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Time Domain Radar Detection of Vital Parameters in a Hospital Bed

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Abstract **-** An off-the-shelf radar sensor board is mounted under the mattress of a hospital bed for the purpose of contactless measurement of human vital parameters. Body vibrations due to pulse and respiration are detected by the radar sensor. Time domain signal processing inside the sensor provides estimates of breathing rate and pulse rate. ECG-based data serve as a reference to evaluate the radar performance. The results are promising in terms of accuracy and robustness, making radar an interesting option for contactless sensing.

Keywords**:** contactless, human sensing, signal processing, radar

1. Introduction

Contactless measurement of human vital parameters has a number of advantages: It increases the comfort for the patient, because no wiring is needed, and it allows automated, continuous measurements, which reduces the workload for nursing staff and broadens the medical data base.

For this purpose an off-the-shelf 60GHz radar sensor board is mounted under the mattress of a hospital bed. The transmitted electromagnetic waves are reflected at the back of the patient and received by the sensor as depicted in Fig. 1. Movements of the patients back, in particular body vibrations due to pulse and respiration are detected by the radar sensor.

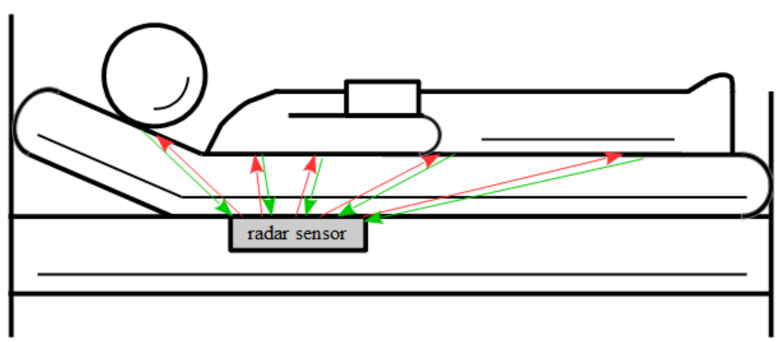

Fig. 1: Principle of radar measurement.

The sensitivity of radar for detecting these parameters has already been proven for the described setting in [1] and for a similar setting in [2]. Efforts in time domain radar signal processing described in this paper show the potential of the radar setting to achieve significant improvements in terms of accuracy and robustness.

2. Methods

2.1. General Approach

Adaptations of both modulation and signal processing are the keys to achieve a proper radar performance for the current application. A suitable radar modulation has already been presented in [1]. Unlike in [2], it provides single TX radar chirps modulated over 4GHz bandwidth, achieving range resolution of 3.75cm. This allows an extraction of the shortest signal propagation path from the radar sensor board to the human body and back, termed range bin. It corresponds to the thickness of the mattress leading to a complex quantity for each single measurement. With one range measurement every 50ms, a complex amplitude signal (CAS) is recorded with 20 samples per second. CAS contains all body movement components, e.g. pulse and respiration components, its phase signal is subject to an optimized signal processing. The signal processing chain is depicted in Fig. 2.

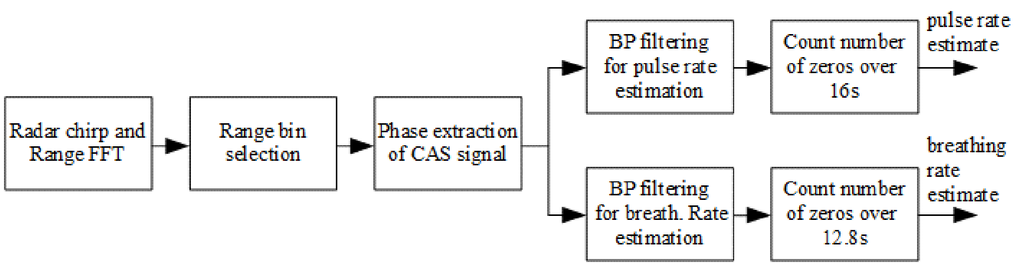

Fig. 2: Radar signal processing chain

Generally the respiration and the pulse component of the phase signal must be separated in order to estimate the breathing rate and the pulse rate in different signal processing lines. This separation is crucial especially for the pulse rate estimation because the peak-peak amplitude of the respiration component is much stronger than the pulse component, typically by 20dB.

