Sub-volume motion detection to speed up image-based navigators and prospective motion correction

Anja Jäger[1,2], Thomas Beck[2], and Andreas Maier[1]

[1]Pattern Recognition Lab, Department of Computer Science, Friedrich-Alexander- Universität Erlangen-Nürnberg, Erlangen, Germany, [2]Siemens Healthcare, MR Application Development, Erlangen, Germany

Synopsis

A method for detection of patient motion based on sub-volumes is presented. Current methods for image-based motion detection are limited because rigid motion parameters can only be detected for full volumes. This limits the potential of navigator acceleration and causes undesirable effects due to respiratory motion in some applications. Our novel approach extends the rigid-body-motion model by detection based on a subset of slices relative to a fully sampled reference volume. It is validated with phantom and in-vivo data and allows for both considerable acceleration of navigator scans and prospective correction of head motion in fMRI applications.

Purpose

Image-based methods to detect patient motion have previously been proposed for prospective [1] motion correction. One limitation is that rigid motion parameters are detected based on full navigator volumes. To provide the means for time-efficient protocols, navigators need to be short to fit into very short TI or TR gaps. Especially in sequences which do not contain dead times like 3D FLASH, the impact on SNR/time and scan time should be minimal [2]. Typical acquisition times for volume navigators with typical resolution of 8x8x8mm³ are in the range of 275ms for 3D-encoded EPI navigators covering 32 slices [3] down to 28ms for SMS-accelerated navigators with only 10 slices [4]. The main focus of previous publications is the acceleration of acquisition techniques without making use of the full potential of motion detection techniques. The proposed method detects patient motion based on a subset of 2D imaging slices. It has the potential to significantly reduce the motion feedback delay for prospective motion detection techniques which rely on a full volume for a motion compensation update [1]. Additionally, the focus on a subset of slices forms the basis to speed up navigator acquisitions. This also extends the applicability to a wider variety of sequences without sufficient dead time. Validation studies were performed in phantoms and in vivo to demonstrate that sub-volume-based motion detection can be used to accurately detect motion. Furthermore, reduced intra-volume motion due to accelerated navigator acquisition demonstrated improved conformity to the rigid-body-motion model assumption.

Methods

The proposed method is based on [1] which iteratively searches for an optimal solution to map each volume to a reference using a rigid motion model. Subject motion is approximated with a first-order Taylor series using the gradient of a reference volume with respect to three rotational and three translational motion parameters. This method is extended to mapping sub-volumes to a fully sampled reference volume. An additional weighting vector g is introduced to specify slice-specific weights. This way, only slices with positive slice weights are entered into the Jacobian matrix to find the least-square solution of the mapping problem.

$$\vec{y} \approx \vec{x} + \underbrace{\begin{pmatrix} \frac{\partial x_0}{\partial p_0} & \cdots & \frac{\partial x_0}{\partial p_5} \\ \vdots & \ddots & \vdots \\ \frac{\partial x_{n-1}}{\partial p_0} & \cdots & \frac{\partial x_{n-1}}{\partial p_5} \end{pmatrix}}_{\vec{J}} \cdot \vec{p} \; with \; \frac{\partial x_i}{\partial p_j} \approx \frac{(\vec{x}(+p_j) - \vec{x}(-p_j))}{2 \cdot p_j}.$$

Optimal motion parameters p=[trans_x;trans_y;trans_z;rot_x;rot_y;rot_z] to map the reference volume x to the navigator volume y can be found iteratively using the pseudo-inverse of the Jacobian matrix J:

$$\vec{p} \approx (\vec{J}^T \cdot \vec{J})^{-1} \cdot \vec{J}^T \cdot (\vec{y} - \vec{x}).$$

The iterative update of navigator sub-volume y uses a linear interpolation extending the slice interpolation to consider the weighting vector g. The interpolation function f at slice position z_0<=z*<=z_1 based on neighboring sub-volume slices at position z_0 and z_1 can be computed using

$$f(z^*) = g_0 \cdot f(z_0) + g_1 \cdot f(z_1) = (z_1 - z^*) \cdot f(z_0) + (z^* - z_0) \cdot f(z_1).$$

All experiments were conducted on a 3T MAGNETOM Skyra scanner (Siemens Healthcare, Erlangen, Germany) using EPI BOLD prototype sequences (2x2x2.1mm^3, TR=3000ms, 96x96 matrix) with expressed prior written consent by the volunteers. The principal frequency band of respiratory motion was found to be in a range [0.4,0.7]Hz. Respiration was monitored using a respiratory belt.

