Ultrasound-navigated MRI: Measurements of Tracking Efficiency and Precision

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Introduction:

Recently, we presented first experimental results on combining ultrasound (US) and MRI to overcome problems of existing motion compensation techniques [1]. US is a real-time modality which can provide anatomical images at high frame rates but at low quality. On the other hand, MR images are usually of higher image quality but suffer on motion artifacts. By combining the advantages of both modalities it should be possible to reduce the motion sensitivity of MR using real-time positional information from the real-time US scanning. In this work we present techniques to improve tracking efficiency and precision in preliminary measurements on a motion phantom.

US image acquisition (56 Hz)	18	ms
Feature extraction: Tracking algorithm	16	ms
(acquisition during tracking) Net 18/2 + 16 ms	25	ms
Transfer coordinates to MR host computer	.1	ms
Host computer to MR control computer	4	ms
Total cycle time of US coordinate update:	29.1	ms

Table 1: Average execution time for each step during the real-time US tracking.

Material and Methods:

A standard clinical US-scanner (VST Master, Diasonics) including a cardiac transducer (2.25 MHz) was used to image a phantom (water-filled balloon with plastic rods) moving in a water tank. Active contours are used to describe the structure to be followed in the acquired US-images. The optimal contour shape is found by a sophisticated state space search based on random numbers ("CONDENSATION" algorithm [2]). This algorithm was used given its adjustable but fixed execution time necessary for constant update rates (12 ms for described hardware and an average number of contour points (i.e. 20)). To further improve the accuracy of the tracking algorithm a simple second order extrapolation by Lagrange's classical formula was implemented. It utilizes three recent measurement points, which were known to lie within at least one forth of a period of the motion cycle.

The MRI scanner was a 1.5T whole-body system (Sonata, Siemens, Erlangen, Germany) running a SSFP (trueFISP) sequence.

The latency of the system was estimated using three different methods: a theoretical summation of the execution times of each step, an estimation using the amplitude of the residual motion and image acquisition with different correctional latency compensation (0 ms, 50 ms, 80 ms, 100 ms, 150 ms).

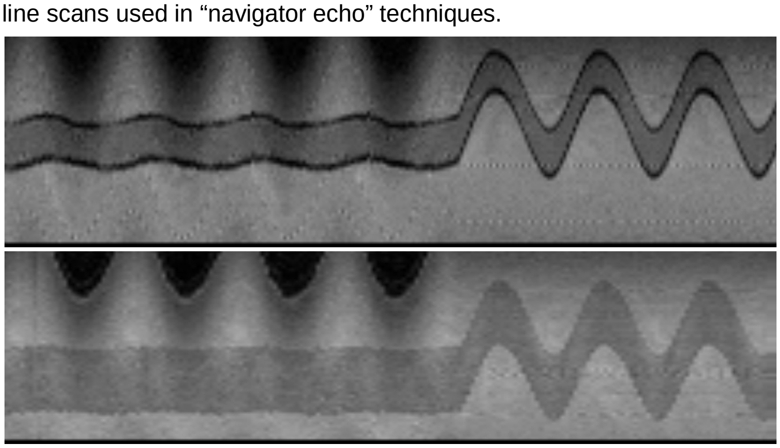
Results:

The execution time for each step (Table 1) yielded an estimated theoretical overall delay between the measurement of the phantom position by the US scanner and the updating of the actual slice information on the MR scanner of about 29 ms. Due to constraints of the sequence control hardware of the MR scanner, there is an additional delay of 20-40 ms (usually 8 times TR of SSFP sequence) until the MR slice is actually acquired. Thus, the delay expected from known sources lies between 50 and 70 ms. The estimation of the latency based on the measurements provided a value of 80 ms.

Figure 1 displays the position of the moving balloon versus time with and without latency correction. Initially, the tracking is switched on and the balloon appears stationary. Further to the right tracking is switched off and the motion of the balloon relative to the MR system becomes apparent. Nonetheless, some residual motion (due to incomplete motion compensation) remains even with tracking enabled (top image in Fig.1). The bottom image in Fig.1 shows the result with a latency correction of 80 ms which removes the residual motion almost entirely. The precision of the repositioning could be improved from 8 mm to <1.5 mm.

Discussion and Conclusion:

A method was presented which allows simultaneous acquisition of US and MR images and to use the US spatial measurements to continuously reposition the MRI slice plane. Results for US-guided MRI on a motion phantom successfully adjusted the slice position and orientation of the MR sequence in real-time. The current setup allows the US-MRI feedback to measure and correct for the displacement of a periodically moving phantom every 30 ms with a latency of 80 ms. Further refinements of US hardware and US acquisition are anticipated to yield the update of US positional information within the TR of the SSFP sequence. This method can be applied to all sequence types for prospective or retrospective correction of motion and should be especially useful for cardiac imaging. The 2D and 3D ultrasound tracking of organs could, in principle, lead to improved tracking accuracy compared to conventional 1D MRI line scans used in "navigator echo" techniques.



References:

1. Feinberg DA, Guenther M: ISMRM 2003, Toronto, p.381
2. Isard M and Blake A. Int. J. Computer Vision 1998, 29(1): 5-28

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Fig. 1: Position of the balloon versus time. On the left side, tracking is enabled while on the right side no tracking is applied. Some residual motion is apparent even with tracking enabled (top). At the bottom the results are shown for an additional latency correction of 80 ms, where the residual motion can be removed almost entirely.