Vital Signs Monitoring for Different Chest Orientations Using an FMCW Radar

Giulia Sacco$^1$, Emanuele Piuzzi$^1$, Erika Pittella$^2$, Stefano Pisa$^1$

(1) Department of Information Engineering, Electronics and Telecommunications, Sapienza University of Rome, 00184, Rome, Italy
(2) Department of Legal and Economic Sciences, Pegaso University, 00186, Rome, Italy
Outline

1 Introduction
2 Radar System at 5.8 GHz
3 Measurements
4 Conclusion
Introduction: Conventional Techniques
Vital Signs Estimation

**Spirometer**
- ✓ Actual Gold Standard for breath monitoring.
- ✗ Does not allow a continuative monitoring.
- ✗ Interferes with respiration.

**Pulse Oximeter**
- ✓ Indicates respiratory disturbance has occurred.
- ✗ Does not provide respiratory rate.

**Electrocardiogram**
- ✓ Actual gold standard for heart monitoring.
- ✓ Allows a continuative monitoring.
- ✗ Requires a direct contact with the body.
Introduction: Conventional Techniques

Position Estimation

**GPS**
- ✓ Worldwide diffused and can reach elevate accuracy.
- × The signal in indoor environment gets highly attenuated and scattered by the roof and walls of the building.

**Video-surveillance**
- ✓ Can be easily used in closed environments.
- × Does not respect the privacy of the patient.
Introduction: Radar technique

Radar systems can perform non-contact sensing of cardiorespiratory activity and position. These results are useful for:

- monitoring patients with compromised skin (burns or chemical contaminations),
- home therapy,
- sleep monitoring,
- detection of humans behind walls or under rubble,
- monitoring people in case of risk of infection or during pandemics (e.g. COVID-19 crisis).
Problem Geometry

The radar system must be able to get information about the subject **position** and the thorax **small movements** due to the respiration and the heartbeat.

but the presence of environmental **clutter** and the **smaller movements** of the chest wall on the **lateral** and **back** sides could worsen the detection.
Outline

1. Introduction

2. Radar System at 5.8 GHz

3. Measurements

4. Conclusion
System Overview

Radar Components

Antenna
Antenna Design

For radar applications antenna requirements are:

- low-cost
- compact

This kind of antenna is typically narrow band, while the fractional bandwidth inside the 5.8 GHz ISM band is of about 2.6%.

A new dual band, high gain patch antenna with side lobe control has been proposed\(^1\).

---

Signal Processing

**TD Matrix**

\[ V_{\text{feed}} \]

\[ 0 \rightarrow t_s \rightarrow \ldots \rightarrow (M-1) \cdot t_s \]

**Fast Time**

**Distance Estimation**

\[ d_s = \frac{f_s \cdot T \cdot c_0}{4 \cdot \text{BW}} \]

**FFT**

**FD Matrix**

\[ 0 \rightarrow d_s \rightarrow \ldots \rightarrow 10(M-1) \cdot d_s \]

**Target Range Bin**

**Vital Signs Estimation**

**Vital Signs Spectrum**

**Beats Per Minute (BPM)**

\[-15 \rightarrow -10 \rightarrow -5 \rightarrow 0 \]

**Normalised Magnitude (dB)**

\[ 0 \rightarrow 0.2 \rightarrow 0.4 \rightarrow 0.6 \rightarrow 0.8 \rightarrow 1 \]

**Time (s)**

\[ 0 \rightarrow 5 \rightarrow 10 \rightarrow 15 \rightarrow 20 \rightarrow 25 \rightarrow 30 \]

**Distance (m)**

\[ 0 \rightarrow 0.25 \rightarrow 0.5 \rightarrow 0.75 \rightarrow 1 \]

**Frequency (Hz)**

\[ 0 \rightarrow 0.2 \rightarrow 0.4 \rightarrow 0.6 \rightarrow 0.8 \rightarrow 1 \]
Outline

1. Introduction
2. Radar System at 5.8 GHz
3. Measurements
4. Conclusion
Position Estimation

Patient with the chest facing the antenna

Patient with the side facing the antenna

The combined use of the **standard deviation** and the **high gain** antennas help isolate the target from the surrounding clutter.
Vital Signs Estimation

**Front**

![Graph showing frequency vs. normalised magnitude for Front view](image)

**Left**

![Graph showing frequency vs. normalised magnitude for Left view](image)

**Back**

![Graph showing frequency vs. normalised magnitude for Back view](image)

**Right**

![Graph showing frequency vs. normalised magnitude for Right view](image)
Vital Signs Estimation

Front

Left

Back

Right
Data Analysis

5 volunteers
3 males and 2 females
4 Orientations
Acquisition time: 30 s
Max error respiratory rate: 0.8 BPM
Max heart rate: 3.1 BPM

Regression

Respiratory Rate

Heart Rate

Bland-Altman Analysis

Respiratory Rate

Heart Rate
Data Analysis

The success rate of the measurements is defined as the time the respiration and heart rate measured by the target stay lower than a specified value of bpm.

Respiratory Rate

Heart Rate

<table>
<thead>
<tr>
<th>Error</th>
<th>Front</th>
<th>Left</th>
<th>Back</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 BPM–1 BPM</td>
<td>100 %</td>
<td>98 %</td>
<td>92 %</td>
<td>86 %</td>
</tr>
<tr>
<td>1 BPM–2 BPM</td>
<td>0 %</td>
<td>2 %</td>
<td>8 %</td>
<td>14 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Error</th>
<th>Front</th>
<th>Left</th>
<th>Back</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 BPM–2 BPM</td>
<td>98 %</td>
<td>84 %</td>
<td>74 %</td>
<td>64 %</td>
</tr>
<tr>
<td>2 BPM–4 BPM</td>
<td>2 %</td>
<td>16 %</td>
<td>26 %</td>
<td>36 %</td>
</tr>
</tbody>
</table>
Outline

1. Introduction
2. Radar System at 5.8 GHz
3. Measurements
4. Conclusion
Conclusions

▶ A complete radar system working in the 5.8 GHz ISM band has been designed.

▶ An algorithm based on the only frequency-modulated continuous wave (FMCW) radar architecture has been proposed to estimate the position and the vital signs in a closed environment.

▶ A new patch geometry has been proposed to overcome the bandwidth limitations of the conventional patch arrays.

▶ The maximum error in terms of bpm was 0.8 BPM and 3.1 BPM for the respiratory and heart rate.

▶ Independently of the orientation, the respiration rate error stayed under 2 BPM in 100% of the measurement time and 100%, 98%, 92%, and 86% under 1 BPM when the chest, the left side, the back, and the right were towards the antenna, respectively. For the hearth rate, all the measurement errors were under 4 BPM and under 2 BPM for 98%, 84%, 74%, and 64% for the front, left, back, and right orientations, respectively.