PROPELLER Reconstruction Using Discrete Fourier Interpolation

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Introduction

Non-Cartesian data collection for PROPELLER MRI [1] requires advanced image reconstruction techniques such as fast gridding algorithms [2]. On the other hand, PROPELLER data are sampled on rotated Cartesian grids, which might open the way for much simpler reconstruction approaches. For instance, it is well known that Cartesian data may be rotated efficiently using the discrete sinc-interpolation [3,4]. In the present study, the applicability and performance of this approach was investigated for PROPELLER image reconstruction.

Methods

Theory: Rotation of Cartesian data by sinc-interpolation may be performed with a 2D chirp-z transform [3] or by shear operations [4]. Both approaches are comparable and show a similar computational complexity. The general scheme of the latter approach, which was employed in the present study, is depicted in Fig.1. An in-plane rotation may be decomposed into three successive shear operations about the *X*-, *Y*- and *X*-axis, respectively. Each shear operation results in a non-integer translation of each row or column, respectively. Such a translation can be performed precisely in the Fourier domain by applying appropriate linear phase shifts. Therefore, the rotation of a square $N_x \times N_x$ image requires $6N_x$ discrete Fourier transforms of size N_x and $3N_x \times N_x$ additional phase multiplications, which results in an overall complexity of $O(N)$, where N denotes the number of pixels.

Implementation: The rotation algorithm has been implemented in C using a processor-optimized FFT-library [5] and was used for PROPELLER image reconstruction. After sampling density correction [6], all blades were rotated to a common k-space grid and added to allow a Cartesian image reconstruction. This resulted in an overall computational complexity of $O(N \cdot B)$, where B denotes the number of blades.

Experiments and Simulations: High-resolution PROPELLER phantom data sets where acquired on a clinical scanner (Philips Achieva, 1.5 T) using TSE-and TFE-sequences (512 samples $\times$ 30 profiles $\times$ 25 blades, (256mm)² FOV). Additional datasets of same size were synthesized analytically using the Shepp-Logan phantom [7]. The data were reconstructed offline onto a 512² image matrix, using a 2GHz Pentium computer. For the experimental data, a phase correction as described in [1] was performed to account for potential shifts in k-space as a result of gradient imperfections.

$$\begin{pmatrix} \cos(\varphi) & -\sin(\varphi) \\ \sin(\varphi) & \cos(\varphi) \end{pmatrix} = \begin{pmatrix} 1 & -\tan(\varphi/2) \\ 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 \\ \sin(\varphi) & 1 \end{pmatrix} \times \begin{pmatrix} 1 & -\tan(\varphi/2) \\ 0 & 1 \end{pmatrix}$$

$$F_x\left\{F_x^{-1}\{M(\mathbf{k})\}e^{(i2\pi c_1 x k_y)}\right\} \quad F_y\left\{F_y^{-1}\{M(\mathbf{k})\}e^{(i2\pi c_2 y k_x)}\right\} \quad F_x\left\{F_x^{-1}\{M(\mathbf{k})\}e^{(i2\pi c_1 x k_y)}\right\}$$

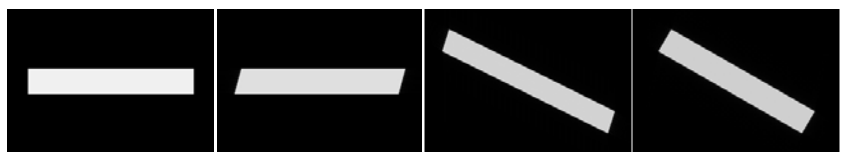

Figure 1: Interpolation on rotated grid. Decomposition of rotation into three successive shear operations is shown (top row: rotation and shear matrices, middle row: corresponding Fourier interpolation, bottom row: Propeller blade example). For clarity, the shear terms $-\tan(\phi)$ and $\sin(\phi)$ were abbreviated as c_1 and c_2, respectively.

Results and Discussion

The reconstruction time was 2s for the 512² images. The images from both measured and simulated data showed very good image quality without significant reconstruction artifacts. A potential, but in practice less relevant drawback of the proposed approach is that the computation time increases linearly with the number of blades, which becomes unfavorable for a large number of blades. This is due to the fact, that each rotation is performed on a square matrix as a result of the long-range sinc-interpolation kernel. If a different interpolation kernel was used (by convolving each blade with a e.g. Kaiser-Bessel filter), the Fourier interpolation could be restricted to smaller segments, thus resulting in an improved computational performance.

In conclusion, the proposed approach represents a simple, fast and powerful alternative to gridding-based convolution techniques for PROPELLER image reconstruction. The approach will suffer from increasing computation time only in case of an extremely large number of blades.

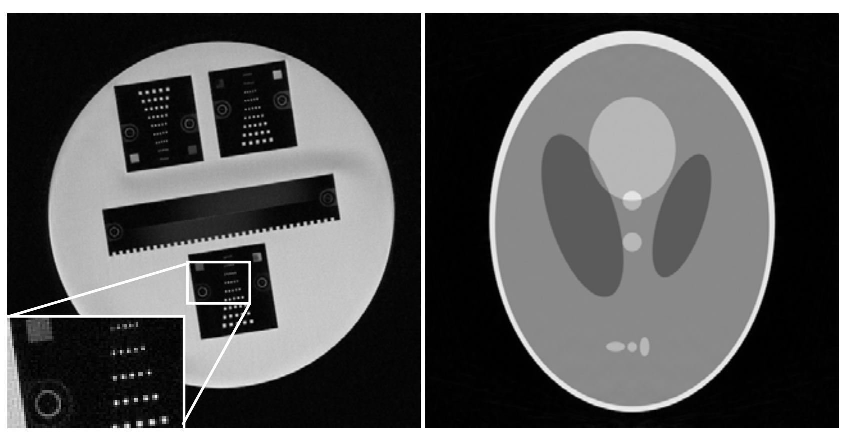

Figure 2: Reconstructed images. Two PROPELLER image are shown, reconstructed from measured (left) and simulated (right) phantom data. The resolution section of the employed quality phantom was magnified (inset, left) to emphasize the achieved resolution.

References

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