Prospective Intra-Image Compensation for Non-Periodic Rigid Body Motion Using Active Markers

S. Krueger[1], T. Schaeffter[1], S. Weiss[1], K. Nehrke[1], T. Rozijn[2], P. Boernert[1]

[1]Philips Research, Hamburg, Germany, [2]Philips Medical Systems, Best, Netherlands

Objective: Motion is one of the most prominent problems for many time-consuming MR imaging procedures. For instance, head motion during 3D scans or functional studies can cause image artifacts or deteriorate the spatial resolution of activation patterns, respectively. Motion can be caused by pathology (e.g. Parkinson's disease), lack of compliance (pediatric imaging), necessity (e.g. fMRI-study on motor reflex involving head motion) or can be simply unintentionally due to very long scan times.

This work follows up on the "inter-image" prospective motion correction as presented by [1] and references therein. A fast, prospective "intra-image", i.e. per single or multiple k-space line(s), 6D rigid body motion correction is presented. The method compensates for arbitrary 6D rigid body motion by using small extra-corporal micro-coils (active markers) for motion tracking.

Navigator-based approaches for prospective intra-image translational and also in-plane rotational motion compensation (orbital navigators) were explored earlier by [2] and [3], respectively. An extension to 3D spherical navigators to correct for rigid 6D motion is presented in [4]. The approach described in [5] handles in-plane rigid and general through-plane motion by analyzing a required number L of corresponding k-space-lines. The inherent temporal resolution of this method is therefore L x TR (repetition time). Image-based approaches as proposed in [6] require the analysis of a full 2D slice to prospectively compensate for in-plane rigid motion, and are, thus, only useful for prospective inter-image correction.

Besides motion compensation for head imaging, kinematic studies for orthopedic applications [7] are imitated. The exercised free motion is corrected for resulting in quasi-static images revealing only the inner motion of e.g. tendons, ligaments and muscles etc..

Fig. 1

Material and Methods: Active µ-coils (active markers) continuously track the motion of a non-periodically, rigidly moving part of the body. Each of the 32 channels of the MR-system (Achieva 1.5T, Philips Medical Systems, Best, The Netherlands) can be used for either tracking of µ-coils or imaging. For tracking of rigid body motion of the head, 4 markers were integrated with standard ear phones to form a rigid geometry (reference) attached to the region of interest (Fig.1). Subsequent tracking shots interleaved with imaging reveal the movement of the reference and the body part of interest, respectively. The rigid motion of this reference point-set is analysed using a singular value decomposition method as described in [8] in real-time on the scanner. The MR control system then computes and updates the required scan geometry to follow the object in real-time. The temporal resolution of the compensation is limited by the time required to perform the tracking shots (3 x TR) + the time required for the evaluation and scan geometry update (5ms), typically resulting in an overall temporal resolution of ~20ms. Motion velocities exceeding the maximum, allowed by the given frame rate and scan resolution, can be detected. This can potentially be used to completely veto and re-acquire data measured within corresponding tracking frames.

Experiments were performed on volunteers using protocols for 3D head imaging. The volunteers were trained to perform a reproducible "head-shake"-type motion. Additionally, protocols for kinematic studies were examined. Fig. 3 shows the example. Here, the hand was imaged while a "hand-wave"-type motion was carried out.

Results and Discussion: The relative accuracy (reproducibility) of the markers, relevant for tracking of relative position changes, was determined to be <100µm. For larger distances from the iso-center (> 150mm), the relative position error increases as a result from gradient non-linearities and B_0-inhomogeneities. B_0-related inaccuracies can be eliminated using a Hadamard encoding scheme, compromising the temporal resolution by 1 TR. A gradient dewarping algorithm could be added optionally, however this would imply a slowdown in tracking speed by ~5-10ms.

