BLIND RETROSPECTIVE MOTION CORRECTION OF MR IMAGES

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Introduction

Patient motion is one of the most challenging problems in MRI. A few millimeters/degrees of translation/rotation can cause strong degradations of the image, ruin morphological details and render subsequent medical analysis meaningless. Prospective correction schemes detect motion by tracking cameras [1] or additional navigator data [2] and keep the image-plane at a fixed orientation relative to the patient's head. Retrospective techniques – as ours – remove artifacts after the acquisition of the image data [3,4].

Method

We focus on Cartesian trajectories and assume a rigid subject and no motion during the acquisition of a single k-space line. We ignore second order effects like motion induced changes of the magnetic field. During the scan, K=$n_y \cdot n_z$ k-space lines are acquired, where each line has six free motion parameters (translation+rotation). We estimate the 6·K free motion parameters from the measurements and use them to reconstruct the sharp image.

Let **F** be the orthonormal N by N Fourier matrix, **u** denote the unknown sharp image of size N=$n_x \cdot n_y \cdot n_z$ and **m** be a binary mask used to switch off all but N/K pixels belonging to a k-space line. Further, **A** is a general rigid motion transformation matrix depending on the 6·K motion parameters θ, and **B** is the Fourier equivalent of **A** such that **FA**=**BF**. We use a Gaussian noise model $\varepsilon \sim N(0, \sigma^2 \mathbf{I})$:

$$\boldsymbol{y} = \sum_{k=1}^{K} diag\ (\boldsymbol{m}_k) \boldsymbol{B}_{\Theta_k} \boldsymbol{F} \boldsymbol{u} + \varepsilon \in \boldsymbol{C}^N, \qquad \boldsymbol{1} = \sum_{k=1}^{K} \boldsymbol{m}_k, \quad (1)$$

$$\boldsymbol{y} = \boldsymbol{B}_\Theta \boldsymbol{F} \boldsymbol{u} + \varepsilon \in \boldsymbol{C}^N, \boldsymbol{B}_\Theta := \begin{bmatrix} \left[\boldsymbol{B}_{\Theta_1}\right]_{\boldsymbol{m}_1} \\ \vdots \\ \left[\boldsymbol{B}_{\Theta_K}\right]_{\boldsymbol{m}_K} \end{bmatrix} \in \boldsymbol{C}^{N \times N} \ (2)$$

$$\alpha = \arg\min_{\Theta} \left(\left| \boldsymbol{G}_x \boldsymbol{F}^T \boldsymbol{B}_\Theta \boldsymbol{y} \right|_1 + \left| \boldsymbol{G}_y \boldsymbol{F}^T \boldsymbol{B}_\Theta \boldsymbol{y} \right|_1 \right), \boldsymbol{u} := \boldsymbol{F}^T \boldsymbol{B}_\alpha \boldsymbol{y} \ (3)$$

B can be decomposed into K blocks of size N/K each, and a multiplication with **B** costs O(N). Each of the K blocks of **B** does a multiplication with a linear phase ramp (translation), and a resampling over the rotated grids in Fourier space. Using our objective Eq. 3, we seek the motion parameters θ, such that spatial image gradients become sparse (sharp **u**). From these motion parameters we invert the motion and recover the sharp image **u**.

Strictly speaking, the degradations we consider are not invertible: Due to rotations there can be regions in k-space with missing information. For now, we neglect these effects and note that for small rotations only the highest frequencies with little signal intensity are affected. We avoid local minima of our highly nonlinear objective by using a multi-scale coarse-to-fine approach. We note that in DC-centered k-space cubes containing low frequencies only, even strong motion will produce little offsets in the spatial domain. Growing the cubes in coarse-to-fine manner, it is possible to obtain good initializations for subsequent scale iterations, and thus to avoid running into local minima. We use the L-BFGS nonlinear optimizer with 40 iterations for each scale. Note that a gradient of Eq. 3 is as expensive as a plain evaluation. The computational bottleneck are the Fast Fourier transforms costing O(N log N).

