradient calibration is approximately 1% (American College of Radiology, 2005), (Mallozzi R. P., 2015). This can leave a residual distortion of 1-2 mm depending upon the distance of the anatomy from isocenter. An additional source of distortion is along the slice direction for 2D sequences, described in another white paper (Mallozzi R. P., 2015). These 2D pulse sequences are those that use a slice-selective gradient and RF pulse combination, rather than a phase encoding gradient to encode the spatial information in the slice direction.

Figures 1 and 2 below show 3x3 plots of distortion versus location in the scanner. The data in the two figures are acquired on the same model scanner for a particular vendor at 1.5T, using the ADNI phantom manufactured by The Phantom Laboratory, Inc., and analyzed by the Image Owl services. Details of the phantom and a similar analysis can be found in the references (Gunter, et al., 2009), (Mallozzi, Blezek, Gunter, Jack, & Levy, 2006). The phantom consists of 165 spheres whose location can be accurately
determined to measure a distortion field, and cover a diameter of approximately 16 cm. Figure 1 shows the distortion for a 3D sagittal acquisition, and figure 2 shows the distortion for a 2D sagittal acquisition on a scanner from the same vendor.

In each case, the horizontal axis shows the distortion in mm, and the vertical axis shows the location in the scanner along one direction. The graphs in the left column show distortion in the x direction, the middle column show distortion in the y direction, and the right column show distortion in the z direction. The top row shows the location of the spheres in the x direction, the middle row shows the location of the spheres in the y direction, and the bottom row shows the location of the spheres in the z direction.

Figure 1: Sagittal 3D volume acquisition of a volume showing location in bore (vertical axes) and distortion (horizontal axes). The graphs along the diagonal from upper left to lower right show the approximately 1 mm distortion that arises from gradient miscalibration.
Figure 2: Sagittal 2D volume acquisition of a volume showing location in bore (vertical axes) and distortion (horizontal axes). Distortion along the slice direction is much more pronounced than in 3D acquisition, with nonlinear distortion particularly evident in the x distortion as a function of z position (lower left graph).

There are several notable observations to make from this data. The first, apparent from some of the graphs along the diagonal that goes from upper left to lower right, the gradient calibration, though within spec, still leads to distortion of approximately 1 mm over the 16 cm spherical diameter covered. This is an in-plane distortion, even after the manufacturer’s correction has been applied. The lower right graph in both Figure 1 and Figure 2 show this effect, as does the center graph of Figure 1.

Second, in the 2D acquisition shown in Figure 2, there is significantly more distortion observable in the slice direction (x in this case) than in the other directions. The lower left graph of Figure 2 shows this pronounced effect. The residual distortion gets as high as plus or minus 2 mm. The reason for this residual distortion is that for 2D pulse sequences, distortion is not corrected in the slice direction. It is always corrected in plane, which is why the distortion is larger in the slice direction. Note that in the 3D
acquisition shown in Figure 1, the nonlinear distortion has been corrected in all three directions, leaving primarily gradient miscalibration and other non-gradient sources of distortion.

Conclusions

Manufacturers’ gradient distortion correction is always performed in plane, but only for 3D pulse sequences is it always applied in the slice direction. Residual distortion on such sequences can be 2mm or more. For both 2D and 3D pulse sequences, residual distortions from imprecise gradient calibration can leave distortions of approximately 1 mm over relatively small fields of view, even in a calibrated scanner that passes the ACR accreditation. Thus total residual distortion, after the manufacturer’s correction, can be 1-3 mm for accredited scanners operating within specifications. Quantitative applications that rely on millimeter or better precision should may be adversely affected by this distortion.

References


