Real-Time Gradient Non-linearity Correction

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Introduction

Applications requiring fast and accurate representations of location, such as real-time interventional procedures, require real-time correction of gradient non-linearity. Current methods correct for both spatial and intensity distortion of the object being imaged through post-processing routines that take considerable time. Spatial distortion is corrected by deriving the gradient error from the actual field map [1], which can be used to map the physical object to the warped gradient space. The correction calculates the physical image by determining the pixel intensity of each physical location from the corresponding warped image. These values are calculated through interpolation since the signal does not usually lie on the pixel boundaries. Voxel size is also affected by gradient non-linearity, so an intensity correction step is performed as well. A new real-time method is proposed for gradient non-linearity correction that treats the acquired image as a surface of gradient iso-contours.

Methods

Two coordinate systems are defined: (x_p, y_p, z_p) as the physical magnet coordinate system and (x_w, y_w, z_w) as the warped coordinate system. The non-linearity of the gradients will cause the distortion from (x_p, y_p, z_p) to (x_w, y_w, z_w). Higher order polynomials are used to represent the mapping from physical to warped space. Equations that describe this mapping can be determined from the spherical harmonic expansion of the magnetic field. Determining how the warped image is mapped to the physical gradient space is achieved by inverting these distortion equations, allowing the solution of (x_p, y_p, z_p) to be determined, given a warped value (x_w, y_w, z_w).

The warped coordinate system was used to define a surface of gradient iso-contours. A warped image was then texture-mapped to this surface, and displayed visually using standard graphics software. In-plane distortion of the image can be effectively corrected by projecting the texture-mapped image onto a plane parallel to the slice. The advantage of this approach was that the warped surface was calculated only once, which allowed the 3D rendering capabilities of modern graphics cards to be leveraged in order to provide real-time projections of the warped image. Signal intensity across the image was also impacted by gradient non-linearity because of distorted voxel size. The correction scale factors were determined by evaluating the product of the partial derivatives of the warped surface. Similar to spatial correction, intensity correction was calculated ahead of time to allow real-time scaling of individual pixel values.

A phantom consisting of three parallel grids, each plane spaced 10 cm apart, was imaged with a spin echo pulse sequence on a GE Signa LX 1.5 T scanner equipped with EchoSpeed gradients (GE Medical Systems, Waukesha, WI, United States) using the following parameters: TR/TE=500/14 ms, receiver bandwidth = ±15.63 kHz, xres=256 and yres=256, slice thickness=2.0 mm and FOV=48.0 cm. Three coronal images of the phantom were acquired with gradient correction disabled. Matlab (Mathworks, Inc.) was used to create surface maps from the calculated error values, to texture-map the warped images to the surface maps, and to correct pixel intensity variations due to voxel size distortion.

Results

One of three uncorrected slices through the grid phantom is shown in Figure 1. The curvature of warped space is displayed in Figure 2 by texture-mapping these warped images to the calculated surface maps. The 3D surfaces were oriented such that the viewpoint was an orthographic projection perpendicular to the slice (Figure 3). After the pixel values were scaled to correct for voxel size distortions, the result was a 2D image equivalent to that determined by conventional correction.

Discussion

A new method of visualizing data to correct for gradient non-linearity has been demonstrated. This is a full 3D correction, an advantage over the three separate 1D corrections conventionally performed today. Combining this correction technique with standard graphics technology (OpenGL, DirectX, etc.) establishes fast and accurate means of representing an object in the physical magnet coordinate system.

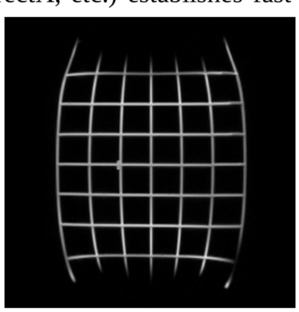

Figure 1

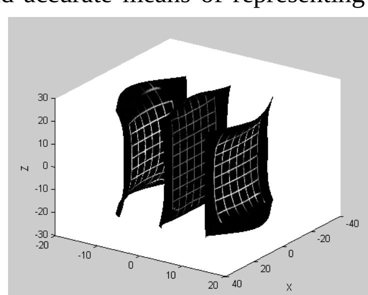

Figure 2

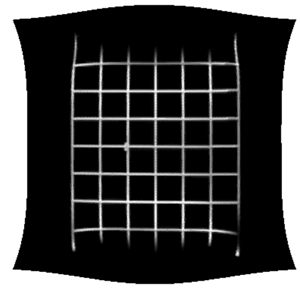

Figure 3

References:

[1] Glover, et al. *Method for Correcting Image Distortion due to Gradient Non-uniformity.* US Patent No. 4,591,789; 1986.