For this purpose bandpass filtering is applied in both processing lines. In the respiration line a second order Butterworth filter is implemented with passband range from 0.1Hz to 0.6Hz, corresponding to 6BPM to 36BPM (breaths per minute), which is a typical range for the breathing rate. The stopband attenuation increase of 12dB/octave is sufficient to suppress the pulse component in the respiration line for typical pulse rates.

In the pulse line more effort must be spent to suppress the respiration component. A fourth order Butterworth filter is applied. In [1] the passband range was set from 0.7Hz to 1.6Hz, corresponding to 42BPM to 96BPM (beats per minute), a typical range for the pulse rate. For this kind of filter, the stopband attenuation increase was 24dB/octave, leading to a proper attenuation of the respiration component in the pulse line. Nevertheless the respiration component attenuation in the pulse line degraded when the current breathing rate increased, leading to temporary erroneous pulse rate estimates in [1].

In a last signal processing stage in each line in Fig. 2, the number of zero crossing in the bandpass filter signals are counted over 12.8 seconds in the respiration line and over 16 seconds in the pulse line, providing estimates for both pulse and breathing rate in the respective line. This alternative technique already showed its potential in [1] and has been developed further with the results being presented in this paper.

2.2. Further Developement

In order to prevent distortions in the pulse line originated from respiration, the filter in the pulse line is now adjusted to the first harmonics instead of the fundamentals, leading to a passband range from 1.4Hz to 3.2Hz. This increases the spectral distance between the two signal components respiration and pulse, leading to a higher attenuation of the respiration component in the pulse line. The counting of zero crossings of the bandpass filtered pulse signal component is conducted over 16 seconds. This leads to a coarse pulse rate estimate. The accuracy turns out to be moderate due to the comparatively high passband range of 1.8Hz.

For this reason a second estimation stage is implemented in the pulse line. Fig. 3 shows the respective two stage signal processing.

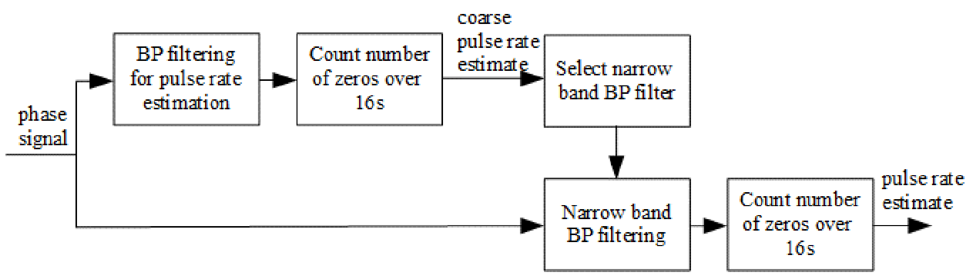

Fig. 3: two stage signal processing in pulse line

Depending on the coarse pulse rate estimate, one out of eight narrow band filters is selected, which filters the phase signal. Each of these filters is a fourth order Butterworth filter with a passband range of 0.4Hz. The output signal of the selected narrow band filter is subject to counting of zero crossings, leading to the final pulse rate estimate.

3. Results

3.1. Measurement Setting

The radar sensor provides estimates of the patient's breathing rate and pulse rate as described above. In order to evaluate the accuracy of these estimates, an additional ECG-based measurement is set up in parallel and all the data is collected in a measurement computer as depicted in Fig. 4.

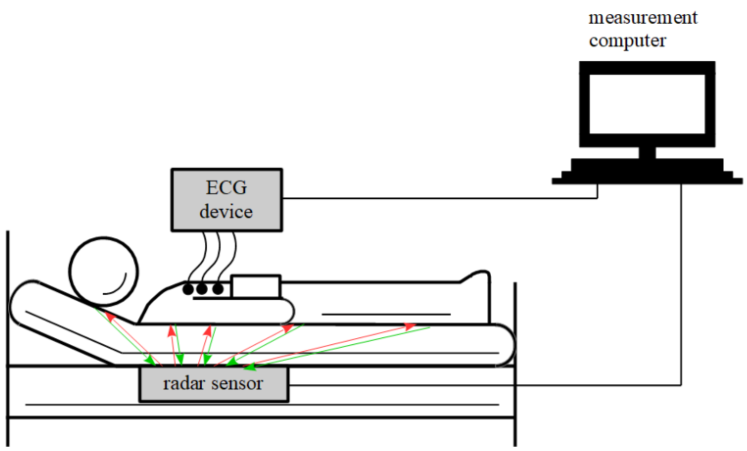

Fig. 4: Vital signs measurement setting.

