Non-rigid Motion Correction in 3D Using Autofocusing with Localized Linear Translations

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INTRODUCTION: Motion degrades the quality of MR studies due to the duration of the scans. Recently, multi-coil arrays have been used to correct for these artifacts [1-3]. However, the additional spatial encoding from coil sensitivities still provides a rich source of unused motion information. Localized autofocusing is proposed to make use of that information for non-rigid motion correction.

METHOD: *Correction Algorithm:* Non-rigid motion can be locally characterized as localized translations. For this approximation to hold, images must be examined at a small enough spatial scale. To accomplish this, localized autofocusing is applied to determine the linear translations that best corrects for motion (Fig. 1). Motion is suppressed when the gradient-entropy is minimized. Usually, this metric is globally calculated [4-5], but in this work, only a small region around the pixel of interest is used to localize the metric. The vast search space is limited to motion measured using a coil array. The coil sensitivities provide a good means to observe linear motion at different spatial locations. For a multi-element coil array, these measurements are a good basis of possible motion trajectories for each image voxel.

Data Acquisition: Motion is measured using a strategy based on Butterfly navigators. These navigators are modifications to the spin-warp sequence that provide intrinsic motion information with negligible overhead [6]. The strategy is incorporated into a 3D spoiled gradient recalled (SPGR) sequence. For accurate navigation reference and motion-free coil-compression calibration [7], a small portion of data around the center of k-space is acquired using respiratory triggering and gating.

Experiments: Free-breathing abdominal studies were performed on pediatric subjects in a 3T GE MR750 scanner. Data was acquired using a 32-channel pediatric torso coil, flip angle = 15°, and bandwidth = 62.5 kHz.

Additional Scan Parameters: Study 1: TE/TR = 2.1/5.5 ms, resolution = 0.94×0.94×3.0 mm^3, FOV = 30×24×15.6 cm^3, navigation per TR = 0.14 ms, and 10% of k-space respiratory triggered and gated. Study 2: TE/TR = 1.7/4.8 ms, resolution = 0.94×1.2×3.0 mm^3, FOV = 30×24×16.2 cm^3, navigation per TR = 0.11 ms, and 5% of k-space respiratory triggered and gated.

RESULTS/DISCUSSION: The autofocusing method was implemented in MATLAB and C++/CUDA. For a data size of 320×256×52 where 32-channels were compressed to 6-virtual coils, the total processing time was ~2 min – practical for online correction. Here, the localized linear model allowed for a simple correction without loosing effectiveness. Motion artifacts from non-rigid motion were reduced (Fig. 3). Image sharpness was improved for many small structures that were poorly visualized prior to correction (Fig 3b). In a few areas, small residual motion-artifacts remain, which can be reduced by using more channels to expand the motion model space.

CONCLUSION: Using the localized gradient-entropy metric, we developed a practical autofocusing scheme for data acquired with a 32-channel coil array. A reduction of non-rigid motion artifacts was demonstrated.

