Vital Signs Monitoring for Different Chest Orientations Using an FMCW Radar

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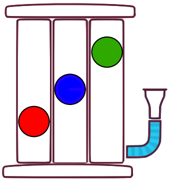
Outline

Introduction: Conventional Techniques

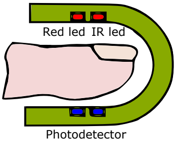
Vital Signs Estimation

Spirometer



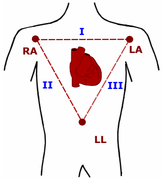
✓ Actual Gold Standard for breath monitoring.
× Does not allow a continuative monitoring.
×Interferes with respiration.

Pulse Oximeter



✓ Indicates respiratory disturbance has occurred.
× Does not provide respiratory rate.

Electrocardiogram

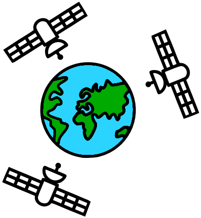


✓ Actual gold standard for heart monitoring.
✓ Allows a continuative monitoring.
× Requires a direct contact with the body.

Introduction: Conventional Techniques

Position Estimation

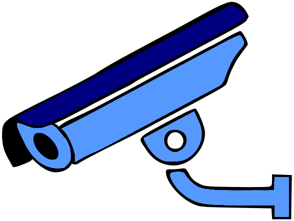
GPS



✓ 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

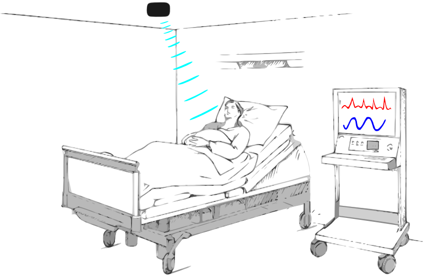


✓ Can be easily used in closed environments.

× 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:

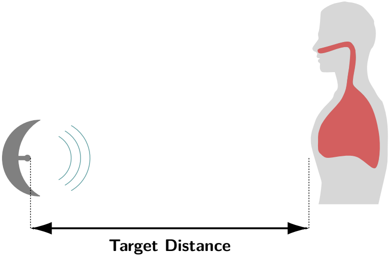


- monitoring patients with **compromised skin** (burns or chemical contaminations),
- **home therapy**,
- **sleep monitoring**,
- detection of **humans behind walls** or **under rubble**,
- monitoring people in case of risk of infection or during **pandemics** (e.g. COVID-19 crisis).

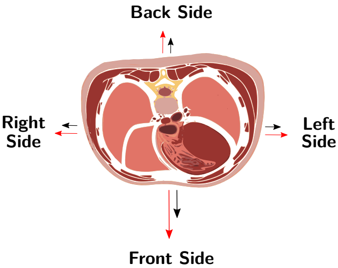
Problem Geometry

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.

Position



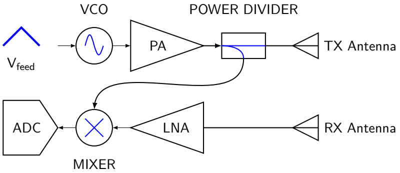
Small Movements



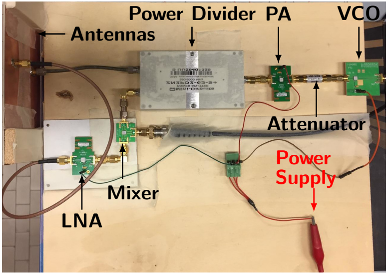
but the presence of environmental **clutter** and the **smaller movements** of the chest wall on the **lateral** and **back** sides could worsen the detection.

Outline

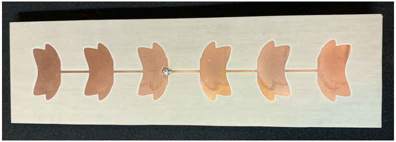
System Overview



Radar Components



Antenna



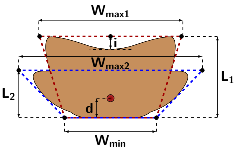
Antenna Design

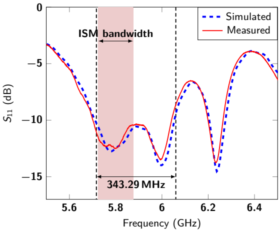
For radar applications antenna requirements are:

