Super-Resolution MRI Reconstruction in Image, Frequency, and Wavelet Domains

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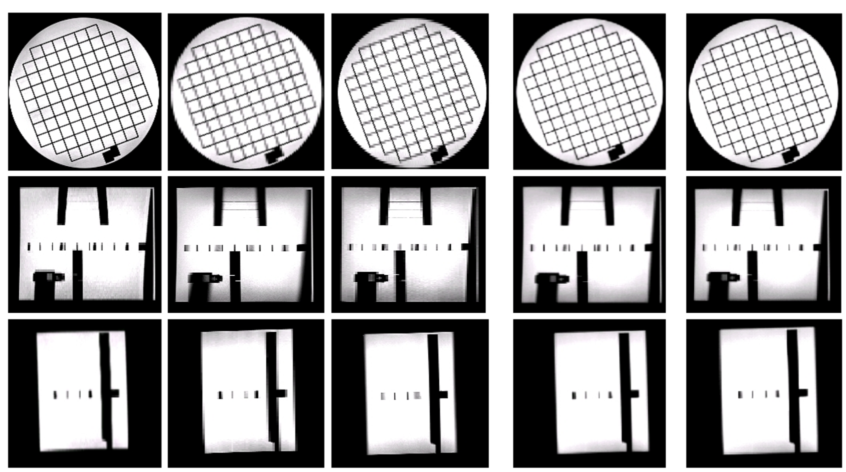
Purpose

The purpose of this educational multimedia poster is to provide an in-depth review of the concept of super-resolution in magnetic resonance imaging with formulations and interpretations in image space, k-space, and wavelet domain. Super-resolution image reconstruction has been conventionally defined in the image processing literature as the process of producing a high-resolution image from multiple low-resolution images. Super-resolution reconstruction relies on the additive information that the low-resolution images provide with their distinct sampling of the imaged scene or imaged object. This can be obtained in digital imaging through shifted sampling. Magnetic resonance imaging (MRI), however, intrinsically collects samples in the frequency domain (k-space); and since Fourier encoding excludes aliasing in frequency and phase encoding directions, distinct sampling of the image space is not readily obtained in true 3D MRI.[1] Nevertheless, distinct sampling of the image space is obtained in 2D MRI, where 2D Fourier encoding is employed. Two-dimensional MRI slice acquisitions are widely used in applications when sampling time is limited to prevent subject motion (e.g. in fast snapshot imaging) or when the desired image contrast yields long repetition times that are not effectively achieved by 3D Fourier encoding. Fast spin echo T2-weighted MRI is an exemplary application, in which high in-plane spatial resolution (in the order of 0.4 mm) is achieved with 2D Fourier encoding, whereas the resolution in the slice select direction is about 3 to 4 times lower (i.e. 1-2 mm). Super-resolution in MRI, thus, has largely focused on the reconstruction of isotropic high-resolution scans from multiple anisotropic thick slice scans, and has shown great benefits in motion-robust MRI, fetal MRI, DW-MRI, T2w MRI, and cardiac MRI among others.

Super-resolution MRI techniques can be considered in three main categories: image-based reconstruction, k-space reconstruction, and wavelet fusion. The majority of the work has focused on reconstruction from multiple orthogonal scans or based on the rotation of slice select direction.[1,2] Also it is normally assumed that there is no motion between scans so super-resolution is obtained under ideal slice acquisition conditions; however, it has also been shown that image-based techniques may be used with slice motion correction to achieve motion-robust super-resolution MRI.[3] These techniques have been particularly useful in T2w MRI of the fetus.[3,4] Two critical aspects of the image-based reconstruction methods are the slice profile in the forward model of slice acquisition, and the image prior in maximum a posteriori (MAP) estimation.[5] The ideal slice profile is a box-car function which is modeled through Haar wavelet bases in wavelet fusion.[6] The slice profile, point spread function (PSF) in slice select direction, and the image priors have significant impact on the performance of super-resolution reconstruction techniques. Experiments have been carried out to evaluate the effect of these parameters and different methods have been compared. Figure 1 shows an example of reconstruction using wavelet fusion and the image-based super-resolution reconstruction method.

Outline of Content

1. Introduction: Super-resolution MRI
2. Methods:
    a. K-space reconstruction
    b. Wavelet fusion
    c. Image-based super-resolution
    d. Motion-robust super-resolution reconstruction
3. Discussion:
    a. Slice profile and PSF
    b. Image priors in MAP estimation
    c. Resolution, SNR, & acquisition time
4. Conclusion



(a) (b) (c) (d) (e)

Fig. 1: Super-resolution reconstruction of the ACR phantom from three orthogonal scans; (a)-(c): axial, coronal, and sagittal scans of the ACR phantom (1x1x3mm resolution), (d) image obtained from wavelet fusion (1mm isotropic resolution), and (e) image obtained from image-based super-resolution reconstruction.

Summary

Super-resolution MRI can be achieved through reconstruction techniques in image, frequency, or wavelet domain, that combine the distinct sampling information obtained from multiple low-resolution 2D scans and generate an image with an isotropic high spatial resolution.

References

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