High resolution MRI from 2D and 3D superresolution applied to single-shot images

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Introduction

In MRI, high spatial resolution is usually achieved by multi-shot acquisition of data, i.e., data collected after multiple RF excitations contribute to each image. If higher resolution is wished for, a larger area of "k-space" (Fourier transform of image space) is acquired - this usually means more RF excitations, or "segments". Diffusion weighted imaging (DWI) and diffusion tensor imaging (DTI) are incompatible with such simple segmented k-space approaches due to the large phase variations resulting from even minimal physiological motion due to the application of the large field gradients necessary for diffusion weighting. The higher the spatial resolution of diffusion tensor imaging data, the more relevant the endeavor of 3D fiber tract tracking in white matter will become and the more robust the algorithms for doing so will be.

We have proposed and implemented the new technique of superresolution diffusion imaging [1], and extended it to 3D. The technique relies on the following two steps:
1. the acquisition of a plurality of single-shot diffusion weighted images, each image being shifted in space with respect to the other images;
2. the use of superresolution post-processing methods in order to combine the sub-pixel information contained in each of the shifted images.

The term superresolution refers to image processing methods that increase spatial resolution by pooling information from a number of images. The original low resolution images may be translated, blurred, rotated or scaled. Supersolution techniques have been used, for example, for reconstructing an image from a few frames of a movie or from pictures taken by a moving satellite.

The extension of the above method to 3D MRI is motivated by the following arguments:
1. In MRI there is a lower limit on slice thickness which is dependent on the RF pulse length and the field gradient strength. With 3D superresolution we can effectively lower this limit.
2. In MRI, the in-plane resolution is almost always better than the resolution in the slice direction. For purposes of 3D fiber tracking using diffusion tensor data, isotropic resolution is the goal.
3. Unlike separate processing of 2D slices, 3D processing leads to "coherence" between slices.
4. 3D super-resolution gives us the flexibility to determine the trade-off that we would like between the high SNR of the thick slices, and the high anatomical accuracy of thin slices.

Methods

Single-shot echo planar imaging (EPI) was used with in-plane resolution of 2mm and slice thickness of 3mm. Diffusion tensor data were acquired from the human brain with a b-value of 1000 s/mm². Eight shifted images were acquired for each gradient direction, with 4 shifts of 0.25 pixel in the phase-encode direction, and 2 shifts of half a pixel in the read-out direction. For the 3D example of the phantom (Figures 1,2), no diffusion weighting was used. There were eight shifts consisting of half a voxel in all 3 directions. Each voxel of the high-resolution image is "covered" spatially by all 8 low-resolution voxels.

The iterative back-projection method of Irani-Peleg [2] was used for combining the image data. This method is based on the minimization of differences between the original low resolution images, and the low resolution images that can be generated (back-projected) from down-sampling the current best guess of the high resolution image. The superresolution algorithm terminates once the error difference between sequential iterations is below a predefined threshold. To show anisotropy indices and principal eigenvectors, the superresolution algorithm was first applied separately to the images acquired for each gradient direction.

Results

All diffusion weighted data improved significantly from the superresolution process. Significantly more detail was apparent in the diffusion-weighted images themselves, in the anisotropy maps calculated from diffusion tensor imaging, and in the vector representations of the fiber tract directions.

We present below the first 3D application of the technique. Figure 1 shows an original EPI 64x64 resolution image of a pomegranite with a slice thickness of 3 mm, interpolated to 128x128. The end result of the 3D superresolution method is shown in Figure 2. In the case of a static phantom such as this, multi-shot imaging does work well, but nevertheless this example shows the potential of the technique.

Discussion

The 2D and 3D superresolution techniques provide high resolution data from the combination of multiple shifted single-shot images. Diffusion tensor data, for example, has been much improved using this method. Quantification of resolution improvement, and comparisons of SNR are underway.

References