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Vital Signs Monitoring for Different Chest Orientations Using an FMCW Radar

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Abstract

In this work the ability of a frequency modulated continuous wave (FMCW) radar to measure the respiratory rate and the heartbeat of a subject in challenging scenarios is tested. The radar, operating in the 5.8 GHz industrial, scientific and medical (ISM) band, has been suitably designed for the proposed application. Four different orientations of the target with regards to the radar antenna have been considered: the measured subject has been positioned with the breast, the left side, the right side and back facing the antenna. In all the scenarii the vital signs have been successfully extracted from the radar signal and compared with a photoplethysmograph and a respiratory belt. The radar was capable of measuring both the respiratory rate and the heartbeat with high accuracy.

1 Introduction

Radar sensors have been investigated in the last two decades as a promising solution for long-term home care monitoring [1, 2]. These sensors are particularly useful, since they are able to estimate the patient position and the information about its respiratory rate and heartbeat, without the need of any cable or electrode. In [3, 4] continuous wave (CW) radars have been proposed for vital sign estimation, but, even if they can measure accurately the breast movements caused by the heart and the respiratory activity, they cannot retrieve the information about the patient distance. As a solution, in [5, 6] hybrid systems have been considered. In this case a CW radar is employed for vital signs estimation and a frequency modulated continuous wave (FMCW) one for the patient position. However, this configuration requires a complex architecture and two different signal processing chains. In [7] it is shown that, with the study of the phase variations associated with the target position, both the information about vital signs and position can be measured with an FMCW radar.

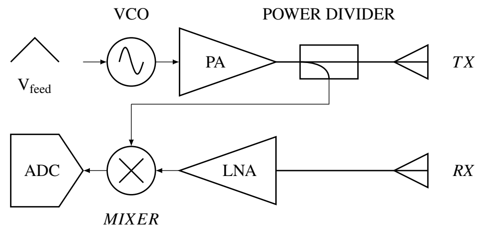


Figure 1. Block diagram of the designed radar.

In this work, the ability of an FMCW radar to measure the vital signs of a patient with different orientations towards the antenna has been tested. The 5.8 GHz FMCW radar used for the measurements together with the antennas [12] have been opportunely designed for the proposed application. The accuracy of the system has been verified by comparing the cardiac and respiratory frequencies with a photoplethysmogram (PPG) and a respiratory belt, respectively. The designed radar and the antennas are described in Section 2. In Section 3 the signal processing chain is reported, while in Section 4 the measurement results are presented. In Section 5 conclusions are drawn.

2 System Overview

The designed system is a single input single output (SISO) FMCW radar, working in the 5.8 GHz industrial, scientific and medical (ISM) band. A block diagram of the system is presented in Figure 1 and the photos of the realized radar and antennas are reported in Figure 2. The transmitting chain of the radar includes a voltage controlled oscillator (VCO), a power

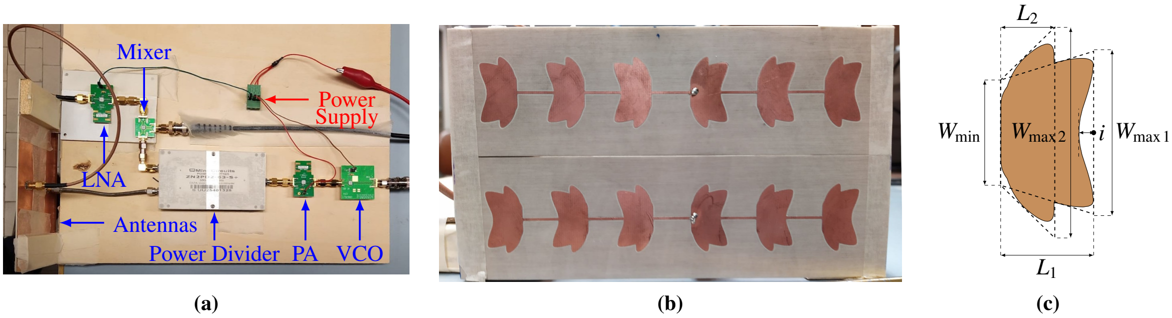


Figure 2. Photo of (a) the radar system and (b) the antennas and (c) geometry of the patch.

