Keyhole-SPRITE: A Method for Resolution Enhancement of Multiple-Point SPRITE Data

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Abstract

The multiple point SPRITE (m-SPRITE) sequence suffers from reduced spatial resolution in the images resulting from the first few points. We present a new keyhole-SPRITE algorithm for spatial resolution enhancement which functions by taking higher spatial frequencies from the latter k-spaces, in an iterative manner, and introducing them into the k-spaces resulting from the earlier points.

Introduction

The inefficient data acquisition scheme of SPI sequences such as SPRITE [1] was recently overcome by the acquisition of multiple data points following each RF excitation [2,3]. Since data acquisition is performed in the presence of active phase encode gradients, each of the data points can be used separately to form independent, and different, k-spaces with correspondingly different FOVs (Figure 1). Therefore, the resolution of each reconstructed image is a function of the time at which each point was acquired. In an earlier work by O. Heid [4] the chirp z-transform [5] was proposed as reconstruction algorithm allowing for FOV scaling of the images to a defined size. The effect of the chirp-z transform, however, is limited to the image rescaling; the resolution of images is unaltered. In this paper we present a method for multiple-point SPRITE which allows for resolution enhancement of the earlier images, where higher spatial frequencies are necessarily neglected, by making appropriate use of the resolution information coming from the later images.

Methods

We have developed an algorithm for enhancing the resolution of each image by making use of the outer parts of k-space from subsequent images. The algorithm is as follows:

1. Chirp z-transformation for reconstruction of the images to a common FOV (results presented in Figure 3).
2. FFT of the images to recalculate k-spaces of identical dimension and sampling density (schematic in top row of Figure 2).
3. Cut out the relevant data of the acquired k-spaces (schematic in top row of Figure 2).
4. Cut out frames of relevant data which extend the preceding data (second row of Figure 2).
5. Extend each data set of step 3 with the succeeding frames of step 4 to composite k-spaces (bottom row of Figure 2).
6. Reconstruct the final images with the inverse FFT (results presented in Figure 4).

The whole reconstruction algorithm was programmed in IDL 6.0 running under MAC OS X. m-SPRITE data from a proton resolution phantom were acquired using a TEM head coil on a VARIAN Unity INOVA 4 Tesla whole-body scanner equipped with a 40mT/m Siemens Sonata gradient system.. The repetition time for the phase encoding steps was set to TR=2ms and 97 multiple points were acquired in the time interval 0.2-0.8ms following the excitation with a dwell time of 6.25µs. The resolution FOV scaling was 4:1. The matrix size was 64×64×32 and the FOV was set to 256×256×256mm for the last acquired datum. A broad band RF pulse of 6.25µs pulse length and a low flip angle of 2° was chosen to excite the whole FOV for the highest gradient. The filter bandwidth was set accordingly to 80kHz.

Results

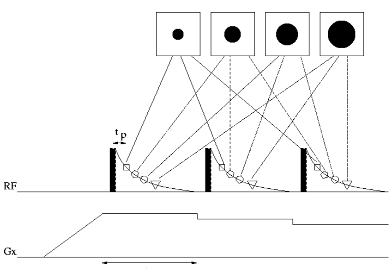

Figure 1: m-SPRITE acquisition scheme. Each multiple point belongs to a different k-space and a different FOV in image space.

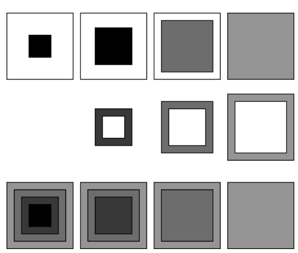

Figure 2:Schematic of keyhole algorithm:
1.row: acquired k-spaces.
2.row: frames of extended k-spaces.
3.row: composite k-spaces

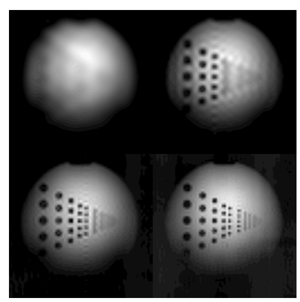

Figure 3: chirp z-transformed images

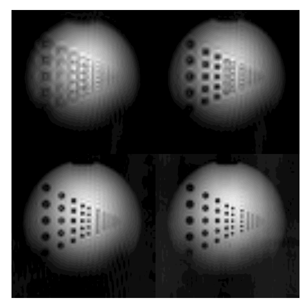

Figure 4: keyhole algorithm reconstructed images

Figure 3 shows the images reconstructed to a common FOV using the Chirp z-transform. The scaling factors are from the upper left to the lower right 4:1, 2:1, 1.33:1 and 1:1. The same images after application of the keyhole algorithm are shown in Figure 4. The effect of resolution enhancement is clearly visible. Ringing artefacts are reduced and blurred structures appear with higher contrast. At too high a scaling factor of 4:1 the precision of the method is diminished.

Conclusions

We demonstrated that the new method does indeed enhance the resolution of m-SPRITE images without requiring the acquisition of additional information. The effect of the algorithm on the resulting resolution increases with the scaling factor but introduces new artefacts when the scaling factor is too high. However, the keyhole-SPRITE method increase the tolerable scaling factor which was limited to 1.25:1 in recent publications [2]. The extension to scaling factors of 2:1 allows acquisition of more data for signal averaging or T_2^*-mapping.

References

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