Strategy for simultaneous region-tracking and temperature-monitoring in the liver during free-breathing

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Introduction: The MR-guidance of thermal therapies in moving organs such as the liver can be a particularly challenging application. It requires the targeted location to be tracked in real-time as it undergoes breathing-related motion, while at the same time obtaining temperature measurements in and around the heated region. A pulse sequence proposed in [1] was implemented and tested here for its ability to provide simultaneous tracking- and temperature-related information. A fast landmark-based image tracking algorithm was implemented to process the resulting images and evaluate the liver's displacement and deformation. Because no ground truth is available to evaluate the registration results, we employed a test-program that could leverage the great ability of the human eye at detecting relative motion between the anatomy and a superimposed object.

Methods: *In vivo* images were obtained on a 3 T scanner using the sequence from Fig. 1. The images featured breathing motion, but no heating. Two different magnetization pathways were sampled: a spin-echo like PSIF early in the TR interval, and a gradient-echo FISP late in the TR interval, thus ensuring that both had maximal temperature sensitivity. The FISP and PSIF images provided very different contrast for blood vessels: Due to flow effects, blood appeared bright in FISP images but dark in PSIF images. A regular RF pulse was used here (to be replaced by a spectral-spatial pulse), and the imaging parameters were: 128×96, 24×24 cm^2, 5 mm slice thickness, 62.5 kHz, 50 time frames, TR = 6.4 ms, TE_{PSIF} = 1.67 ms, TE_{FISP} = 4.7 ms, 8-channel cardiac coil placed over the abdomen.

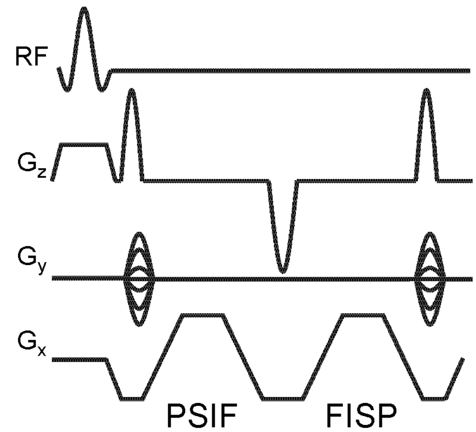

Fig. 1: The implemented sequence acquires a spin-echo like PSIF, followed by a gradient-echo FISP. Both pathways are temperature sensitive, and offer very different contrasts for blood vessels thus facilitating motion detection.

A fast landmark-based tracking scheme was implemented. The algorithm tracked the displacements of the blood vessels, allowing any location in the parenchyma to be tracked with respect to all nearby vessels. The algorithm reached 215 frames per second (fps) when run by itself on a 2.5 GHz microprocessor.

Temperature changes were evaluated using the referenceless method of [2], using 5×5 pixel regions centered at the pixel of interest. There was no actual heating in the *in vivo* experiment, i.e., $\Delta T(t) = 0$ C, where T is temperature and *t* is time (not shown here, the method was also tested in phantoms with heating). Phase errors due to motion were well suppressed, and T errors were mostly due to random noise. A 1.7 s averaging window was used for T results.

A test program was created to help evaluate the quality of the landmark tracking. Five readers were asked to select locations in a static view of the liver, and then visually judge from a movie how well a superimposed symbol (green circle in Fig. 2) appeared 'pinned' to the liver. Scores were given on a 1 to 5 scale, with 0 = un-related, 1 = large deviations, 2 = sizeable deviations, 3 = somewhat tracked, 4 = well tracked and 5 = pinned to anatomy.

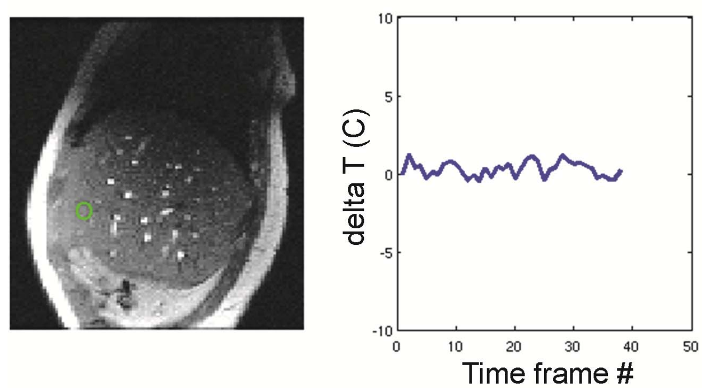

Fig. 2: Snapshot of the display generated by the test program. The user selects a point/ROI within the liver (green circle), which is then tracked in the presence of breathing-related motion and deformation (FISP image displayed). A plot of the temperature at the selected point is updated as time evolves.

Results: As shown in Table 1, the users found that selected locations had been overall well tracked (mean score of 4.1), and T noise was at an arguably reasonable level (mean of 1.43 C). An echo-planar version of the sequence was also implemented, and it is expected that increasing the echo-train-length and TR will reduce T noise levels but negatively affect registration. Our next step will be to enable limited 3D coverage with accelerated imaging, to allow through-slice motion to be tracked.

READER	SCORE (0 is worst, 5 is best)	T noise at user-selected locations
# 1	4.0 ± 0.0	1.46 ± 0.95 C
# 2	4.0 ± 0.4	1.16 ± 0.69 C
# 3	4.4 ± 0.5	1.48 ± 0.80 C
# 4	4.6 ± 0.5	1.16 ± 0.45 C
# 5	3.4 ± 0.9	1.87 ± 1.65 C
OVERALL	**4.1 ± 0.7**	**1.43 ± 0.95 C**

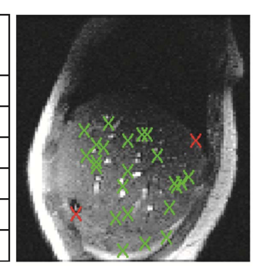

Table 1 and Fig. 3: Scores from all 5 users are listed, along with the temperature noise at the user-selected locations. Overall, the average score was slightly over 4, meaning the users judged that, visually, the ROI tracked well the underlying tissue's motion. All 5×5 = 25 user-selected locations are shown in Fig. 3, and the only two locations that received a score below 3.5 are shown in red.

[1] Madore et al. MRM 2011;66:658. [2] Rieke et al. MRM 2004;51:1223. Support from R01CA149342 and P41RR019703 is acknowledged.