

Clinical Validation of a New Radar System for Multi-Parameter Vital Sign Detection in Patients

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Summary:

This work presents a 77 GHz radar system for contactless monitoring of motion, respiration, heart rate, and heart rate variability. The system improves signal-to-noise ratio, spatial flexibility, and temporal resolution compared to previous designs. Clinical measurements over multiple nights demonstrate reliable detection of respiratory patterns, apnea events, and cardiac features. Advanced signal processing enables robust separation of respiration and heartbeat signals. The results highlight the system's potential for real-world clinical monitoring.

Keywords: FMCW radar, patient monitoring, signal analysis, sensor arrays, heart rate variability

Introduction

Contactless monitoring of vital signs has gained significant importance in clinical and home-care environments, as conventional wearable sensors can cause discomfort and limit patient mobility. Radar-based approaches, particularly frequency modulated continuous wave (FMCW) systems, enable non-invasive detection of physiological motion such as respiration and heartbeat [1,3].

Recent research has extended these systems toward more advanced applications, including heart rate variability (HRV) estimation and sleep apnea detection [2,4]. However, accurate extraction of cardiac features remains challenging due to the dominance of respiratory motion in the radar signal.

The integration of multiple-input multiple-output (MIMO) radar architectures significantly improves spatial resolution and interference suppression, enabling reliable measurements even in complex environments [3].

Background, Motivation and Objective

Most existing studies focus on individual vital parameters, whereas clinical practice requires a comprehensive monitoring solution. A previously developed system demonstrated the feasibility of radar-based monitoring but suffered from several limitations [6]. In particular, the transmit power and resulting signal-to-noise ratio were insufficient for reliable heart rate and HRV estimation. The system required placement beside the

bed, which is impractical in clinical environments, and its temporal resolution was too low to capture rapid cardiac dynamics.

The objective of this work is to overcome these limitations by introducing an improved radar system and to validate its performance in a clinical setting over extended monitoring periods.

Description of the New System

The proposed system is based on a 77 GHz INRAS RadarLog MIMO radar and a Microsoft Kinect depth camera as reference, see Fig. 1.

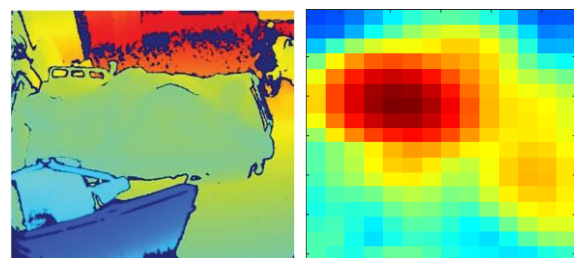


Fig. 1. Illustration of the depth camera image (left) and the radar image (right) for a patient in bed.

The radar signal is segmented into time windows of approx. 30 s. For each window, a range-angle representation is computed using a 2D fast Fourier transform (FFT). Static reflections are suppressed, and the $k \in \{1, \dots, K\}$ strongest reflection points are selected for further processing.

The phase evolution $\varphi_k[t]$ of these points is analyzed. A low-pass filter is applied to extract the respiratory component $\varphi_k^{LP}[t]$ and the respiration

rate is estimated via FFT using the fundamental frequency and its first two harmonics. This also enables the detection of apnea events.

To extract cardiac information, the second order derivative of the phase signal

$$\ddot{\varphi}_k[t] = \frac{1}{16} (\varphi_k[t+3] + \varphi_k[t-3] + 2\varphi_k[t+2] + 2\varphi_k[t-2] - \varphi_k[t+1] - \varphi_k[t-1] - 4\varphi_k[t]) \quad (1)$$

is computed, following the approach in [5]. The computation of $\psi_k[t] = \ddot{\varphi}_k[t] - \ddot{\varphi}_k^{LP}[t]$ further suppresses low-frequency respiratory components, where $\ddot{\varphi}_k^{LP}[t]$ is the second derivative of the low-pass filtered phase.

The temporal spacing between detected peaks is used to estimate HRV, while heart rate is additionally determined in the frequency domain. Patient motion is identified by thresholding of the phase acceleration signal.

Results

The system was initially validated in laboratory conditions using reference sensors, including inductive belts for respiration and a pulse oximeter for cardiac measurements. Subsequently, clinical measurements were conducted on five patients with multiple sclerosis in a rehabilitation clinic. In total, more than 20 nights of data (approx. 12 hours each) were recorded. The radar system was mounted on the ceiling 2.8 m away from the patient, ensuring unobtrusive operation.

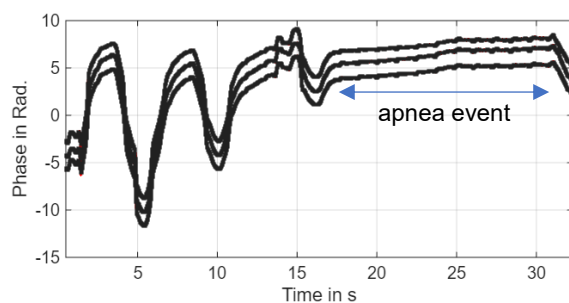


Fig. 2. Measured phase evolution generated by respiration in three reflection points.

The results demonstrate that respiratory patterns and apnea events can be clearly identified (Fig. 2). The phase signal shows distinct variations corresponding to breathing cycles, and apnea events are detectable as interruptions in the periodic pattern, consistent with findings in [4].

Cardiac signals are also successfully extracted, see histogram in Fig. 3. The heartrate varies over the course of the night, reflecting different physiological states.

The second derivative of the phase signal reveals distinct peaks corresponding to heartbeats (Fig. 4), enabling reliable estimation of heart rate and HRV, in agreement with prior work [2,5].

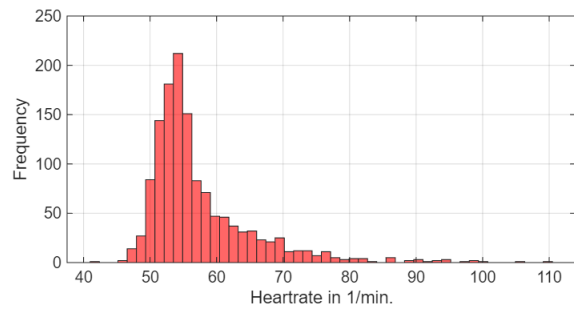


Fig. 3. Measured heartrate over the whole night.

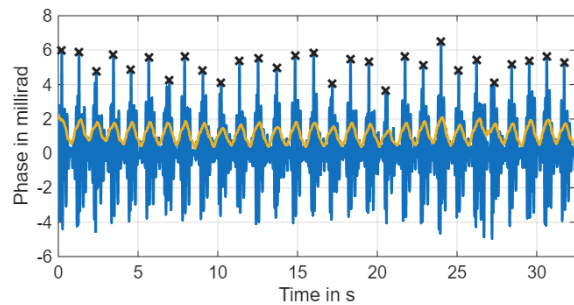


Fig. 4. Acceleration signal during normal respiration. Individual peaks are clearly visible.

In addition, the system reliably detects patient motion and presence, allowing differentiation between resting and active periods.

Discussion

In this study, a manual evaluation was performed by medical staff after one night to assess the health status. The measurement system can be enhanced by immediate data analysis, thus providing real-time information for nursing care.

References

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