Figures

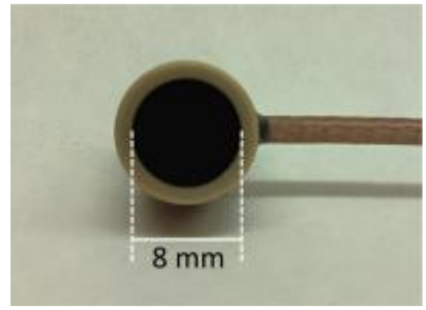


Figure 1: Close-up view of the 5MHz MR-compatible, single-element ultrasound transducer used here for hybrid data acquisition. While there was nothing special about the transducer itself or the MR images, correlations between the two offered interesting possibilities, such as scannerless synthetic MRI as demonstrated here.

Figure 2: The USrd transducer, patched on a volunteer using adhesive bandage. The blue pipe is a safety measure and guides all cables (USrd transmit/receive and optical fibers for temperature monitoring).

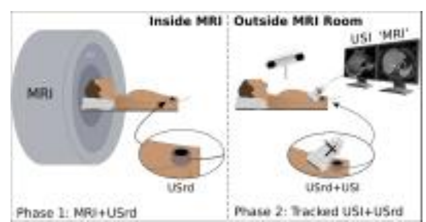
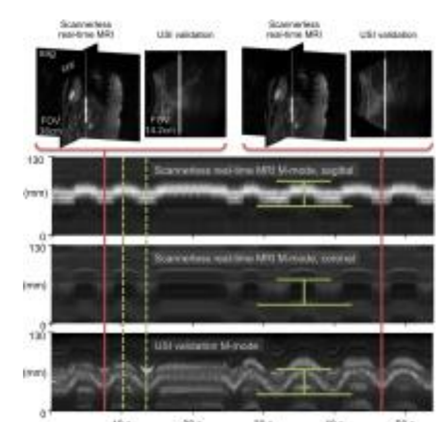


Figure 3: Data was acquired from 3 volunteers as shown above. In phase 1 (learning phase), hybrid USrd and MRI is acquired for 2 min. Using a regression model learned from this data, MRI of respiratory motion is synthesized outside the MRI room in phase 2. For validation, optically-tracked 2D ultrasound images (USI) are simultaneously acquired during phase 2. Using optical 3D tracking, the operator's hand motion is tracked while extracting the M-mode line (see Figure 4, USI validation).



Scannerless real-time MRI

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Synopsis

MRI can provide favorable image quality for image-guided interventions, but both magnetic field of the scanner and limited patient access inside the bore impose many limitations on image-guidance endeavors. The aim of this work was to estimate MRI of respiratory organ motion outside the scanner, which allows for a wider range of interventional applications. A single-element ultrasound transducer was used as a surrogate for the MR scanner outside the bore, after the correlation between both signals had been learned in a preceding training phase. Validation of estimated MR images outside the bore was performed using tracked 2D ultrasound.

Purpose

To generate streams of synthetic MR images outside the bore of the scanner, using data from a small, single-element ultrasound transducer, for image-guided therapy purposes.

Introduction

MRI is increasingly used for image-guided interventions, such as tumor ablation, needle placement and biopsies, due mostly to its excellent soft-tissue contrast [1]. However, patient access is severely limited by the physical confines of the bore, and the need for MR-safe hardware can have a clear impact on the availability, cost, and sometimes even the effectiveness of the devices involved.

MRI and ultrasound imaging have complementary strengths and have been combined in the past [2-4]. Hybrid ultrasound-MRI based on a simple single-element ultrasound transducer patch has previously been proposed to boost temporal resolution during real-time MRI [5-7]: With one MR image acquired roughly every second, the ultrasound raw data (USrd) signals and learned correlations with MRI can be employed to create synthetic frames and boost temporal resolution by up to two orders of magnitude [5]. In contrast, the present work goes further in the sense that synthetic MRI is performed outside the bore, and outside the MR scan room altogether, without any new MR data being acquired. For validation purposes, optically-tracked 2D ultrasound imaging (USI) was performed at the same time as scannerless real-time synthetic MRI, during free breathing, and results from both modalities were compared.

Methods

Three volunteers were imaged following informed consent with an IRB-approved protocol. During the training phase, MRI and USrd data were acquired jointly over a 2 min free-breathing period. The single-element USrd transducer (Fig. 1) was held in place by a simple adhesive bandage (e.g., see Fig. 2); it could be placed on either side of the abdomen but was located on the right side here, just below the ribs. The transducer was fired every TR=10ms (i.e., a repetition rate of 100Hz) and its signal U_t was centered at 5MHz. The US field was not focused, it was intended to penetrate the abdominal cavity and get reflected, possibly more than once, and to come back as a unique fingerprint of the current breathing state. The MRI aspect of the hybrid scan involved acquiring abdominal images I from two different planes, a sagittal and a coronal one, in alternation and repeatedly (matrix size 192x192, FOV 38x38cm, TR 10ms, acceleration rate 3.2, 0.6s per image, bandwidth $\pm$37.4Mhz).

A regression model was employed to estimate an unknown MR image I_t based on USrd signal U_t, using all acquired data pairs $D = \{U, I\}$ for training, according to

$$\mathbb{E}[I_t | U_t, D] \approx \frac{\sum_i I_i \, \mathcal{N}(U_t; U_i, \Sigma)}{\sum_i \mathcal{N}(U_t; U_i, \Sigma)}, \qquad [1]$$

where $\mathcal{N}(\cdot)$ is a Gaussian kernel with covariance matrix Σ. Furthermore, the agreement of multiple planes was accounted for, as described in [5].

The subject was then moved outside the MRI scan room, with the USrd patch still in place (see Fig. 3). The outside location, with unhindered volunteer access and no magnetic field, allowed optically-tracked 2D ultrasound imaging (USI) to be performed for validation purposes (Analogic Corporation, abdominal convex array model 8820e), in a sagittal plane that approximately corresponded with that of the MRI acquisition. The USI probe was tracked using a Polaris Vicra (NDI Medical) optical tracking system to compensate for the operator's hand-motion. The model from Eq. 1 was applied to the USrd signals acquired outside the scan room, to estimate an outside-the-scanner MR image sequence at 100Hz.

Results

The USI data provided accurate, spatially resolved ground-truth motion to help validate the scannerless stream of MRI images generated outside the scan room by means of M-mode plots (a single line of pixels plotted over time). For the US images, the location of this line was determined frame-by-frame based on the tracking data, to account for in-plane probe motion. Figure 4 shows the M-mode plot of subject 1 inside and outside the scanner. The motion in synthetic MR images accurately represents the true underlying respiratory motion, as observed by 2D ultrasound. For the other two datasets, equivalent results were obtained.

Discussion and Conclusion

Scannerless real-time imaging was performed in a space outside the MRI scan room where procedures could be performed, if patients were recruited rather than healthy volunteers. During an actual procedure the USrd device would be kept well away from the sterile zone, on either side of the body. Since the device does not need to be located close to the treated anatomy, USrd signals would not be expected to be overly affected by the procedure itself, but future results during procedures would be needed to confirm this statement.

Acknowledgements

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References

Figure 4: Scannerless high-speed MRI was achieved from outside the bore and scan room, based on USrd sensor data. Tracked 2D ultrasound images (USI) provided validation. Two time frames are shown (red markings) for subject 1. White lines in images show the 130-mm extent, in superior-inferior direction, chosen for M-mode display. Reference green lines are provided for comparing USI and MRI M-mode results, i.e., they help visualize temporal (dashed lines) and spatial (full lines) agreement.

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