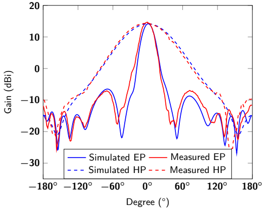
- low-cost
- compact

Series fed array

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



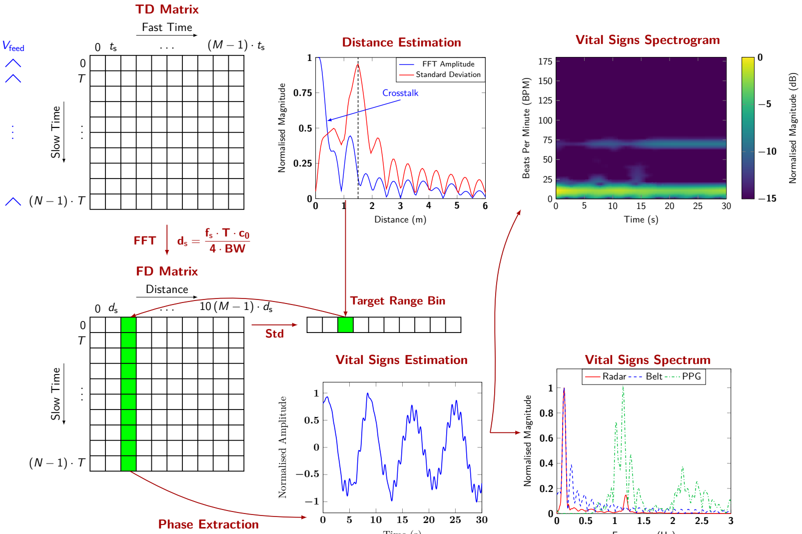




A new **dual band**, **high gain** patch antenna with **side lobe control** has been proposed[1].

[1] G. Sacco, P. D'Atanasio, and S. Pisa, "A wideband and low-sidelobe series-fed patch array at 5.8 ghz for radar applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 19, no. 1, pp. 9–13, 2019.

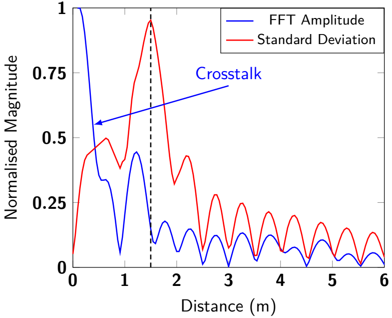
Signal Processing



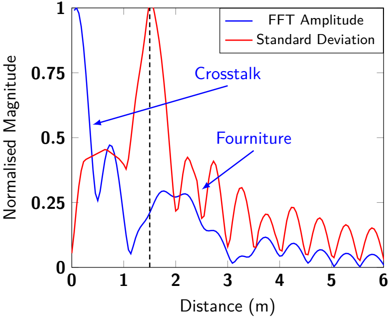
Outline

Position Estimation

Patient with the chest facing the antenna



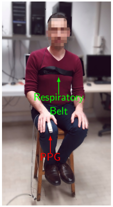
Patient with the side facing the antenna

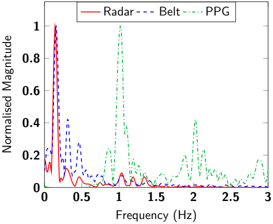


The combined use of the **standard deviation** and the **high gain** antennas help isolate the target from the surrounding clutter.

