Phantom-based geometric distortion correction for volumetric imaging of Alzheimer's disease

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Synopsis: Structural MRI of the central nervous system is a promising method to diagnose and track the progression of neuro-degenerative diseases such as Alzheimer's disease. Such techniques often require longitudinal measurements on multiple scanners over periods of months to years, with stability of fractions of a percent. We have developed a phantom-based calibration technique to enable MR scanners to meet these stringent requirements. The technique has been successful in phantom experiments and has successfully corrected scaling errors from gradient coil calibration on human subjects. We present also in-progress studies on correcting multi-scanner data.

Background and Significance: Neuronal loss in Alzheimer's disease correlates with global atrophy of the brain [1,2] and regional atrophy in several medial temporal lobe structures [3-5]. Structural MRI of the brain is a promising surrogate marker for use in early diagnosis and disease tracking. To achieve clinical utility, these measurements should be performed with accuracy better than about ½ %. Variation in such measurements can arise from the hardware, analysis algorithms, patient handling/motion, and true biological variability. In this work we seek to reduce the variation due to the hardware to negligible levels.

Hardware-induced variations have been suggested as an important source of error in MR brain volumetric measurements [2]. Longitudinal volumetric studies can span several years; any change in scanner equipment, such as upgrades or new coils, could jeopardize the entire existing set of longitudinal data for a clinical site. It is important, therefore, to have a means of maintaining continuity between different hardware configurations as well as to maintain high stability within a single scanner.

Methods: We have developed a phantom-based calibration protocol. The phantom, shown in figure 1, is a 20-cm sphere filled with distilled water, in which is embedded an array of 171 one-cm diameter spheres filled with copper-sulfate solution. The small spheres appear bright in the MR images and can be localized with subvoxel-accuracy. Geometric distortions in the images cause the apparent positions of these spheres to shift, and from this information a distortion map of the imaging volume is generated. The map is then applied in reverse to the anatomical images to undo the effects of the distortion.

We have tested the technique on phantoms and on human volunteers, both by introducing controlled distortions in the imaging volume by scaling the gradient amplifiers, and by imaging on multiple scanners. Three volunteers were imaged on a single scanner while the gradient amplifiers were scaled to give errors of 2% and 4% relative to a baseline scan. Five volunteers were imaged on three scanners to test the correction of multiple-scanner data. Images were acquired on GE 1.5T scanners using a 3D SPGR sequence with 1.6mm slice thickness and matrix size 256 x 192, with a 22 cm FOV. Relative brain volume measurements were made using a boundary shift integral (BSI) method preceded by either a nine degree of freedom or a six degree of freedom registration procedure. Volume changes were taken as the aggregate of the scaling applied in the registration procedure and the changes measured with the BSI.

Results & Discussion: Figure 2 shows the results of the scaling experiment on three volunteers. The horizontal axis shows the scaling applied along a single axis by adjusting the gradient coil calibration along that axis. The vertical axis of the figure shows the measured volume of the whole brain, relative to the 0% scaling baseline image, in percent. Ideal measurements would show this error to be 2% and 4% at the respective applied scaling levels. The measurements are shown both for the raw data and the corrected data. Raw volume measurements are very close to the applied errors of 2% and 4%. With the correction procedure applied, the errors have been reduced to less than 0.25%, from as large as 4%.

Inter-scanner correction has been applied successfully on phantoms (figure 3) and with moderate benefit so far on human volunteers. Figure 3 shows the results of relative volume measurements of a half-liter spherical phantom on three different GE 1.5T machines. The images were taken using a T1-weighted SPGR sequence and segmented using a threshold-based algorithm. Raw data (red) shows variation up to 1.6%; application of the correction brings the error down to about 0.25% (blue triangles). On human volunteers, the correction scheme has successfully reduced the mean differences between volume measurements on different scanners, though not the variance. The use of the phantom-based correction shows an overall benefit to BSI measurements following either six or nine degree of freedom registration.

Conclusions: The phantom-based calibration technique has demonstrated substantial correction both on phantom and in vivo data. Errors in gradient scaling have been detected and corrected, with errors reduced from 4% to less than 0.25%. Inter-scanner correction has been demonstrated on phantoms to accuracies of 0.25%. In vivo inter-scanner correction has demonstrated benefit, but is an ongoing area of research to bring it to a similar level of performance as correction of phantom images.

References:

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Figure 1: Photo of calibration phantom consisting of 171 small spheres arranged in an array.

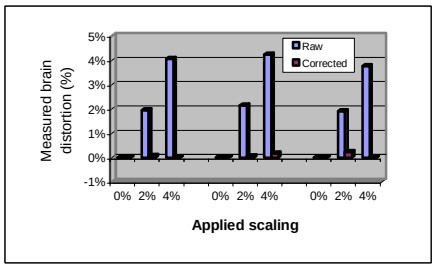

Figure 2: Scaling experiment on human volunteers. Applied volume 'error' is shown on horizontal axis for three volunteers. Measured errors shown on vertical axis for raw, corrected data.

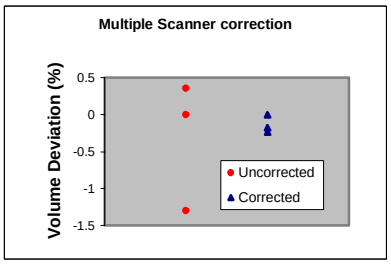

Figure 3: Inter-scanner correction on phantom data. See text for details.