Detecting rapid organ motion using a hybrid MR-ultrasound setup and Bayesian data processing

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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: In the context of image-guided therapy, MR images with good spatial and temporal resolution, good spatial coverage, good SNR and excellent contrast characteristics are often desired and rarely attained. To reap the benefits of the superior contrast capabilities of MRI one may need to sacrifice somewhat the temporal resolution. A hybrid MR-ultrasound setup was developed so that the very high acquisition rates achieved by the ultrasound (US) system might help compensate for a slower and presumably higher-quality MR acquisition (Fig. 1). The setup and algorithm utilized here can track organ motion during regular breathing and also detect/handle the more drastic motion involved in coughing or gasping.

Fig. 1: The experimental setup includes a US transducer and a (Lego-built) safety device.

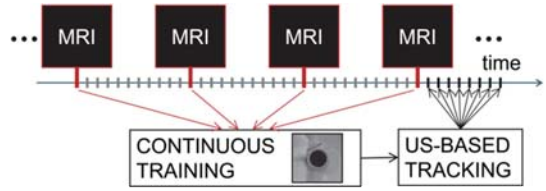

Fig. 2: *A single-transducer US tracking scheme[1] is used to fill-in time gaps from an MR-based tracking scheme[2].*

Methods: The liver of a human volunteer was imaged *in vivo* with the proposed system (Fig. 1), following informed consent. A single-element ultrasound transducer was used to obtain rapid measurements[1,2] (140 fps) while steady-state gradient-echo MR images were acquired at a slower rate (3 T system, TE/TR = 4/7 ms, BW = ±250 kHz, 8-coil array, 5 mm slice, 128×96 matrix, 1.5 fps). The goal is for incoming MR images to help continuously train the algorithm, and for incoming US signals to help fill-in what would otherwise have been unknown gaps between the last MR image to have been acquired and the next not-yet-acquired one (Fig 2).

The present work involved developing a Bayesian algorithm capable of handling the incoming MR and US data along with metrics to help detect periods of unusual motion activity such as during gasping or coughing. The algorithm requires data acquired over several cycles of normal patient motion (e.g., breathing) to be properly trained, and can then successfully predict the maximum a-posteriori position of a target that corresponds to incoming US samples, based on knowledge derived from previously-acquired MR and US data. However, in the presence of rapid motion due to coughing or gasping, artifacts and image degradation may mask the MR image features that were used in tracking, interrupting the flow of MR-based information required for the hybrid algorithm to function properly (Fig. 3). A US-based criterion has been developed to help decide when motion is too rapid to be properly handled and exceeds pre-set tolerance parameters, and when proper operation can be resumed. This could be used for example to interrupt an MR-guided thermal ablation procedure for safety concerns.

The US signal can be viewed as a function of space and time $U(x,t)$. The orientation of the gradient of $U(x,t)$ provides a coarse estimate of the instantaneous organ velocity dx/dt along the US beam, and is used here to detect rapid organ motion. At each time point, a gradient orientation histogram is computed from the current and previous US frames. The percentage of the gradient measurements exceeding an instantaneous velocity threshold is used to signal rapid organ motion and disable tracking. Normal operation can resume once the period of unusual motion activity ends.

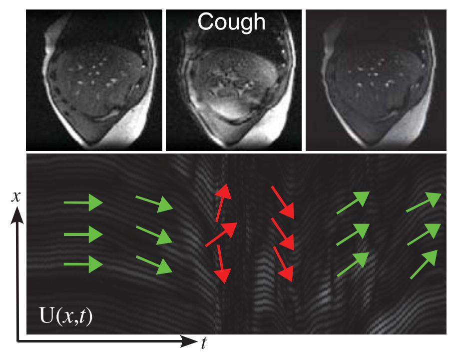

Fig. 3: *MR (upper) and US (lower) data acquired simultaneously over the course of a cough. MR landmarks (hepatic blood vessels, hyper intense points in MR) cannot be localized due rapid coughing motion (upper center), causing tracking failure.US gradient orientation (arrows) is used to detect rapid motion (red arrows).*

Results: Experiments were performed to evaluate the ability of the algorithm to handle free-breathing motion interspersed with coughing episodes. The US gradient was evaluated at the spatio-temporal resolution of the US signal (7.5e-3mm,7.0e-3s), and a causal filter was then used to smooth measurements over time. Figure 4 shows synchronized landmark prediction errors (quantified against a manually-labeled ground truth), the percentage of US gradient orientation above 1m/s, and the US data sequence. In all cases, the onset of MR degradation due to coughing was detected when 15% of the US gradients indicated a tissue velocity of 1m/s or greater. The nominal landmark tracking accuracy outside of coughing episodes was measured at 2.6±1.9mm.

Discussion and Conclusion: A system based on the use of a single-element US transducer was employed to detect rapid organ motion while MR images were acquired. A Bayesian algorithm was developed to handle the flow of hybrid data, and criteria were developed to detect periods of unusual activity (e.g., coughing).

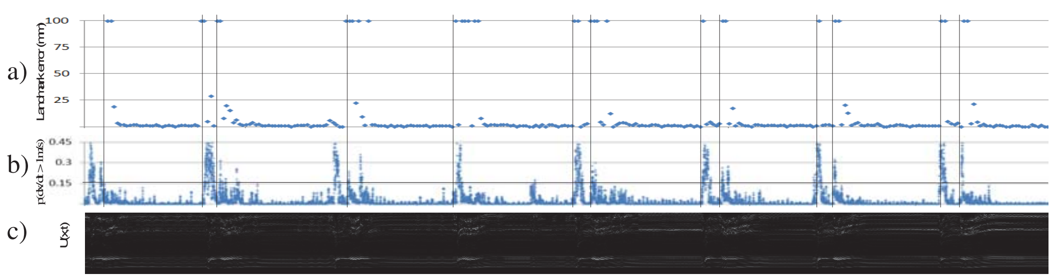

Fig. 4: *a) MR landmark localization error, b) gradient percentage over 1m/s and c) US signal. Spikes in localization error indicate MR frames in which automatic tracking landmarks are unobservable due to rapid coughing motion.*

References:

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