

Boosting MR Temporal Resolution using Rapid Ultrasound Measurements, for Motion-Tracking Purposes

Matthew Toews¹, Chang-Sheng Mei¹, Renxin Chu¹, W Scott Hoge¹, Benjamin M Schwartz¹, Guangyi Wang^{1,2}, Lawrence P Panych¹, and Bruno Madore¹

¹Department of Radiology, Harvard Medical School, Brigham and Women's Hospital, Boston, MA, United States, ²Department of Radiology, Guangdong General Hospital, Guangdong Academy of Medical Sciences, Guangzhou, Guangdong, China

Target audience: Researchers in the field of MR-guided therapy involved in procedures where the MR sampling rate proves to be a limiting factor.

Purpose: It is generally believed that a sampling rate of at least 20 frames per second (fps) or so might be necessary to properly resolve breathing motion in a clinical setting, as patients may present with rapid breathing patterns that may even include instances of gasping. While one can certainly reach 20 fps with fast MR imaging methods, it is typically done at great costs in terms of image quality and spatial coverage. To properly guide interventional procedures, the acquired MR images should ideally offer a level of overall quality and information content that tends to be mostly incompatible with the fastest imaging sequences available. For example, to guide thermal therapies in moving organs, the MR data should help determine whether the heat is being properly delivered to the target and nowhere else, and whether the temperature dose has reached therapeutic levels over the whole target, while simultaneously tracking the precise location of the target as it moves due to breathing and possibly due to bulk motion as well. Especially when any amount of 3D coverage is desired, a sequence capable of providing good-quality non-distorted images with all the needed thermal information content cannot realistically be expected to run at 20 fps or more. The present work offers a solution in the form of a boost in temporal resolution obtained by infusing ultrasound (US) data with very-high temporal resolution (about 100 fps or more) into the reconstruction process, allowing the acquired MR-based tracking rate (about 2 fps here) to be effectively raised to at least 20 fps, as needed for lesion-tracking purposes.

Methods: A 3D motion-tracking approach based on the use of a single-element US transducer was recently proposed¹. The method requires a training phase where a lookup database is gathered, followed by a tracking phase where incoming US waveforms are matched against many different possible object configurations from the lookup database. Assuming that appropriate training could be performed, the US signal contains information to allow displacements, rotations, deformations and just about any other kind of changes to be detected¹. A different tracking approach, based on the use of a dual-pathway MR sequence to detect blood vessels and of a landmark-based registration algorithm to track their displacements, was also recently proposed². The present work can be viewed as a merger of these two very different schemes. As shown in Fig. 1, the MR-based approach provides tracking information at a low frame rate (about 2 fps here) while the US-based approach fills-in the time gaps in-between MR frames. The algorithm is causal, as required in real-time imaging, and MR images from the recent past get used toward continuously training the US scheme.

In vivo MR and US data were acquired simultaneously from the liver of a human subject, see Fig. 2, following informed consent with an IRB-approved protocol (3 T scanner, dual pathway steady-state sequence², 128×96, 24×24 cm², 5 mm slice thickness, ±62.5 kHz, TR = 6.4 ms, TE_{PSIF} = 1.67 ms, TE_{FISP} = 4.7 ms, 8-channel cardiac coil placed over the abdomen). US data were acquired using an MR compatible broadband transducer with a nominal center frequency of 5 MHz, and a US echo sequences of 20K samples was sampled every TR. Figure 3 shows the frame-to-frame evolution of one small segment of the US echoes and one small line region from the MR images, to demonstrate that both datasets were acquired simultaneously and are synchronized. Looking along the horizontal axis in Fig. 3, one can readily notice that the US signal has a temporal resolution much superior to that of the MR signal.

The locations of blood vessels in MR frames were tracked across time frames using a fast landmark-based registration algorithm². US samples are compressed via principal component analysis (PCA) for efficiency, and a particle filter was used to identify frames where US data were most similar to those at the current time point. An MR image and vessel locations (along with target location) could then be predicted for the current time point via interpolation.

Results: Our system was evaluated on a sequence of 45 MR images (see Fig 3) and a past history of 30 MR images was maintained, meaning that the last 15 images (i.e., #31 onward) could be used for testing purposes. The algorithm could predict MR frames based on the US data at a rate of approximately 20 fps on a single core 2.5 GHz processor. Accuracy was measured as the discrepancy between predicted and real MR images, at time points where real MR images were available. More specifically, accuracy was measured in terms of the average displacement of manually selected vessel locations. Accuracy was measured to be 1.9 mm, with std of 1.6 mm. For baseline comparison, accuracy was also measured for prediction based on the previous MR frame (2.8 mm, std of 1.4). Predicted results significantly outperformed results obtained using the baseline (t-test, $p=0.046$), see Fig 4.

Conclusion: The gap that separates consecutive MR time frames can be filled-in using US data, allowing motion-tracking to be performed even when the native MR frame rate might be insufficient, thus allowing higher-quality, slower MR acquisitions to be performed (instead of faster but lower-quality ones).

References: [1] Schwartz et al. MRM Epub ahead of publication. [2] Madore et al. ISMRM 2012:1576. Support from grants R01CA149342, P41EB015898 and R01EB010195 is acknowledged.

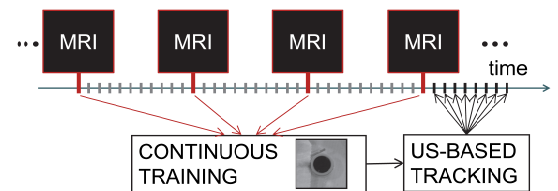


Fig. 1: The single-transducer US tracking scheme¹ is used to fill-in time gaps from the MR-based tracking scheme², i.e., the period between the last known MR image and the next (future) one. MR images from the recent past are used to continuously train the US scheme.



Fig. 2: The experimental setup includes a US transducer and a (Lego-built) safety device.

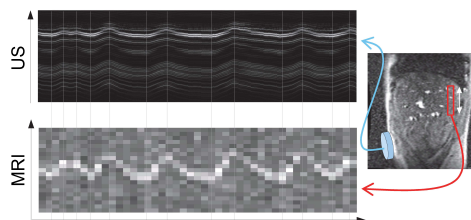


Fig. 3: Both US and MRI data were acquired simultaneously, in a synchronized manner, at a rate of 1.6 Hz and 156 Hz, respectively.

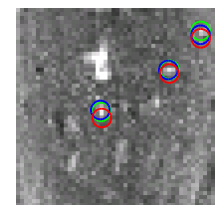


Fig. 4: Landmark vessel locations (circles) overlaid on a ground truth MR frame. Green – ground truth, Blue – predicted, Red – previous frame baseline.