Effects of Gradient Distortion on Low Frequency Current Density Imaging

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Abstract – Low frequency current density imaging (LF-CDI) is a technique that uses MRI to measure volume current density (CD) distributions in tissue. 3D LF-CDI requires registration of three phase image sets corresponding to three orthogonal orientations of a subject. Proper registration is not possible in the presence of non-spherically symmetric distortion as in MRI. Mis-registration causes CD artifacts such as spurious CD values and CD curls. One source of distortion is nonlinear gradient fields. This can be measured and corrected using an appropriate phantom and data processing as is done here for an LF-CDI data set.

Introduction: Low frequency current density imaging (LF-CDI) is a technique that uses MRI to measure volume current density distributions in tissue [1]. Electrical current flowing in tissue creates a magnetic field. The component of this magnetic field, B_J, which is parallel to the main static field of the MRI is encoded into the phase data of an MRI acquisition as in

$$B_J = \frac{\phi}{\gamma T_c} \quad (1)$$

where ϕ is phase, T_c is the duration of an applied square current pulse and γ is gyromagnetic ratio. Current density vectors can be computed from these measurements of magnetic field components by the quasi-static version of Maxwell's equation

$$\mathbf{J} = \frac{1}{\mu_0}\left[\left(\frac{\partial B_z}{\partial y} - \frac{\partial B_y}{\partial z}\right)\mathbf{i} + \left(\frac{\partial B_x}{\partial z} - \frac{\partial B_z}{\partial x}\right)\mathbf{j} + \left(\frac{\partial B_y}{\partial x} - \frac{\partial B_x}{\partial y}\right)\mathbf{k}\right] \quad (2)$$

Equation (2) indicates that measurements of three orthogonal components of magnetic field, B_x, B_y and B_z are required to compute the complete vector field **J**. This requirement implies that three orthogonal orientations of the subject must be acquired. Further, these three data sets must be properly registered with each other in order for the differences indicated in equation (2) to compute correct current density values. Proper voxel-by-voxel registration is not possible in the presence of non-spherically symmetric distortion as is the case in MRI systems. Mis-registered voxels in LF-CDI data processing lead to current density artifacts such as spurious current density values and current density curls [2]. Sources of system-based distortion include nonlinear gradient fields and static field inhomogeneity. Sources of object-based distortion include magnetic susceptibility and chemical shift. System-based distortions can be measured and corrected using an appropriate phantom and data processing [3]. In this abstract, nonlinear gradient distortion is measured and corrected for an LF-CDI data set. The results of this correction and its impact on the results of the LF-CDI experiment are discussed.

Methods: To measure distortion due to nonlinear gradients, an acrylic phantom was constructed that contains a regularly spaced 3D grid of spheres that can be filled with water. The 8 mm diameter spheres were spaced 15 mm center-to-center. Sphere locating and mapping software was created to determine the transformation from the measured (i.e. distorted) space to the actual space. Interpolation was used to complete mapping for points located between the sphere centers. The correction was applied to the phase images used to compute current densities for a 3D LFCDI experiment. The subject of the experiment was 3 kg post-mortem pig with current being applied through standard flexible pediatric-sized defibrillation electrodes located in an anterior-anterior position similar to human external defibrillation procedures.

Results: Distortion corrections for magnitude data has been covered extensively in the literature, however, phase data distortion correction presents some different challenges. Figure 1 shows a phase image from a 3D phase data set that was corrected for gradient distortion. Note the unusual phase transition lines occurring within the range of ±π. LF-CDI data was processed for both data sets with uncorrected gradient distortion, Figure 2(a), and with corrected gradient distortion, Figure 2(b). Note the substantial differences in current flow directions shown by the streamlines.

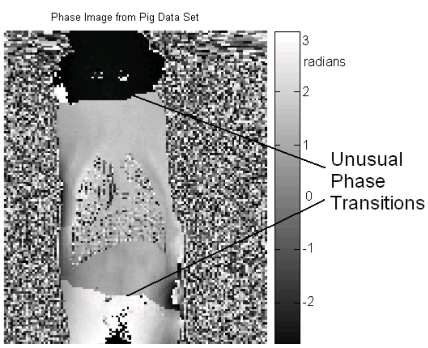

Fig. 1: Phase data corrected for gradient distortion.

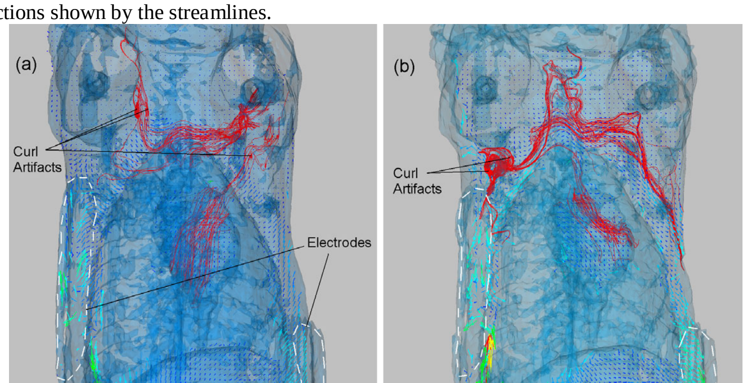

Fig. 2: Pig torso with streamlines representing current density vector field (a) without distortion correction, and (b) with distortion correction.

Discussion: The unusual phase transition lines of Figure 1 occur because the gradient distortion correction involves movement of phase data between different 2D phase planes (i.e. slices) that have no absolute relationship with respect to each other. In fact, this relationship is random and actual phase transitions would have different values if the same experiment were repeated. The effects of these transitions on LF-CDI experimental results are now being studied. A preliminary comparison of LF-CDI experimental results with and without gradient distortion correction is shown in Figures 2(a) and 2(b). The differences are substantial in that groups of streamlines appear to take different courses through the tissue. Some of the current density curl artifacts appear to have vanished after correction while others remain. The remaining curl artifacts are mainly situated close to electrodes where good LF-CDI results are more difficult to achieve.

References

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