Robust and Fast Evaluation of Orbital Navigator Data for Rigid Body Motion Estimation

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Introduction

Motion during image acquisition can cause serious image artifacts. To overcome this problem the use of navigator signals ([1-3]) has been proposed combined with either real-time correction of the data acquisition or motion compensated reconstruction. The quality of the correction depends critically on the estimated motion derived from the navigator signal. Here, we present a fast, robust and precise algorithm to evaluate data from an orbital navigator trajectory and its application to motion compensated reconstruction.

Methods

Fig. 1 shows k-space trajectories of common navigators to measure rigid body motion in 2D. The classical navigator [1] (a) and floating navigator [2] (b) provide only information about shifts. In contrast to these, the orbital navigator [3] (c) provides also information about rotation, which is all that is needed for 2D rigid body motion correction.

The signal of the orbital navigator S' depends on the rotation angle α and the shift in x/y-direction (Δx/Δy) in the following way:

$$S'(\theta) = S(\theta - \alpha) e^{2\pi i k_\rho \left(\frac{\Delta x}{\mathrm{FOV_x}} \cos\theta + \frac{\Delta y}{\mathrm{FOV_y}} \sin\theta \right)} \quad (1)$$

Here, θ is the azimuthal angle of the navigator signal, k is the radius of the orbital navigator in k-space, S is the navigator signal of the object without motion and FOVx/y is the size of the field of view. I.e., rotations cause a displacement of the signal magnitude, shifts cause a sinusodial phase difference with respect to a reference navigator signal.

The rotation angle is determined by the maximum of the cross-correlation of |S| and |S'|. Sub-sample accuracy can be achieved by fitting a parabola to the derivative of the cross-correlation using the 3 values around the maximum position.

The estimation of the shift is more difficult because phase-wraps can occur and the phase difference can be determined only very inaccurately for samples with low magnitude. The second point prevents using an unwrapping algorithm because noise can cause such large fluctuations that can be mistaken for phase-wraps by an unwrapping algorithm. Fig. 2 shows an example where for several points true phase-wraps occur but for one point the large phase jump is caused by excessive noise (red arrow).

We used a 3 step approach to determine the shift in a robust way:

1.) Exclude data points which have a phase error above 0.3 rad. This divides the dataset into several segments of valid data.

2.) Unwrap each individual segment.

3.) Use a linear least-squares algorithm to determine the shift parameters and the relative position of the different segments.

As an optional 4th step, the shift estimate can be improved considerably by using a non-linear optimization algorithm which is initialized with the result of the linear fit (see Fig. 3). Using the non-linear algorithm alone fails because of a large number of local minima.

Results and Discussion

Fig. 4 shows the precision of the estimated shift for a phantom and a volunteer head scan for different navigator radii. The best precision is achieved for k~15 but the dependence on the radius is not very strong. The fluctuations are much larger in vivo than for phantoms but the absolute values are still quite small.

As an example, Fig. 5 shows a comparison of a standard and a motion compensated reconstruction using the navigator data underlining the high precision of the motion estimation.

Discussion and Conclusion

Various other methods to determine the shift have been proposed. The methods from [3,4] are limited to small shifts where phase wrapping does not occur. The approach presented in [5] proposes to use the derivative of the phase difference to deal with phase wraps but this amplifies the susceptibility to noise. Our method has the advantage that it can deal with phase wraps, is robust against noise, and can be executed very quickly.

References

[1] Ehman and Felmlee, Radiology, 173: 255-263, 1989
[2] Kadah, et al. MRM 51:403-407, 2004; [3] Fu, et al., MRM 34: 746-753, 1995
[4] Ward, et al., MRM 43: 459-469, 2000; [5] Moriguchi, et al., MRM 50:423-428, 2003

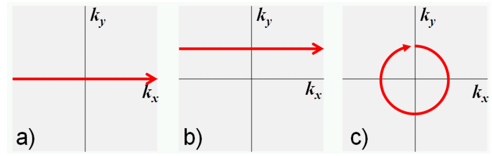

Fig. 1: Schematic representation of k-space trajectories for the classical navigator (a), the floating navigator (b), and the orbital navigator (c).

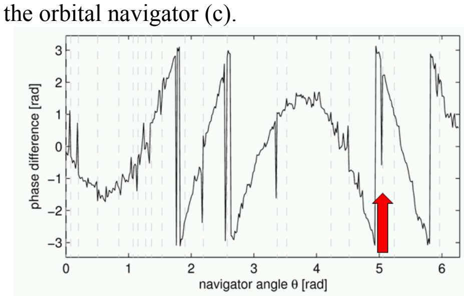

Fig. 2: Phase difference between two orbital navigator signals. The red arrow marks a point where noise causes a fluctuation that would be mistaken for a phase-wrap by an unwrapping algorithm. The dashed vertical lines mark the segment borders used in the linear fit.

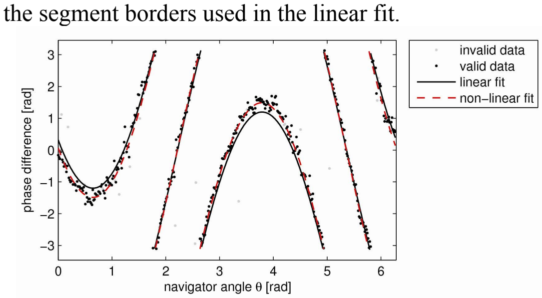

Fig. 3: Results of the parameter estimation. Note the improved accuracy of the non-linear fit which is initialized by the result of the linear fit.

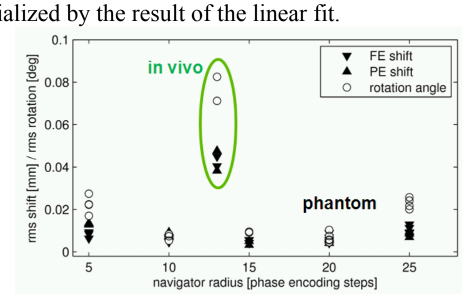

Fig. 4: Standard deviation of the estimated motion parameters.

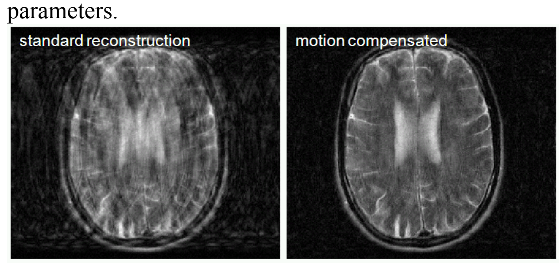

Fig. 5: Example of motion compensated reconstruction using the estimated navigator parameters.