A 3-Dimensional Phantom and Method for Mapping and Correcting Geometric Distortion in Magnetic Resonance Imaging

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Introduction

Geometric distortion in magnetic resonance imaging (MRI) arising from gradient field non-linearity and the inhomogeneity of the static field has been commonly mapped by phantoms. The most popular phantom is the grid phantom which consists of a two-dimensional array of orthogonally interlocking plastic strips. Parallel cylindrical tubes of circular cross section have also been used. A common feature of these phantoms is that the distortion can only be mapped within the imaging plane. The third component that is along the normal of the imaging plane is not defined and, therefore, is immeasurable. In this sense, these phantoms can be regarded as 2-dimensional (2D) phantoms. Clearly, with 2D phantoms the geometric distortion cannot be completely mapped. Additionally, mapping of the distortion with 2D phantoms for the entire imaging space often requires multiple scans with the phantom be placed at different locations and different orientations. The entire process can be cumbersome and time consuming.

For a complete mapping of geometric distortion in MRI, phantoms with control points defined in 3-dimensions (3D) are required. One such phantom using spheres to define points in 3D has been proposed [1]. Here, we propose an alternative approach to define control points in 3D. We use the intercepting point of three orthogonal planes to define a point in 3D space. With this approach, we have designed an effective 3D phantom for mapping geometric distortion in MRI.

A 3D phantom

A simple implementation of our design approach is to use the grid pattern employed in the 2D grid phantom and to use the grid sheet surface as the third plane. We can, therefore, construct 3D phantoms that consist of layers of grid sheets aligned in parallel with equal spacing along the third dimension. Each of the two sheet surfaces defines a layer of control points. Using this approach, we have built a 3D phantom for a body coil (see Fig. 1). It contained 15 grid sheets. The spacing between the grid sheets was set to be equal to the width of the grid sheets which is 9 *mm*. These grid sheets were purchased commercially and they were normally used for building ventilation. The body coil 3D phantom had 19×19 (381) crosses. Therefore, it contained 19×19×30 (10830) control points. The separations between the control points along the three orthogonal axes are, 14.28 *mm*, 14.39 *mm* and 9.0 *mm*, respectively, thus forming an effective volume of (257.04×259.02×261.0) mm^3. The external dimensions of the 3D phantom are 310 *mm*×310 *mm*×310 *mm*.

Extraction of the control points and correction

A fully automated image processing procedure has been developed which enables the extraction of the positions of the control points in the phantom image with sub-voxel accuracy. As the positions of the control points are defined by the positions of the intercepting planes, image first derivatives were extensively used in the extraction process. When the coordinates of the control points in the distorted space are located, correction on distortion becomes an interpolation modeling process. We have implemented a range of 3D interpolation models ranging from simple tri-linear interpolation to more complex spline-based models for correction using the mapped distortion data.

An illustrative mapping example

To demonstrate the effectiveness of the 3D phantom, we present the geometric distortion in a Siemens Sonata 1.5 T MRI scanner mapped by the 3D phantom as an example. The phantom image was acquired using a 3D imaging sequence called *Vibe*. The mapping involved a single phantom scan. The acquisition time was less than ~8 min.. Fig. 2(a) is a representative axial slice of the phantom taken at z =117 *mm* from the isocentre. Significant distortion is clearly visible. The distortion along the z axis is manifested by the bending of flat grid sheets. The extraction for the positions of 10830 control points was all successful. Accuracy was assessed by estimating the measured residual geometric distortions in the corrected image. Correction was carried out using a tri-linear interpolation method. The mean absolute residual errors along all three nominal axes after correction were ~0.1 *mm*. The corresponding slice of the corrected image to Fig.2 (a) is shown in Fig. 2(b).

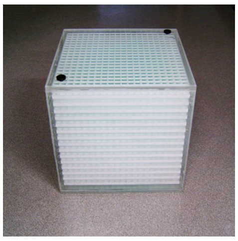

Fig. 1 *A photograph of the 3D phantom*

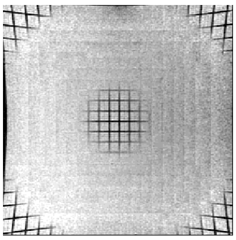

Fig. 2(a) *An axial slice of the phantom image (uncorrected)*

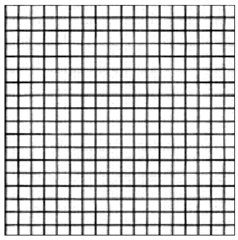

Fig. 2(b) *The corresponding slice after correction*

Discussion and conclusion

The new 3D phantom described herein offers a number of advantages. First, the 3D phantom allows the distortion be mapped along all three orthogonal axes in a single scan whereas with 2D phantoms, distortion is only mapped in the imaging planes. With 2D phantoms, the third component normal to the imaging planes is undefined and is immeasurable. Secondly, the 3D phantom provides a comprehensive mapping of the geometric distortion in the entire imaging space due to a dense array of control points. The body-coil phantom described herein had 10,830 control points. In fact, with our new design it is easy to incorporate as many control points as desired by simply changing the dimensions of the grid. By contrast, for 3D phantoms using spheres as control points, the number of control points can be limited [1]. Thirdly, the accuracy in the mapping of geometric distortion with the new 3D phantom is high. The errors in the illustrative example were in the order of ~0.1 *mm*. Finally, with the mapped distortion data, a range of 3D interpolation models (both global and local interpolation models) can be used for correction for geometric distortions. In conclusion, the new 3D phantom should find a wide range of applications particularly in MRI quality assurance, improvement in quantitative analysis, and MRI spatial localization as used in radiotherapy and radiosurgery.

[1] Breeuwer M, Holden M, Zylka W. Detection and correction of geometric distortion in 3D MR images Proc SPIE 2001;4322:1110-1120.