Assessment of Manufacturers' Correction Methods for Geometric Distortion in MRI using a 3-Dimensional Phantom

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Introduction

As magnetic resonance imaging technology is further developed, demand for high performance gradient coils with fast switching speed and stronger gradient strength has also increased. To meet this demand, short gradient coils are being used. Short gradient coils are often associated with greater gradient nonlinearity and this increased gradient non-linearity could be a major concern in certain applications. The most obvious effect of gradient non-linearity in MRI is geometric distortion. There are methods that have been developed to correct for geometric distortion in MRI [1,2]. The major manufacturers such as GE and Siemens also have correction methods available to users. We understand these methods are 2-dimensional (2D) correction methods. In other words, the correction is only carried out in the imaging planes. The purpose of this study is to carry out an assessment on these correction methods and to discuss the limitations of the correction method in 2D especially when applied for correcting MR images acquired with high performance gradient coils. The geometric distortion in the present study is mapped using a new 3-dimensional phantom we recently developed. An advantage of this 3D phantom is that the geometric distortion can be comprehensively and accurately mapped in all three dimensions in a single scan by using a dense array of control points that are defined in the 3D space. Two high performance MRI systems, a Siemens Sonata 1.5T and a GE Twin Speed 1.5T were used for the assessment.

The method

A detailed description of the 3D phantom and the method for mapping geometric distortion are given in a separate presentation. Briefly, the 3D phantom used for the present work was constructed using grid sheets of orthogonally interlocking plastic stripes. The grid sheets are aligned in parallel along the normal of the sheet surface with gaps equal to the width of the sheets. Each of the sheet surfaces defines a layer of control points. The 3D phantom used here contained $19 \times 19 \times 30$ (10830) control points in an effective volume of $257.04 \times 259.02 \times 261.0\ mm^3$. The phantom is a cube with external dimensions of 310 $mm \times 310\ mm \times 310\ mm$. We have also developed a fully automated image processing procedure which enables the extraction of the positions of the control points in the phantom image with sub-voxel precision. The correspondence established between the measured coordinates of the control points in the distorted image space and their true locations defined by the geometry of the phantom provides a comprehensive mapping of geometric distortion. The phantom images were acquired using a 3D gradient echo sequence called *Vibe* on the Siemens Sonata 1.5 T system. The voxel's dimensions were 1.3 $mm \times 1.3\ mm \times 1.3\ mm$. We used the *3D FSPGR* sequence on the GE Twin Speed 1.5T system. The voxel's dimensions were 1.3 $mm \times 1.3\ mm \times 1.4\ mm$. For the assessment, phantom images were acquired both with and without correction method.

Results

Fig.1 (a) and (b) are two axial slices of the 3D phantom acquired on the Siemens Sonata 1.5 T system, with and without the correction at z = 117 *mm* from the isocentre. In Fig. 1(c) and (d), two representative axial slices acquired on the GE's 1.5T Twin Speed (Zoom mode, z =113.4 *mm*) with and without the correction are shown. In Table 1, the maximum geometric distortion within the volume of interest defined by the phantom and calculated as the absolute percentage difference between the measured distances in the distorted image space and their true distances defined by the geometry of the phantom is summarized.

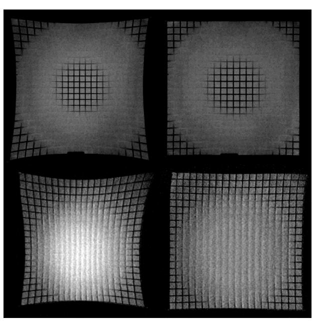

Fig. 1. *Representative axial slices of the 3D phantom:*
(a) Sonata no correction;
(b) Sonata with correction;
(c) GE Twin Speed no correction;
(d) GE Twin Speed with correction.

Gradient	**GE Twin Speed (Zoom mode)**		**Siemens Sonata**	
	no corr.	corr.	no corr.	corr.
X	23.4	1.5	8.4	1.2
Y	17.8	1.2	7.2	1.3
Z	6.7	6.7	9.1	9.1

Table 1. *The maximum geometric distortion (%) within the volume of interest defined by the 3D phantom measured without correction (no corr.) and with correction (corr.),(Off-centre placement (y axis) of the phantom in the GE scans was partially responsible for larger distortions measured).*

Discussion and conclusions

As shown both in Fig. 1 and Table 1, both correction methods from GE and Siemens correct the distortions within the imaging plane (the axial slice in this case). The distortion along the x and y axes has significantly been reduced after correction. As expected, the 2D methods applied no correction on the distortion along the z axis so that the distortion was unchanged (see Table 1). A severe limitation of the 2D correction methods can be explained by inspection of Fig. 1. For example, in Fig. 1 (a) and (b), the grid patterns at the centre of the images and those seen at the corners are from two separate grid sheets and the gap between them is 9 *mm* (which is also the width of the sheets). In other words, the z positions of the pixels in the centre of the image differ at least by 9 *mm* to those at the corners and 2D correction methods applied in the xy plane have no effect on the distortion along the z axis. Therefore, care should be exercised when using 2D correction methods especially for correcting 3D volumetric data acquired with high performance gradients as these gradients have much greater non-linearity problems as shown here. Correction can be carried out in 3D using the mapped distortion data by the 3D phantom. Both global and local interpolation methods can be used. A more detailed discussion on correction in 3D is given in an accompanied presentation.

[1] Glover GH, Pelc NJ, Methods for correcting image distortions due to gradient non-uniformity. US patent 4591789; 1986.
[2] Langlois S, Desvignes M, Constans JM, Revenu M. MRI geometric distortion: a simple approach to correcting the effects of non-linear gradient fields. J. magn Reson Imaging 1999;9:821-831.