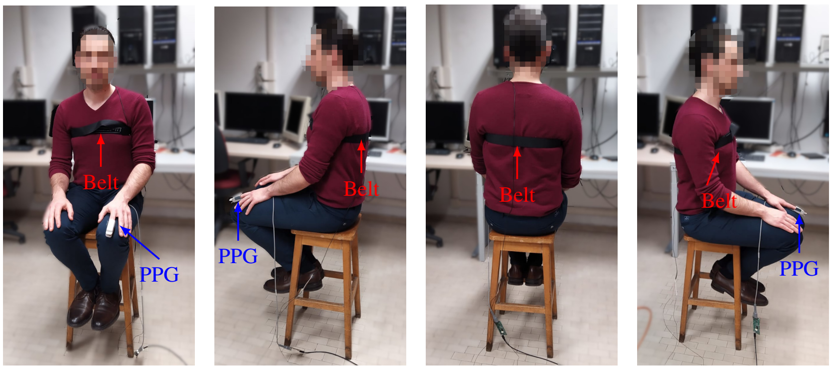
amplifier (PA), a power divider and the transmitting antenna. The VCO is fed with a triangular signal, that has been preferred to the ramp one since it does not present strong discontinuities, responsible of unwanted harmonic components in the measured signals. The receiving chain includes the receiving antenna, a low noise amplifier (LNA), a mixer and an analog to digital converter (ADC). To obtain a cheap system, discrete components have been chosen. In particular, the selected components are the HMC587LC4B [8] for the VCO, the HMC392ALC4 [9] for both the PA and the LNA, the HMC557A [10] for the mixer and ZN2PD2-63-S+ for the power divider [11]. The antennas have been suitably designed for the proposed application [12]. Each radiating element is a series fed array composed of six patches. The shape of the patch is reported in Figure 2c. It has been optimised to increase the bandwidth, typically extremely narrow for this kind of antennas, and to reduce the side lobe level. More specifically, a bandwidth increase has been achieved with a dual band structure, obtained with the superposition of two tapered patches with different lengths (L_1 and L_2 in Figure 2c). The side lobe level is controlled by the curvature degree of the upper edge of the patch, that modulates the fraction of power transferred from one patch to the following one. With the proposed design the antenna has a gain of about 14 dB and a side lobe level (SLL) of about −20 dB inside the whole band.

3 Signal Processing

The acquisition of the signals measured by the radar is performed with a DAQ NI USB 6361 [13]. Every acquisition lasts $T_a = 30\,\mathrm{s}$, a reasonable amount of time for the accurate vital signs estimation. The triangular signal V_{feed}, used to pilot the radar VCO, has a frequency $f_T = 300\,\mathrm{Hz}$ and the collected data are sampled with a frequency $f_s = 50\,\mathrm{kHz}$. The data is arranged in a matrix with a number of columns equal to the number of samples collected in one period of the signal V_{feed} and a number of rows equal to $T_a \cdot f_T$. To extract the range information, a fast fourier transform (FFT) of the matrix along the rows (*i.e.* in *fast time*) is computed. After the FFT, the standard deviation along the columns (*i.e.* in *slow time*) of the resulting matrix, has been computed to isolate the contribution of the target from the surrounding clutter. With this operation, the subject can clearly be distinguished from static objects thanks to the movements of its chest, associated with its respiration and heart activity. Once the target position has been defined, the phase of the data column corresponding to the target position can be extracted [7]. From the phase spectrum the frequencies corresponding to the heartbeat and the respiratory rate can be identified.