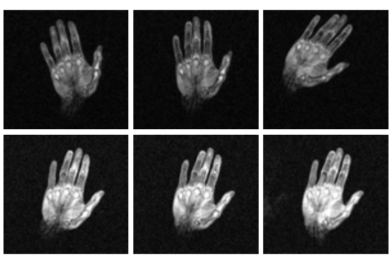

Fig. 3

For head imaging, the prospective intra-image compensation reveals significant improvements in image quality. Fig. 2 shows two exemplary slices from a 3D T1-weighted TFE scan (TR = 4.4ms, TE = 1.8ms, α=20°, 300mm FOV, 192 matrix, 50 slices, slice thickness = 2mm, turbo-factor = 10, scan time = 70s) of a volunteer's head without any motion and no motion compensation applied (top), with significant rotational (40°) and translational (10-50mm) motion during image acquisition, without motion compensation (middle) and with motion compensation (bottom).

The scan time for a motion-compensated scan using the proposed technology can be optimized by adapting the tracking rate and the maximum accepted velocity according to the statistics of the expected motion resulting in a trade-off between these two parameters: For steady fast motion, an appropriate tracking speed is required. Vetoing of data and using a too low tracking speed would result in significantly longer scan times. For short tremor-like motion patterns, however, the tracking frame-rate can be relatively low, and a veto of corresponding data is advantageous.

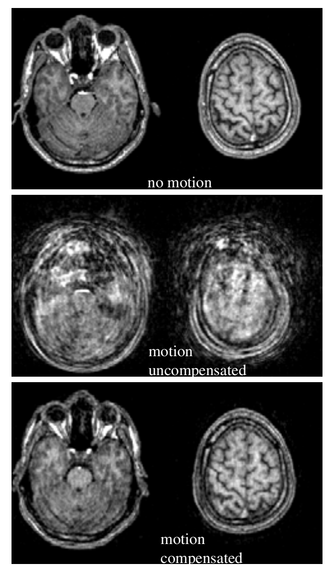

Fig. 2

For the kinematic studies, quasi-static images of the hand during free hand movements were produced (Fig. 3). The top three images show the character of the motion. The lower row shows parts of the resulting image sequence compensated for the exercised motion, which, when played in cine mode, nicely displays the residual inner elastic motion of tendons, ligaments and muscles.

Conclusion and Outlook: We demonstrated a prospective, fast, intra-image motion compensation approach based on active markers (MR-trackable µ-coils) and their application to two potential clinical cases (Brain imaging and 3D kinematic studies in orthopedics). Tests were performed on volunteers. The results prove the overall feasibility of the concept. A significant improvement of image quality in the presence of strong motion has been shown for head images from volunteers. The kinematic studies show that free motion can be allowed and compensated leaving the residual elastic inner motion of e.g. tendons and ligaments to be diagnosed.

[1] Derbyshire JA et al., Dynamic scan-plane tracking using MR position monitoring. JMRI 1998;8(4):924–932.
[2] Ehman RL, Felmlee JP, Adaptive technique for high-definition MR imaging of moving structures. Radiology 173, 255-263, 1989
[3] Fu ZW et al.. Orbital navigator echoes for motion measurements in magnetic resonance imaging. MRM 1995;34:746–753.
[4] Welch EB et al., Spherical navigator echoes for full 3D rigid body motion measurement in MRI , MRM 47 (1): 32-41 JAN 2002
[5] Pipe JG. Motion correction with PROPELLER MR IMAGING: application to head motion and free-breathing cardiac imaging. MRM 1999;42:963–969
[6] Thesen S et al., Prospective Acquisition Correction for Head Motion With Image-Based Tracking for Real-Time fMRI, MRM 44:457–465 (2000)
[7] Shellock FG et al., Patellofemoral joint - Kinematic MR imaging to assess tracking abnormalities, Radiology 168 (2): 551-553 Aug 1988
[8] Umeyama S, Least-squares estimation of transformation parameters between two point patterns, IEEE-TPAMI, vol. 13, pp. 376-380, 1991.