Inverse MRI: Imaging a Freely Rotating Object

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Introduction

In traditional MR acquisitions, k-space is sampled in a pre-determined fashion e.g: raster, radial or spiral, with each measurement placed in a pre-allocated part of k-space. By analogy with the radar technique inverse synthetic aperture radar (ISAR)\(^1\), it is possible to reconstruct an image of an object moving in an unknown way, by estimating the position of the object for each measurement. Rotation of the object rotates the k-space position of the associated measurement, so by determining the motion of the object, each measurement can be correctly placed in k-space, and the resulting non-uniformly sampled k-space can be reconstructed. The novelty of this approach is that unknown object motion is seen as an aid rather than a hindrance to image acquisition. A potential advantage is that a small, cheap MR scanner could be built without phase-encoding gradients. By analogy with inverse SAR, we call this technique inverse MRI. In this proof-of-concept paper, we demonstrate that non-uniform rotational motion of an object can be used to reconstruct images, using conventional slice select and readout gradients, but no phase-encoding.

Methods

Images were acquired using a conventional 1.5T MR scanner (Philips Gyroscan ACS2), using a 256 line dual echo spin-echo acquisition TR=800ms,TE\(_1=11\)ms, TE\(_2=200\)ms with the phase encode gradient turned off. The object was attached to a specially designed rig that fixed the center of rotation, and was rotated by a minimum of 180° free-hand (ie: with variable angular velocity). A 5mm diameter marker containing 0.5mM GdDTPA was attached to the rig. Due to choice of echo times, only the marker had high intensity in the second echo.

Using software written in Matlab, each echo underwent a 1D Fourier transform to generate a space-time hybrid space. The marker was automatically tracked in the second echo hybrid space also known as a sinogram (Figure 1), as the path of the marker is an approximation to a sinusoid. To calculate the center of rotation of the object the half way point between the maximum and minimum displacement of the marker path is found. The angle of acquisition at each point is found from the inverse cosine of the ratio of the displacement at that point to the maximum displacement from the centre.

Two methods of reconstruction were used, in the first, hybrid space was interpolated in the time direction to give uniform angular sampling, and an image reconstructed by filtered backprojection. In the second the data were regridded onto a regular Cartesian grid before Fourier transforming in two dimensions.

The backprojection method uses modulus data and therefore phase issues are not a concern. In the regridding method complex data are used and it is important to ensure all sources of phase error have been removed. This includes field of view offsets as these are applied in the form of phase shifts across the k-space data.

![Figure 1: Sinogram (space direction is horizontal).](image1)

Results

Figure 2 shows the images obtained after reconstructing a transverse slice through the hand (the top three images were obtained from the same scan). The top image shows reconstruction assuming equal angular spacing of the projections and uses regridding; this is severely affected by ghosting to the extent that the marker is not distinguishable. The second image is reconstructed using filtered backprojection and the angles calculated as described above; there is some streaking and blurring artifact. The third image uses the same angles to regrid the data and whilst there is some streaking the image contrast is good. The bottom image was obtained using a conventional imaging sequence of a still hand with a phase-encoding gradient, this is the gold standard and is shown for comparison.

![Figure 2: Hand images from top, equal angular spacing (regridded), backprojected, regridded, conventional image.](image2)

Discussion

In this proof-of-concept paper we show that quality images can be obtained using non-uniform object motion rather than phase-encoding to sample k-space. There is potential to simplify and reduce the cost of making scanners using the free rotation of an object; angular velocity does not need to be constant. The method is suitable for any object that can be rotated through a minimum of 180°. One application is joint imaging in the hand. The method could also be used for objects that are imaged using conventional phase-encoding techniques but suffer from rotational motion during the acquisition e.g cardiac imaging. The ideas described here could provide greater k-space data to aid in the production of images without motion artifact.

Regridded images show better image quality than backprojected images as they do not suffer from streaking artifact. Some of the artifact in these images may be a result of in-plane motion of the hand in addition to rotation. Future work will include using autofocus techniques\(^2\) to enable image reconstruction without the need for a marker. This may be achieved by iteratively improving the image quality using the images reconstructed assuming equal angular spacing (top image, Figure 2) as a starting point. Disgarding the marker would enable the technique to be used on all imaging sequences and in situations where a marker is not practical.

In summary this work demonstrates that hand images can be obtained without the use of phase-encoding gradients by using non-uniform object motion.

References
