Self-Referenced Flip Angle Mapping for Hyperpolarized Gas MRI

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Introduction

Hyperpolarized noble gas imaging is a novel form of non-equilibrium imaging where the gas magnetization is slowly depleted both by RF excitation and a reduced T1 due to the presence of paramagnetic oxygen. When imaging is performed with constant flip angle excitations, artifacts are observed. To compensate for the decaying magnetization, Zhao et al. described a variable increasing flip angle method to reduce these artifacts. [1] An additional source of artifacts are B1 field inhomogeneities. To obtain a B1 Flip Angle (FA) map, researchers typically perform an additional scan. Two consecutive images are acquired, I1(x,y) and I2(x,y), with N phase encodes for both imaging and estimation of a local FA map. These methods may not obviate the need for faster sequence design and the use of parallel coils for hyperpolarized gas imaging, but these methods obviate a separate scan for determining the FA map.

The FA error maps for the part of k-space that is undersampled on each component acquisition, is estimated by interpolation from neighboring k-space data. The ratio of the voxel intensities from the serial images is then used in Equation 1. More importantly, these two components can also be recombined to yield a fully sampled image.

Methods

The method we propose is to split up the acquisition of k-space into two serially acquired components. To obtain a FA map, the part of k-space that is undersampled on each component acquisition, is estimated by interpolation from neighboring k-space data. The ratio of the voxel intensities from the serial images is then used in Equation 1. More importantly, these two components can also be recombined to yield a fully sampled image. A Numerical Lung Phantom (NLP) was constructed (see Figure 1). The B1 field profile was modeled using the equation:

\[ B_1(r) = \exp(-r^2/(2\alpha^2)) \]

where \( \alpha \) is a falloff coefficient for the RF field and \( r \) is the radial distance from the center of the coil. This numerical phantom is displayed in Figure 1b. To simulate data acquisition, a set of ideal images is created using the expression:

\[ I(x,y,i) = NLPI(x,y)\sin(\alpha_y \cdot B_1(x,y))\cos^{-1}(\alpha_x \cdot B_1(x,y)) \]

where \( \alpha_0 \) is the maximum flip angle and \( i \) denotes the image number within a set. Each image then is Radon or Fourier transformed into k-space and one column from the transformed image matrix is written to an acquisition matrix.

Results

To approximate the field profiles, Figure 2 shows two different acquisition methods: Cartesian and radial gradient recalled echo sequences. The radial method uses an interleaved acquisition which effectively breaks up one image into two interleaved undersampled images while the Cartesian method uses two half Fourier images.

Discussion

We have demonstrated through our simulations that it is possible to split up the acquisition of k-space into two parts to obtain both a FA map and a fully sampled image. Theoretically, this technique works because the B1 field profile is homogeneous and varies slowly over the sample of interest. Therefore, most of the information for determining FA maps is located in the central portion of k-space. Therefore, by breaking up the acquisition, k-space is acquired in an efficient manner that allows both imaging and estimation of a local FA map. These methods may not obviate the need for faster sequence design and the use of parallel coils for hyperpolarized gas imaging, but these methods obviate a separate scan for determining the FA map.

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References