Pilot-Tone: A compact, stand-alone device for tracking and correcting patient motion in MRI exams

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INTRODUCTION:

The sensitivity of MRI to motion impairs its reliability and diagnostic utility for examining the chest and abdomen[1]. External sensors such as respiratory belts have traditionally been used, however, oftentimes they are unreliable and tend to suffer from poor sensitivity[2]. Moreover, Self-navigation[3] technique, which extracts motion information from k-space center, is heavily dependent on imaging parameters (e.g. TR, number of slices) and can be too slow for certain types of physiological motion. Recently, we have introduced an alternative approach, called Pilot-Tone (PT). PT[4,5] is a small radiofrequency transmitter that generates a reference RF signal that is modulated by the subject's breathing pattern. Using PT, respiratory motion can be obtained with a high sampling rate and can be used for reconstructing motion-resolved images from free-breathing scans. More recently, we have created a dedicated open-source repository (https://cai2r.net/resources/3t-pilot-tone/) where PT device and its software (on GitHub) can be available for use in other MRI applications.

METHODS:

Hardware: PT transmitter is a small, non-magnetic stand-alone device with a rechargeable battery, placed inside a 3D-printed case (Fig. 1). The RF signal is generated by a 24.671 MHz standard clock oscillator whose fifth harmonic is at the desired frequency. The PT transmitter is placed outside the MR bore such that physiological movement of the subject causes coil load variations, resulting in modulations of the PT signal detected by the MR receive coil. **Software:** The PT signal is received in parallel to the MR signal during each readout, resulting in a unique imprinted signal in the image data (Fig. 2a). The respiratory signal is extracted by a fit in the frequency domain (Fig 2b): $A \cdot \exp(-i \cdot 2\pi \cdot f \cdot t)$, where f is the PT frequency and A is the complex amplitude signal, which modulates in accordance with the respiration. The breathing-induced PT signal, picked up by each receive coil, is extracted by a peak-detection algorithm and processed by principal component analysis (PCA), resulting in respiratory signal from all coils (Fig. 2c). Lastly, the respiratory signal is used by an eXtra-Dimensional (XD) reconstruction pipeline[3], which bins the continuously acquired radial data into different respiratory states from inhale to exhale (Fig. 2d). Our study protocol included a free-breathing radial stack-of-stars 3D GRE (RAVE) sequence with golden-angle acquisition with TR/TE=4.0/1.7ms, BW=500Hz/pixel, 102-240 slices, 800 radial views, and 1.6mm isotropic resolution.

Figure 1: Pilot-Tone device

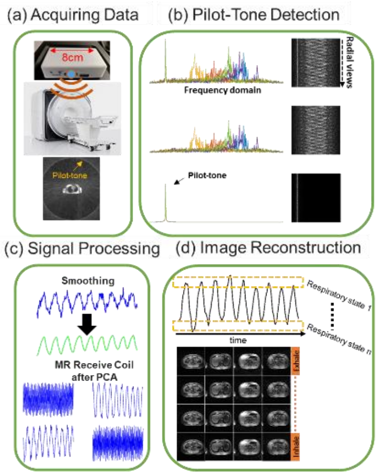

Figure 2: Pilot-Tone workflow

RESULTS AND DISCUSSION:

A reconstruction of averaged motion data (Fig. 3a) is compared to gridding and XD reconstruction binned to six respiratory states using the k-space center (Fig. 3b) and PT (Fig. 3c) motion signals. Data reconstructed with standard gridding shows inferior image quality when compared to XD reconstruction, for both methods. While the averaged motion data is clearly blurred, the use of the PT signal to bin the same data resulted in fewer motion artifacts, sharper vessels, and clearer anatomical details of liver and lung for both gridded and XD image reconstruction compared to k-space center (see yellow arrows).

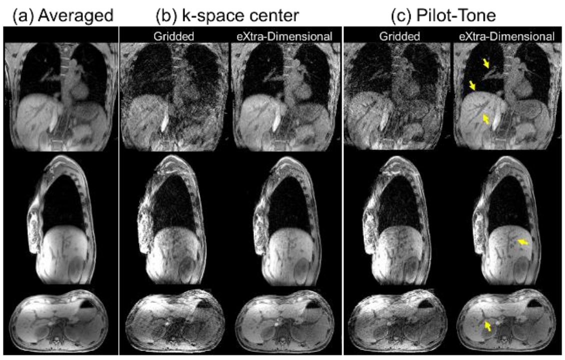

Figure 3: (a) Averaged-motion reconstruction compared to motion-resolved reconstruction using (b) k-space center and (c) PT respiratory motion signals.

CONCLUSION:

The small dimensions (8 cm) and high sampling rate associated with our open-source PT tool, offer great potential for tracking of breathing signals. PT's capabilities were also found to be useful with other radial stack-of-stars pulse sequences and was also shown to be effective in a low-field 0.55 T magnet.

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