Results

We acquired 2D TSE images and 3D FLASH/MPRAGE volumes of the human head as a relatively rigid target. Results are shown in Figures 1 and 2. Major quality improvements are possible in the 2D case and substantial improvement in the 3D case. Resampling on a rotated grid was done on a GPU. On a 2.66 GHz PC with nVIdia GT 430, the recovery of a 128·128·128 volume takes 10 minutes.

Conclusion

We propose a new retrospective method for which no tracking devices or specialized sequences are required. We improve the image quality of TSE, FLASH, and MPRAGE sequences. We are currently developing the adaptation of the algorithm to tolerate non-rigid motion.

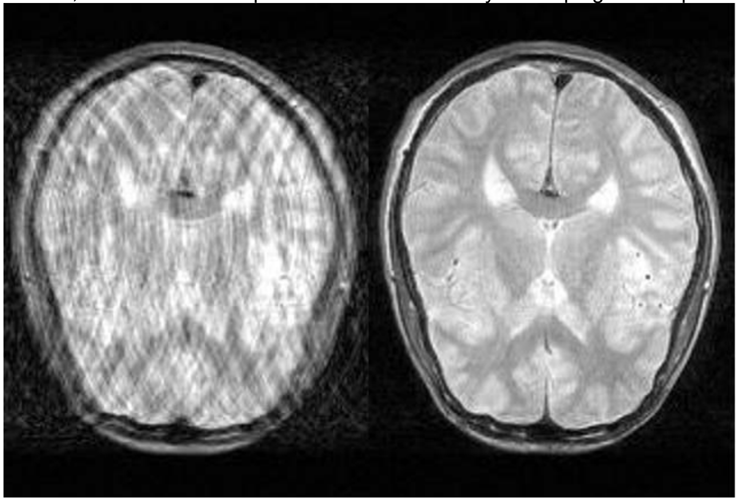

Fig. 1: TSE, left – degraded, right - restored with our algorithm.

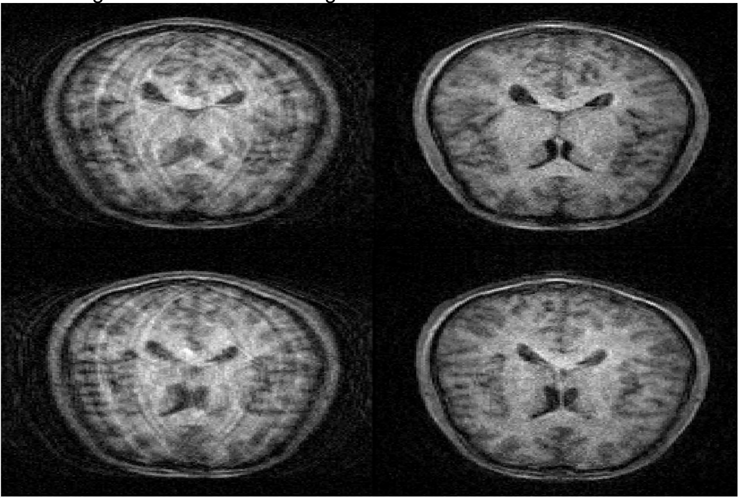

Fig. 2: MPRAGE, left – slices from degraded volume, right - restoration.

References

[1] M. Zaitsev, C. Dold, G. Sakas, J. Hennig, and O. Speck. Neuroimage, 31(3):1038-1050, 2006.
[2] A. Costa, D. Petrie, Y. Yen, and M. Drangova. MRM, 53(1):150-158, 2005.
[3] P. Kochunov, J. L. Lancaster, D. C. Glahn, D. Purdy, A. R. Laird, F. Gao, and P. Fox. Human Brain Mapping, 27:957-962, 2006.
[4] K. O. Johnson, R. K. Robison, and J. G. Pipe. IEEE Transactions on Medical Imaging, 30(3):655-665, 2011.