Results

The rigid-body-motion model assumes that all motion happens between volumes. This model assumption does especially not hold for long TR acquisitions and motion parameters detected on full volumes. Fig.1 shows the impact of physiologically induced motion to translational motion as a low-frequency motion drift for slow sampling, whereas faster sampling reveals clear correlation to physiologically induced and real head motion. Analogous to this, Fig.2 shows the impact on rotational parameters. The proposed algorithm is able to reveal these effects even for long TRs due to an increased motion update rate on the basis of sub-volumes. Fig.3 shows results of a phantom experiment. The phantom was moved manually during a time series of 210 volume acquisitions. Parameters detected based on full volumes [1] (blue) and motion detection using only slices with even slice index (green) show very good correlation as confirmed by mean squared errors shown in Tab.1.

Discussion & Conclusion

We demonstrated a technique for sub-volume motion detection which can be applied for prospective motion correction. Navigator-based approaches benefit from reduced acquisition time for each navigator due to reduced requirements to the number of slices. Image-based approaches benefit from reduced feedback delay as the motion update can be generated after a subset of slices compared to full-volume updates [1]. Preliminary validation studies with phantoms and volunteers show that motion parameters can be detected robustly based on a subset of 50% of all slices with minimal effect on the accuracy. Additionally, reduced intra-volume motion due to physiological motion is contained. With the possible extension to simultaneous-multi-slice acceleration, this supports the application of image-based navigators for minimal delay.

Acknowledgements

No acknowledgement found.

References

[1] Thesen et al. MRM, 2000, 44:457-465

[2] Tidsall et al. ISMRM 2015 #0882

[3] Tisdall et al. MRM 2012, 68:389-399

[4] Bhat et al. ISMRM 2015, #817

Figures

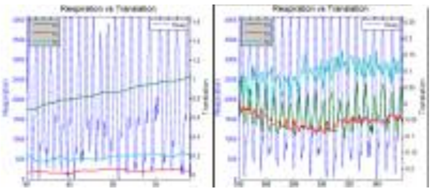


Figure 1: Impact of physiologically induced motion to detected translational motion parameters depending on TR. For slow sampling rate (TR=3000ms, left), only a low-frequency motion drift is detected. Faster sampling (TR=500ms, right) reveals clear correlation of trans$_z$ and trans$_x$ to the respiratory signal which is caused by actual head motion (trans$_z$) and B0 effects (trans$_x$ = phase encoding direction).

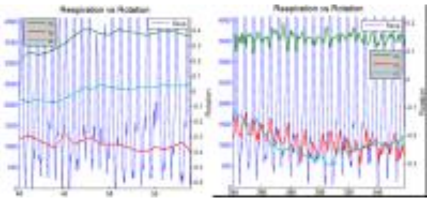


Figure 2: Impact on rotational parameters: Faster sampling (TR=500ms, right) reveals correlation of roty to the respiratory signal. trans$_x$ in Fig. 1 and rot$_y$ in Fig. 2 corresponds to actual head nodding motion due to respiration.

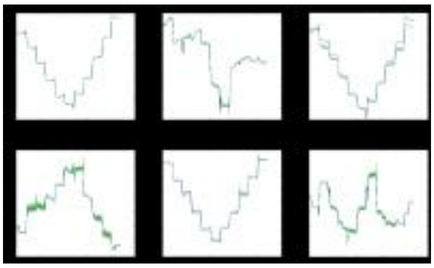
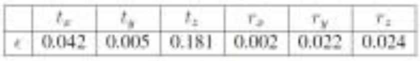


Figure 3: Phantom and volunteer results show that motion parameters can be detected robustly based on a subset of 50% of all slices (green) with minimal effect on the accuracy compared to full volume motion detection (blue).



	t_x	t_y	t_z	r_x	r_y	r_z
ϵ	0.042	0.005	0.181	0.002	0.022	0.024

Table 1: Mean squared error between motion detection for one and two subvolumes.