Progressive Dual-Kriging for 2D and 3D qMRI data interpolation

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Introduction

In many in vivo MRI acquisitions, the image resolution is low and induces considerable segmentation errors with a poor and limited visual interpretation. Acquiring high resolution images reduces the patient comfort and results in considerable cost due to an increase of the acquisition time. Shape-based interpolation techniques are used to increase the apparent spatial resolution of MR images, but they do not improve the acquired spatial resolution. A commonly used technique is the zero padding, which has the advantage of being robust, fast and easy, but suffers from the Gibbs ringing artifact. Several interpolation techniques such as the nearest-neighbour, the bilinear or the bicubic interpolation suffer from their accuracy and to the lack of flexibility. We present here a new multidimensional Kriging technique to interpolate 2D and 3D MR data. The objectives were (1) to validate Kriging in MR images interpolation, and (2) to adapt Kriging to 3D diffusion anisotropy reconstruction.

Methods

We performed two quantitative MR acquisitions on a bovine tail segment including intervertebral discs from the 2nd to the 4th caudal vertebrae with two different spatial resolutions using a Philips SENSE Head 8-elements coil in a Philips Achieva X 3.0T MR system. The relaxation times were determined by using a multiple inversion-recovery turbo spin-echo sequence for T1 and a spin-echo sequence with multiple echo times for T2. The MT images were obtained using a gradient echo sequence with and without a magnetization transfer saturation pulse. The diffusion tensor was extracted from a spin-echo EPI diffusion-weighted sequence, with 15 non-collinear diffusion encoding directions. The same MR sequences were used in both acquisitions where only the acquired matrix size was increased from 128x128 to 256x256 for the T1, T2 and MTR sequences and from 64x64 to 128x128 for the diffusion sequence. T1, T2 and ADC were extracted from the signal intensity by non-linear regressions to their respective signal expressions. We adopted the Dual-Kriging formulation and we introduced the technique of progressive Kriging, which consists in Kriging the given Cartesian data region-by-region. Kriging parameters were optimized to minimize the relative errors. For each MR sequence, Kriging was compared to other interpolation techniques in term of signal mean within the ROI including the zero padding, the nearest neighbour, the bilinear and the bicubic techniques. The ROI was centered within the Nucleus Pulposus because of the signal distribution being hyper-intense and thus most sensitive to partial volume artifact and signal changes during interpolation. To adapt the Kriging technique to 3D diffusion anisotropy reconstruction, we interpolated each of the directional (x,y and z) maps following a spatial calibration of the data.

Results

When comparing the signal mean within the ROI, Kriging and Zero Padding has shown slightly better results when compared to the Nearest neighbour, the Bilinear or the Bicubic interpolation techniques (Fig. 1). Kriging system provided relatively high performance and low error within the regions of interest. Components contours tend to be corrected and better defined, following the Kriging interpolation as opposed to other interpolation techniques. By interpolating the 3D diffusion anisotropy, visual analysis seems to become much easier and imply less images treatment prior to analyse the data as we augmented the tensors density. However, the slices had to be close enough to each other to permit decent interpolation between adjacent slices.

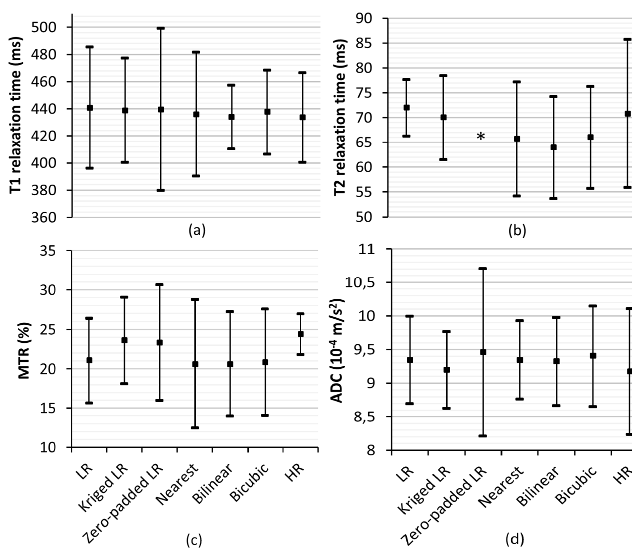

Fig. 1. T1 (a) and T2 (b) relaxation times (ms), MTR (c) and ADC (d) mean within the ROI. *.Gibbs ringing artefact was encountered in the zero-padded T2 maps due to the post-fitting noise.

Discussion

Progressive Dual-Kriging is a flexible technique that can be optimized to interpolate 2D and 3D qMRI data based on the signal distribution. The computation is relatively fast and the interpolation is better fitted to the signal distribution as opposed to the more common zero padding technique. Kriging technique has shown relatively good results when compared to the other techniques. It provides an artefact-free interpolation that can be used qualitatively or quantitatively. Kriging technique may be implemented in real-time applications for robust and stable images enhancement. In this study, Kriging technique was successfully adapted to other applications such as diffusion tensors reconstruction. As a further step, a variographic study may be required to allow pixel-by-pixel analysis.

References

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