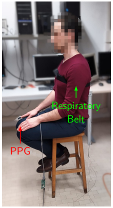
Vital Signs Estimation

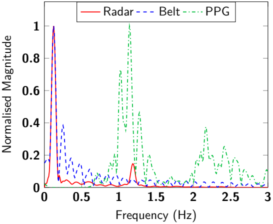
Front



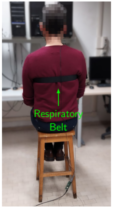


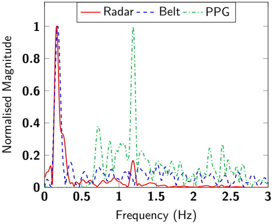
Left



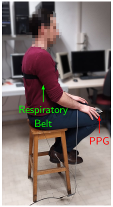


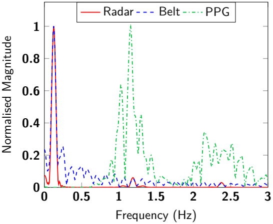
Back





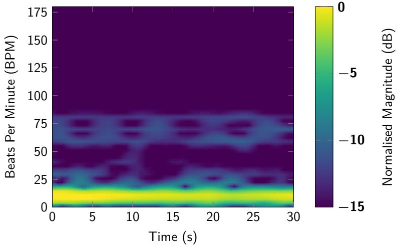
Right



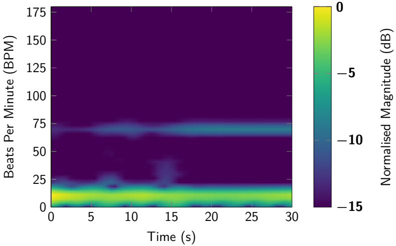


Vital Signs Estimation

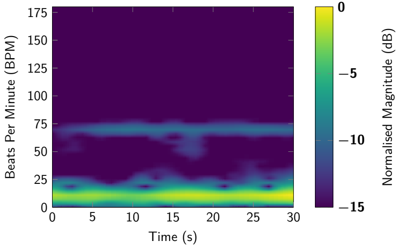
Front



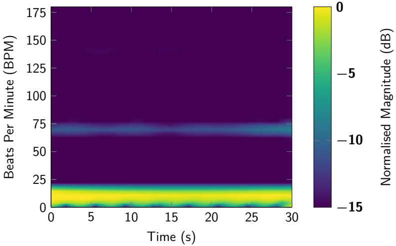
Left



Back



Right



Data Analysis

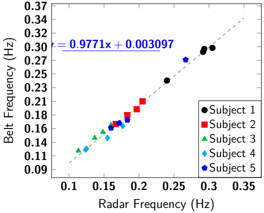
5 volunteers
3 males and 2 females

4 Orientations
Acquisition time: 30 s

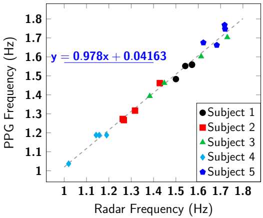
Max error respiratory rate: 0.8 BPM
Max heart rate: 3.1 BPM

Regression

Respiratory Rate

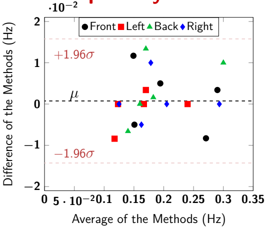


Heart Rate

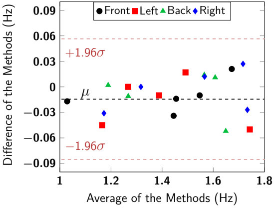


Bland-Altman Analysis

Respiratory Rate

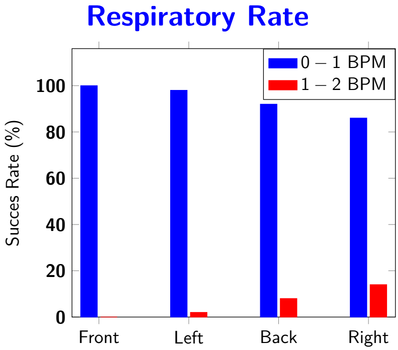


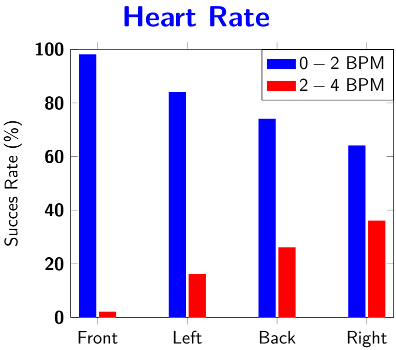
Heart Rate



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.





Error	Front	Left	Back	Right
0 BPM–1 BPM	100 %	98 %	92 %	86 %
1 BPM–2 BPM	0 %	2 %	8 %	14 %

Error	Front	Left	Back	Right
0 BPM–2 BPM	98 %	84 %	74 %	64 %
2 BPM–4 BPM	2 %	16 %	26 %	36 %

Outline

Conclusions

- A complete radar system working in the 5.8 GHz ISM band has been designed.
- An algorithm based on the only frequency-modulated continous 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.