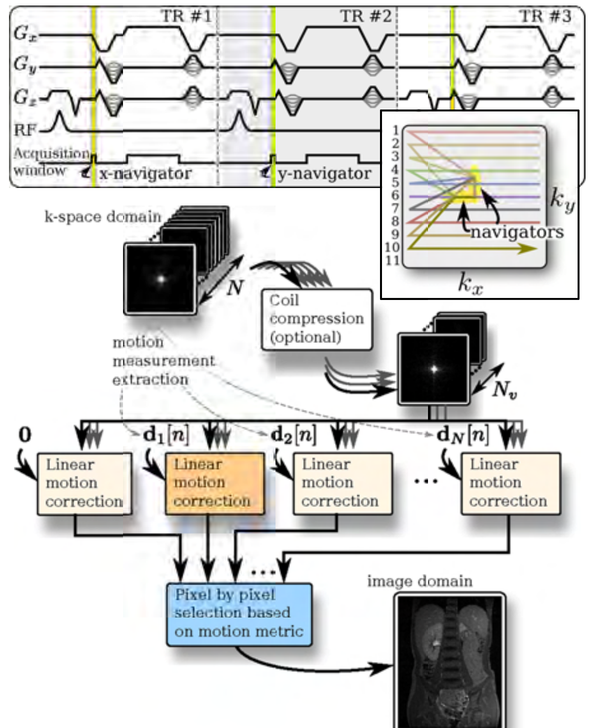

FIG. 1: *Method overview.* **top:** 3D spin-warp sequence modified to acquire Butterfly navigators in *x* (TR #1), *y* (TR #2), and *z* (TR #3). **middle:** Example 2D Butterfly trajectory where navigation data is collected along each axes. **bottom:** Correction overview. In the highlighted "linear motion correction" block, the motion measured from coil 1 ($\mathbf{d}_1[n]$) is used to perform linear translations on data from all N_v coils. Coil combination (i.e. sum-of-squares) is then applied to the result in the image-domain. Trajectory $\mathbf{d}_0[n] = 0$ represents the case of no motion.

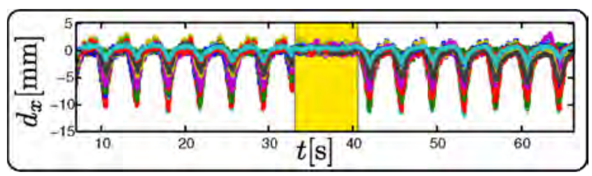

FIG. 2 (*above*): *Study 1 motion measurements from a 32-channel coil array.* The patient was scanned in the coronal orientation, where d_x represents superior/inferior motion (d_y and d_z are not shown). The yellow highlights the k-space data that was respiratory triggered/gated.

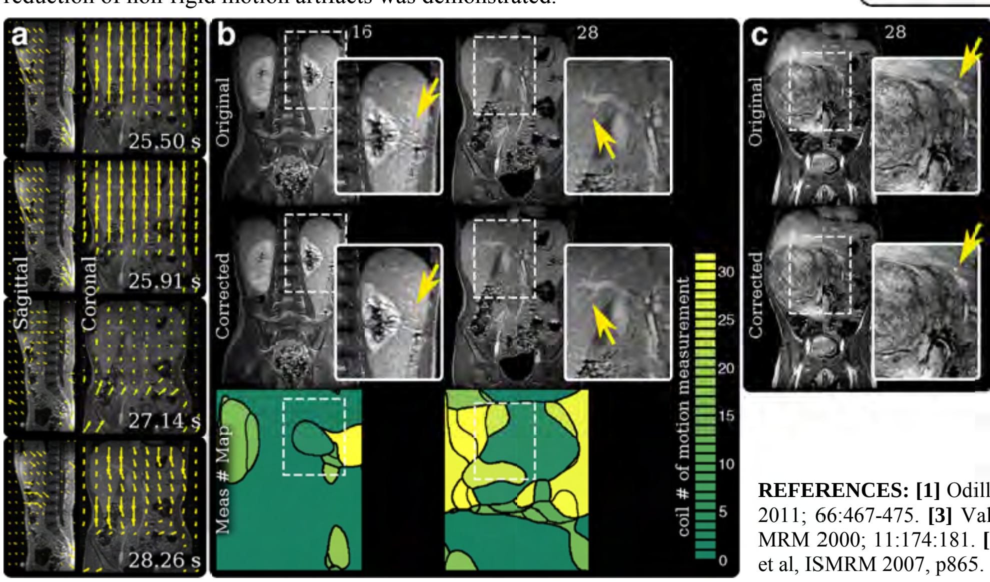

FIG. 3 (*left*): *Abdominal study results.* **a:** Study 1 derived translation maps that show motion in different respiratory phases. **b:** Study 1 of a 6-yr old patient. **c:** Study 2 of a 2-yr-old patient with renal tumor. In **(a),** an increase in sharpness and structure can be seen in the liver vessels. The measurement # maps shows which coil # was used to correct each pixel. The motion measured from one coil can extend beyond where that coil is most sensitive. In **(c)**, ghosting artifacts were suppressed, and a lesion became better defined.

REFERENCES: **[1]** Odille et al, MRM 2008; 60:146-157. **[2]** Hu et al, MRM 2011; 66:467-475. **[3]** Valliant et al, ISMRM 2011, p4605. **[4]** McGee et al, MRM 2000; 11:174:181. **[5]** Lin and Song, MRI 2006; 24:751-760. **[6]** Lustig et al, ISMRM 2007, p865. **[7]** Zhang et al, ISMRM 2011, p2857.