Quantitative experimental validation of an analytic model for intensity non-uniformity in MRI

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Introduction
Intensity non-uniformity, the smooth intensity variation often seen in MR images, has been a subject of recent interest as it can significantly degrade the performance of automated tissue classification techniques and other kinds of quantitative image analysis. In this work, we investigate the extent to which the intensity non-uniformity observed can be accounted for by a simple electromagnetic model of the interaction with the subject. Our results, validated experimentally, are shown to be accurate to within 1%-2% RMS, suggesting that by adapting the model to the geometry of a human head, the technique could be used to compensate for this artifact in vivo.

Methods and Results
Analytic solutions derived from first principles for the excitation field and reception sensitivity present when imaging using 1.5 T magnets and circularly polarized RF coils have been given for the cases of circular [2] and elliptic [3] cylinders. The latter is of interest since an elliptic cylinder with dimensions similar to that of a human head produces an asymmetric field pattern. We used these solutions to produce simulated spin echo images with various properties that we then compared to real images of an MR phantom.

Local variations in the direction of the rotating excitation field, which result in phase shifts, require careful attention when modelling intensity non-uniformity for asymmetric objects. While phase shifts during excitation which are inherent in the geometry of the coil are canceled by corresponding phase shifts during reception, phase shifts due to induced currents and dielectric resonance are not. This asymmetry means:

- excitation and reception field patterns are independent
- MRI images do not in general have uniform phase.

The formation of a spin echo image by combining the excitation and reception fields, taking into account their phase, is shown in the following figure. The cylinder has conductivity 252 m, relative permittivity 80, and major and minor diameters of 20 cm and 15 cm respectively.

We constructed two plastic cylindrical containers with elliptic and circular cross sections respectively to validate our model of intensity non-uniformity. Each cylinder was filled with water and various concentrations of NaCl, to produce solutions with conductivity similar to that of biological tissues at 64 MHz [1]. For our experiments, the cylinders were aligned axially with the isocenter of the body coil of a 1.5 T Siemens Vision MRI scanner and scanned transversally using a $B_1$ field mapping sequence [4] as well as a standard spin echo sequence.

Discussion and Conclusions
Our investigation revealed some counterintuitive aspects of intensity non-uniformity:

- measuring the $B_1$ magnetic fields in the absence of an object will substantially underestimate non-uniformity within an object
- an object having left-right symmetry may not have a symmetric pattern of intensity variation
- measuring the excitation field alone is not sufficient to predict image intensity variations

In conclusion, we found electrodynamic interaction with the object to be the primary cause of intensity non-uniformity, and that the magnitude of the artifact depends on the pulse sequence, the shape of the object, as well its resistive and permittive properties.

References