An Alternative Concept for Non-Sequence Interfering, Contact-free Respiration Monitoring

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Introduction

Respiratory motion is a challenging problem in MRI, especially in abdominal and cardiac imaging. Appropriate motion detection and correction is needed to cope with this problem, and to improve diagnostic image quality. The respiratory navigator [1] is an existing MR based motion detection method and thus contact-free, it provides very good accuracy but has several disadvantages: the additional MR sequence that is needed to acquire the navigator signal not only costs time, it may also interrupt the steady state, particularly in cine imaging with continuous data acquisition. Moreover, it needs to be planned on a scout image. Recently, a new principle [2,3] was proposed for respiratory motion detection, which has the potential to overcome all these problems. It is based on the evaluation of motion-induced changes in the properties of the employed RF transmit coil. Thus, real-time information on respiratory motion can be obtained completely independent from the MR image acquisition sequence. The present method was implemented on a clinical MR system, and the measured respiratory motion curve was compared with that obtained with conventional respiratory navigators.

Methods

Patient motion, e.g. due to respiration, influences the RF coil loading. Changes in RF coil loading can be measured during RF pulse transmission. A pick-up coil (PUC) monitoring approach was used to measure the complex current in a transmit coil, while it is in its tuned state. The technique was implemented on a whole body 3T MRI system (Achieva, Philips Medical Systems, Netherlands), equipped with eight parallel RF transmit channels [4]. Each of the eight individual RF transmit elements of the multi-channel body coil (MBC) [5] is equipped with a different PUC-unit. The basic intention of the PUCs is to detect potential unsafe system operation [6] and to facilitate system calibration [7]. However, the same information can further be used to detect respiratory motion. In MRI imaging experiments, the transmit currents in the RF coil elements are sampled during the RF pulses. Real-time Kalman filtering [8] was applied to smooth the PUC signals for the individual channels, which resulted in a respiration curve approximation. To achieve optimal results with the Kalman filter, initial coefficients have to be estimated. This can, e.g., been done in a short extra preparation phase as the coefficients are respiration curve dependent. Different alternative processing steps were investigated to generate one final PUC signal: (a) select the best SNR channel for motion sensing (b) perform a noise optimized channel combination taking the noise figure in each channel into account (c) perform a spatially weighted signal combination taking the Tx coil sensitivities and a desired spatial target into account.

To access the accuracy of the final combined PUC signals, with respect to a pencil beam navigator signal, in-vivo imaging experiments were performed for 7 healthy volunteers. Gradient echo imaging was performed (TR=50 ms, TE=2.3, $\alpha=10°$, FOV=320mm) while each phase encoding step was preceded by a separate navigator, placed to the right hemi diaphragm, not interfering with imaging. The PUC signals of the slice selective RF pulses were sampled simultaneously via the eight pick-up coils with a temporal resolution of 3.2µs. The information about the amplitude change was extracted from the monitored PUC signals by averaging each RF pulse, and combined using the approaches (a)-(c) mentioned above to determine the respiration state. Initial gating experiments have been performed.

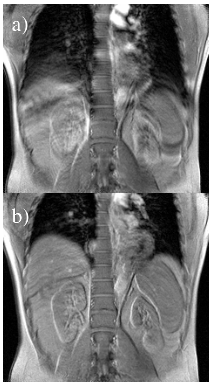

Fig. 4:
a) Image acquired during free breathing (a) and gating (b).

Results and Discussion

Examples for typical respiration signals for the eight different PUC signals are shown for a given volunteer in Fig. 1. Not all Tx elements are sensitive for proximity reasons because not all of them are exposed to moving anatomy. This finding agrees very nicely to the arrangement of the coil elements in the magnet bore. Real-time Kalman filtering has been shown to be very effective to suppress channel dependent noise. All different PUC signal combination algorithms (a)-(c) delivered good quality signals sufficient for respiration motion phase sensing. The combination approach (c) was not as powerful as expected. The gain to further confine the spatial origin of the PUC signal, e.g. to right hemi diaphragm, by incorporating transversal Tx coil sensitivities into the signal averaging process was small compared to a simple average of the 4 nearest PUC coil signals. The combined PUC signals show a surprisingly good correlation to the navigator signal (see Fig. 2). This is a very important finding because it allows for further refinements of the approach. A short calibration phase over a couple of respiratory cycles was found to be sufficient to calibrate a simple model [9] matching the quantitative navigator signal to the PUC signal (see Fig. 3). This offers the opportunity to use the PUC signal not only for gating but also for prospective tracking in the future. The combined PUC (approach a, b) are directly accessible by the real-time spectrometer with a latency of 20 ms, allowing for gated image acquisition, which reduces respiratory motion artifacts (see Fig. 4).

Conclusion

The proposed respiration monitoring concept was successfully implemented on a clinical MR system. It provides a contact-free measurement of respiratory motion and operates independently of the imaging sequence. Therefore, potential adverse effects on the steady state magnetization are eliminated. The motion pattern detected with the present approach shows a good correlation with that obtained with conventional respiratory navigators. The present technique can ideally be used for respiratory gating. Eventually, the presented approach may provide a quantitative measure of diaphragmatic motion (in millimeters).

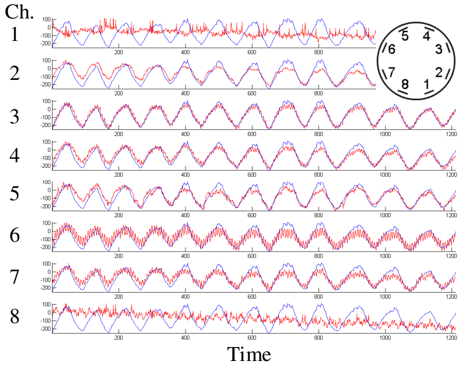

Fig. 1: Respiration signals (red) of all eight Tx channels together with the navigator signal (blue) is shown for one volunteer.

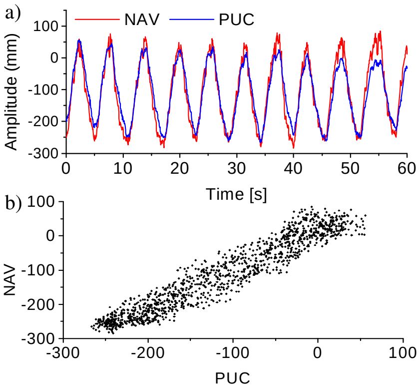

Fig. 2: Comparison of one PUC signal with the navigator signal (a) and correlation between navigator and PUC signal (b).

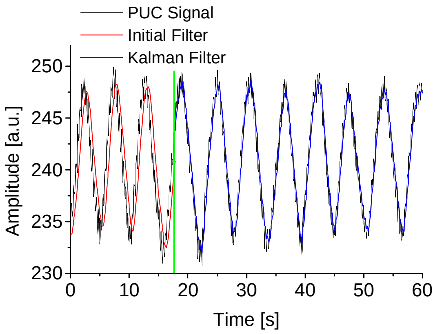

Fig. 3: Unfiltered PUC signal (black) with initial coefficients estimation (red) and kalman filtered signal (blue).

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