Microwave doppler radar for cardiac and respiratory activity measurement – preliminary results

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MICROWAVE DOPPLER RADAR FOR CARDIAC AND RESPIRATORY ACTIVITY MEASUREMENT – PRELIMINARY RESULTS

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Abstract: *We present a design for a 868 MHz microwave Doppler radar system integrated in a foam mattress for measurements of cardiac and respiratory activity from the back of a subject. For this application, lower frequency and higher penetration depths promise a deeper physiological characterization than previously proposed radar systems at 2.4 GHz and above. Within this contribution we present preliminary results from a proband study which prove the applicability of the proposed system.*

Keywords: *Cardiac Activity, Respiratory activity, Doppler radar, Mattress*

Introduction

Over the past few years, progress has been made in the optimization of continuous-wave Doppler Radar systems for sensing cardiac and respiratory motion activity from a distance by measurement of surface motion in the far-field [1,4,5]. Physiologically, the quantity to be measured in this approach is cardiac and respiratory motion s of the chest wall. Technically, basic principle of these systems is a two-antenna system where the phase shift φ between transmit and receive signals is directly proportional to s:

$$\Delta\varphi = \frac{4\pi}{\lambda} \cdot \Delta s \qquad (1)$$

For this purpose, recent work focusses on frequencies with low penetration depth such as f = c/λ of 2.4 GHz, 24 GHz and 60 GHz.

Contrary, for special applications, measurement from the back at small distance may be useful: Beyond sleep monitoring and bed sensors, current works list triggering of medical devices [2] and resuscitation monitoring [3]. Due to small surface motion of the back wall, in this case a lower frequency and thus higher wavelength promises a better signal quality. This contribution therefore proposes a setup based on a radar frequency of 868 MHz and presents first results which were gained in a proband study using 18 healthy subjects.

Methods

Basic concept

Our work focusses on a radar frequency of 868 MHz where penetration depth in muscle is about 4.3cm (wavelength 4.6 cm) [6]. This also shows that our work takes place completely in the near-field of the antennas. Thus, equation (1) does not readily apply.

Antenna design

We optimized a pair of patch antennas for integration into a foam mattress next to the surface (distance to skin 1 mm, a thin shirt is also possible), as presented in [7]. Outer geometry of these antennas is determined by optimization in a high-frequency model of the body (see fig.1); bandwidth is artificially increased by using a "U" profile and using a thick Teflon layer and thus higher than 150 MHz in order to provide independency of individual dielectric parameters of the body. Furthermore, for optimal coupling, we use a through-hole microstrip feed line.

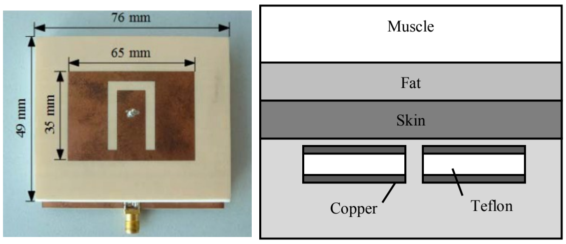

Figure 1: Patch antenna layout and setup geometry

Electronics concept

For generation of the transmit signal we use a local oscillator. This transmit signal is mixed with the receive signal in an I/Q demodulator in order to extract amplitude and phase information.

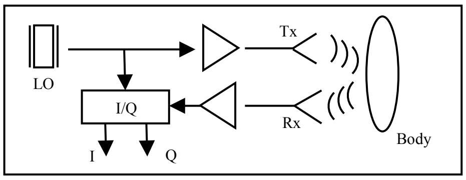

Figure 2: Electronics concept

Measurement setup

To characterize our signals, the Radar components are measured in parallel to classic ECG, pulse ear clip and respiration belt sensors using ADInstruments sensors and synchronous A/D converter *PowerLab 35/16*. Sampling rate is 2 kHz.

Measurement procedure and subjects

22 recordings of 18 healthy subjects (avg. 27 y, 1.80 m, 80 kg; 4 female) were measured for 10 minutes each in the relaxed, lying state with the antennas located on the upper back with a fixed reference on the proband's neck.

Signal processing

Demodulated components I and Q are transformed to (global) Amplitude A and Phase P signals via

$$A = \sqrt{I^2 + Q^2}, P = \arctan\left(\frac{Q}{I}\right) \quad (2)$$

For elimination of thermic drift and change of coupling conditions (e.g. sweat), a 10 s-windowed moving average is subtracted from all signals.

For separation of signal components, respiratory activity is extracted by FIR-based low-pass filtering at 0.5 Hz, cardiac activity by band-pass filtering 1 Hz .. 40 Hz.

Characterization in frequency domain is performed using windowed FFT (Hamming-window) on 1 min segments and averaging of the results. Thus, resolution in frequency domain is 0.015 Hz. Rates are determined using a maximum search in the resulting power spectrum.

Results

The following image gives an example of the normalized power spectrum of both radar signals and the reference signals (before separation by filters and averaging). Respiratory information dominates the phase signal; cardiac information is mostly contained in the amplitude signal.