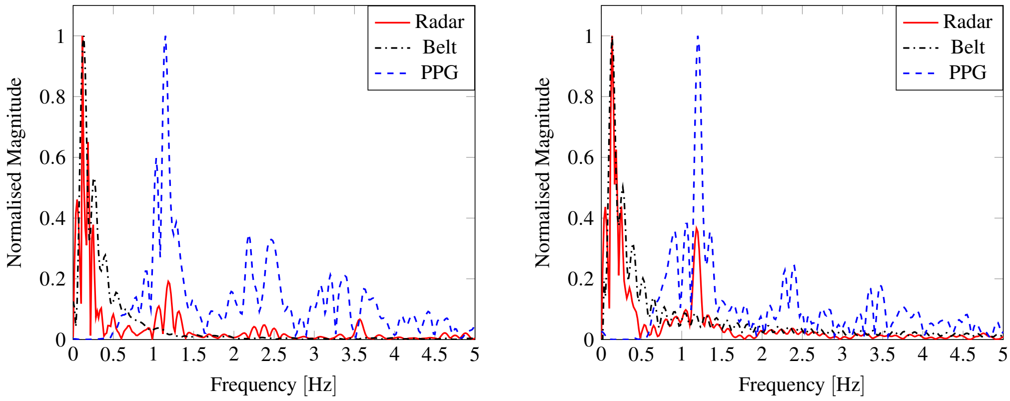
4 Experimental Results

Experimental evaluations have been conducted considering one subject positioned in the line of sight of the radar and invited to breath normally. To reproduce a realistic scenario, in which the patient orientation is unknown, measurements have been repeated considering four different orientations of the breast towards the antenna (see Figure 3). For all the four orientations the subject is at 1.5 m from the antenna. A finger PPG and a respiratory belt have been used as references for heartbeat and respiratory rate, respectively. The belt and PPG positions are indicated in Figure 3 with red and blue arrows respectively, except for the Figure 3c in which only the respiratory sensor is visible, since

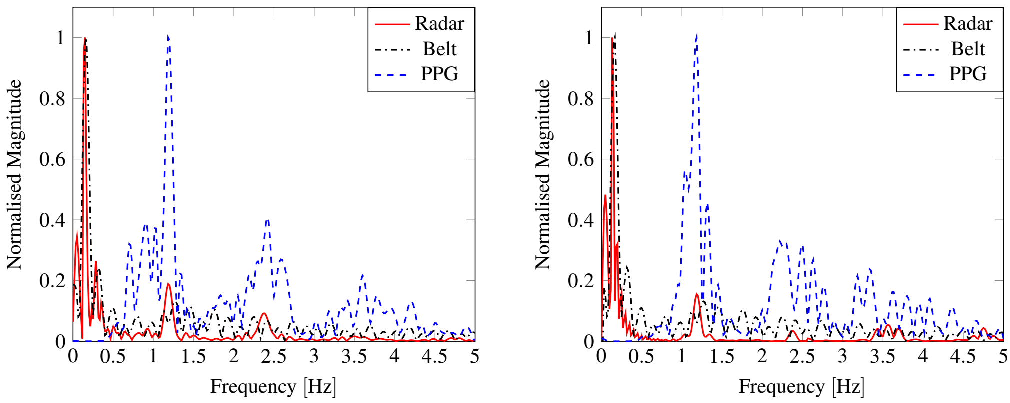


(a) (b) (c) (d)

Figure 3. Photo of the measured subject with (a) the breast, (b) the left side, (c) the back and (d) the right side facing the antenna.



(a) (b)



(c) (d)

Figure 4. Spectrum of the Doppler signal for the target at 1.5 m and with (a) the breast, (b) the left side, (c) the back and (d) the right side facing the antenna.

the PPG is covered by the body of the measured subject. Figure 4 reports, for the different configurations, the normalized amplitude of the spectra of the respiratory belt, the PPG and the Doppler signal extracted by the radar. In all four scenarii, two peaks that correspond to the respiratory and heart frequencies measured by their respective references, can be clearly identified in the Doppler spectrum. The high quality of the match between the frequency picks measured by the radar and the references, regardless of the thorax orientation, indicate that the FMCW radar is very adapted to the practical measurement of vital signs in challenging settings. This radar is proving to be a useful sensor for healthcare monitoring in realistic applications.

5 Conclusions

This work assesses the ability of an FMCW radar to measure the distance and the vital signs (respiratory rate and heartbeat) of a subject in a realistic indoor environment, in which the target orientation is usually unknown. A radar system working at 5.8 GHz together with the radiating elements has been designed and realised. The system has been used to measure the respiratory rate and the heartbeat of a subject positioned at 1.5 m from the antenna. Four different scenarios have been considered, depending on the target orientation. The vital signs of one subject with the breast, the left side, the back and the right side towards the antenna have been measured. Radar data have been compared with the signals of a respiratory belt and a PPG used as reference. In all the four considered scenarios the radar correctly estimated both the respiratory rate and the heart beat.

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