Monitoring Respiratory Motion Using Continuous Wave Doppler Radar in a Near Field Multi Antenna Approach

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Purpose:

To avoid motion artifacts in medical imaging or to minimize exposure of healthy tissues in radiation therapy medical devices are often synchronized with the patient's respiration.

Materials and Methods:

To assess respiratory motion, many methods are in use, today. Most of them measure the respiration motion outside of the body by evaluating thorax or abdomen displacement. Disadvantages of these techniques are the need for patient preparation and the fact, that a slight time delay between internal organ motion and displacement measured outside of the body occurs which can differ from day to day [1], [2].

Assessment of respiratory motion using radar waves is known for more than 35 years [3]. Measurement is done by evaluating the variation of the distance between the radar transmitter and the chest or abdomen surface. Consequently, the output of these devices is similar to the gating methods used today.

We designed a continuous wave Doppler radar system operating on 869 MHz. In contrast to other publications, we use separate transmit and receive antennas which gives us a higher degree of freedom in placing the antennas. To achieve a larger radar-sensitive area to simplify patient positioning, more antennas are used. To avoid the requirement for more transmit and receive units we use coax switches to switch every 4 ms to the next antenna. Figure 1 shows the wiring between the switches and the antennas.

As opposed to earlier publications, we placed the antennas close to the body. The radar waves propagate into the body and are reflected on the boundaries between different tissues, i.e. the outline of organs. For the test person measurements we located the antennas on top of a standard CT table, see figure 3. The test persons lie in the supine position on the table, directly above the antennas. The radar measurement was executed having the radar antennas on six different positions along the spine as shown in figure 2. In further applications, the antennas may be integrated in the patient table.

The system was tested using 10 test persons (6 male, 4 female). As a reference the respiratory signal from a state-of-the-art external respiratory gating system was recorded simultaneously. For each test person and each antenna position two datasets were recorded: For the first acquisition, the test person was advised to normal breathing, for the second acquisition normal breathing was interrupted by a single deep inhale and a single deep exhale breath-hold.

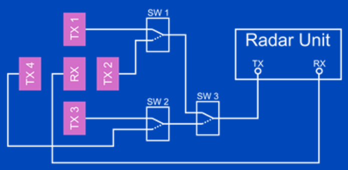

Fig. 1. Arrangement of the antennas and the connections between the radar unit, the coax switches (SW) and the antennas.

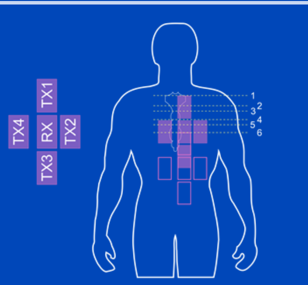

Fig. 2. Location of the six measurement positions relative to the sternum. The filled rectangles illustrate the antennas at position one, the blank rectangles the antennas at position six.

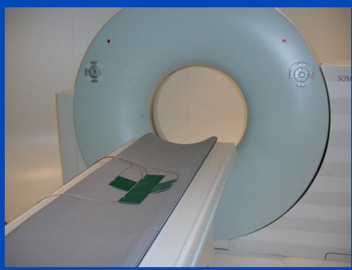

Fig. 3. Placement of the antennas above the CT table. The test persons rest on fully clothed directly above the antennas.

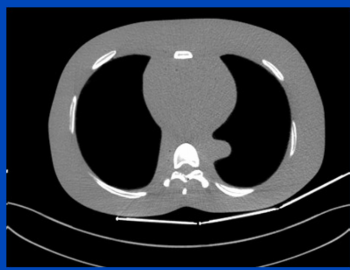

Fig. 4. CT image having a thorax phantom above the antennas.

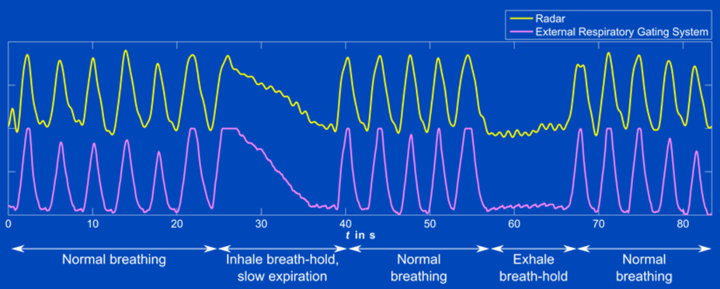

Fig. 5. Example dataset. The upper curve shows the respiratory motion measured with our radar system, the bottom curve shows the respiratory motion measured with the external respiratory gating system.

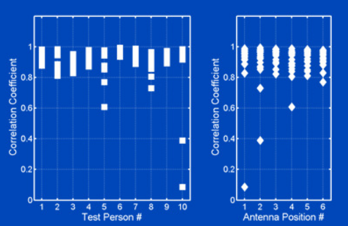

Fig. 6. (left) Correlation coefficients from all measured data sets between respiratory motion calculated form the radar data and respiratory motion measured with the external respiratory gating system.
(right) Calculated correlation coefficients from all measured data sets ordered according to antenna position.

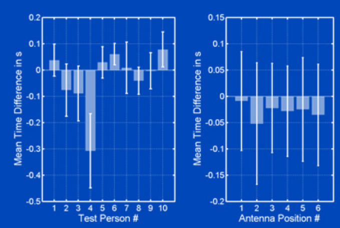

Fig. 7. (left) Mean time shift between the external respiratory gating system and the proposed radar system for all test persons. A positive value indicates that the signals from the external gating system are ahead of the signals from the radar system.
(right) Mean time shift from all measured data sets ordered according to the antenna position.

Results:

Figure 5 shows a comparison between the respiratory motion measured with our radar system and the respiratory motion measured with the external respiratory gating system. Each measurement pair (radar vs. external gating system) was compared by calculating the Pearson correlation coefficient. The calculated correlation coefficients for all datasets sorted according to the test person numbers could be seen in figure 6 (left). The mean value for the correlation coefficient is 0.917 with a standard deviation of 0.108. So the respiratory motion calculated with our radar system has a high correlation to the respiratory motion measured with a state-of-the-art external respiratory gating system. For figure 6 (right) the same correlation coefficients are sorted according to the antenna positions. Obviously our approach of using more antennas is able to reliably detect the respiratory motion regardless of the patient position.

In addition to quantify the correlation we also evaluated the time shift between the radar dataset and the external respiratory gating system. Figure 7 (left) shows the calculated time shifts for each test person. As one can see, the time difference varies from person to person and is not constant, not even for the same person. In figure 7 (right) the same values are sorted according to the antenna positions. No correlation of the trigger points with the antenna position was found. This again confirms that our approach by using more antennas is able to reliably detect the respiratory motion regardless of the exact patient position.

In reference [2] the time shift between the motion of implanted markers and the motion detected by an external respiratory gating system is measured. The authors report time shifts up to 0.6 seconds, depending on day and person. Evaluating the time shift occurred during our measurements show similar results. This may indicate that the proposed radar system is able to measure internal motion better than existing systems.

Conclusion:

Our preliminary experience indicates that the proposed radar system well detects respiratory motion. It appears to have the potential to be used for respiratory gating, and to replace other external motion detection systems that evaluate the motion of the body contours rather than the internal motion.

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