3.2. Measurement Results

A measurement was executed over 12 minutes according to the setting depicted in Fig. 4, recording pulse rates and breathing rates both radar-based and EGC-based. All the graphs are depicted in Fig. 5.

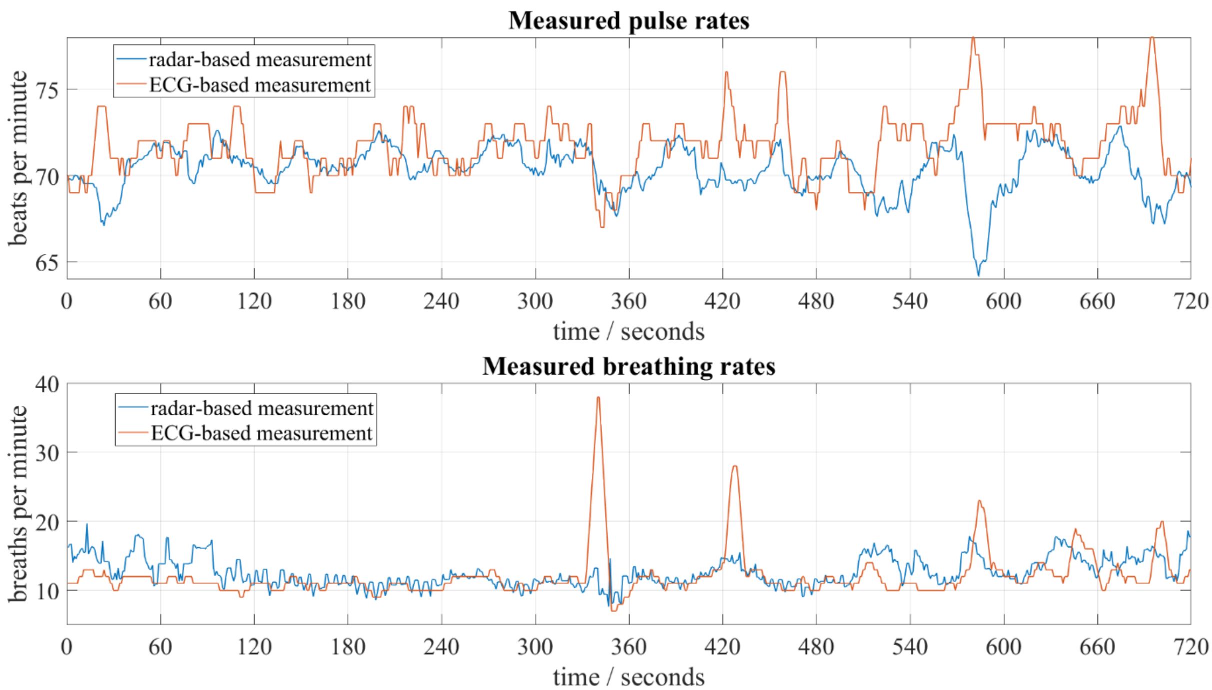

Fig. 5: Recorded pulse and breathing rates

The accuracy of the radar-based pulse measurement turns out to be quite high and lies within the ECG accuracy interval of ±3BPM most of the time. Only during distinct movements of the test person, e.g. at time 580 seconds, a higher deviation between these two quantities can be observed. This issue is in the scope of current work to make the radar less susceptible to such effects.

The radar-based breathing rate estimates show only little deviation from the ECG-based values. Some peaks in the ECG graph are probably due to problems with the electrodes of the ECG device, making the radar-based estimates even more reliable.

4. Conclusion

The measurement results show that radar is suitable for contactless measurements in a hospital bed, featuring a broader medical data base, less workload for nursing staff and increased comfort for patients. Anyhow further effort is necessary to enhance the accuracy of the technology. The robustness against patient movements, e.g. turnovers, should also be evaluated.

References

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