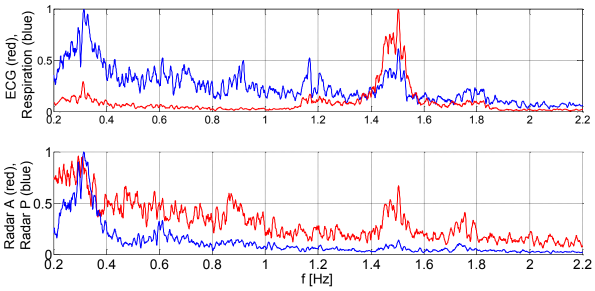

Figure 3: Signals example in frequency domain (normalized power spectrum) of a subject at heart rate 90 bpm

Using a +/-10 % tolerance band around the reference rate, both respiration and heart rates may be extracted correctly in 90.9 % of recordings. Errors in respiration rate are driven by limited frequency resolution; cardiac information is suppressed by electronic noise in 2 recordings.

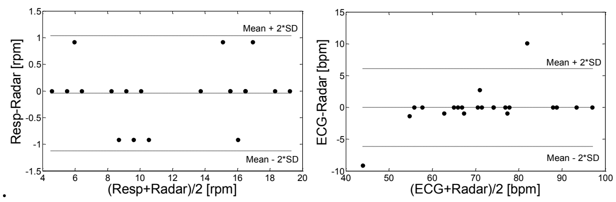

Figure 4: Bland-Altmann plots for the matching of respiration and heart rates

The following images give examples of the filtered (and synchronized) signals in the time domain.

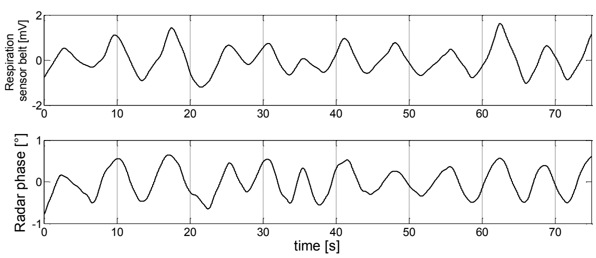

Figure 5: Respiration signals example

In our measurements, cardiac activity information is better visible in the amplitude, which is due to phase noise in our setup which masks the cardiac information.

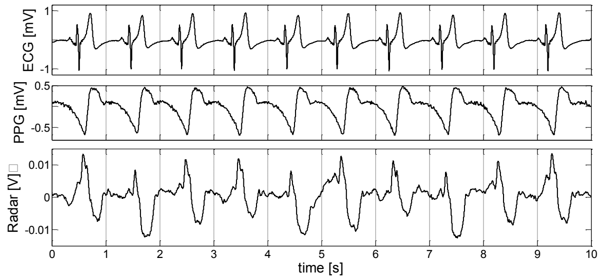

Figure 6: Cardiac signals example

Discussion

Our setup shows the feasibility for integration of optimized antennas into a mattress setup – although signal information is lower than using the standard sensors. Contrary to simple not-optimized patch antennas that we used in a first test run in the past, the setup proved to be robust to motion in the vicinity of the subject.

Our further studies will concentrate on the behaviour and modelling of the signals in time domain where the main challenge lies in separation of the cardiac component from the dominating respiratory signal.

Bibliography

[1] K. Tavakolian, F. Zadeh, Y. Chuo, A. Vaseghi and B. Kaminska, "Development of a Novel Contactless Mechanocardiograph Device", *International Journal of Telemedicine and Applications,* 2008.

[2] F. Pfanner, T. Allmendinger, T. Flohr and M. Kachelrieß, "Monitoring respiratory and cardiac motion in CT using a continuous wave Doppler radar", *ECR,* 2013.

[3] M. Hofmann, J.-C. Edelmann, A. Bolz, R. Weigel, G. Fischer and D. Kissinger, "RF based feedback system for cardiopulmonary resuscitation," *Biomedical Wireless Technologies, Networks, and Sensing Systems (BioWireleSS), 2012 IEEE Topical Conference on,* 2012.

[4] A. Droitcur, "Non-contact measurement of heart and respiration rates with a single-chip microwave doppler radar", PhD thesis:Stanford University, 2006.

[5] M. Varanini, P. Berardi, F. Conforti and M. Micalizzi, "Cardiac and Respiratory Monitoring through Non-Invasive and Contactless Radar Technique," *Computers in Cardiology*, vol. 35, pp. 149-152, 2008.

[6] Italian National Research Council, Institute for Applied Physics, "Dielectric Properties of Body Tissues" Florence, Italy, URL (as of 2013-04-06): http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.htm

[7] R. Hahnel, Q. Wang, R. Trieb, D. Plettemeier and A. Henning, "Antenna Design for Heartbeat Detection for Triggering Purposes of Medical Devices", *International Workshop on Antenna Technology (iWAT)*, Karlsruhe, Germany, 2013.