Can the IR-UWB Radar Sensor Substitute the PSG-based Primary Vital Signs' Measurements?

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ΕΠΙΧΕΙΡΗΣΙΑΚΟ ΠΡΟΓΡΑΜΜΑ
ΑΝΤΑΓΩΝΙΣΤΙΚΟΤΗΤΑ • ΕΠΙΧΕΙΡΗΜΑΤΙΚΟΤΗΤΑ • ΚΑΙΝΟΤΟΜΙΑ

Short CV: Anastasia Pentari

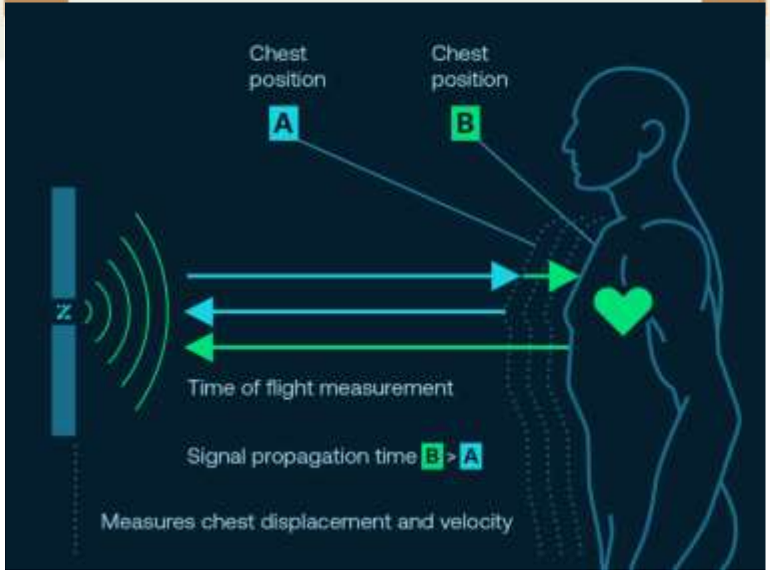
- BSc & MSc studies: School of Electrical and Computer Engineering, Technical University of Crete
  - Focused on image processing and object detection in static and moving background
- PhD studies: Department of Computer Science, University of Crete
  - Focused on biomedical image and signal processing (including MRI, EEG)
- Postdoctoral Researcher: Computational Biomedicine Laboratory of FORTH-Hellas, under the Supervision of Prof. Manolis Tsiknakis
  - Main interests: biosignal processing and analysis (including radar-based signals, speech signals, machine learning and deep learning techniques)

Main Purpose

- The main goal of the “HealthSonar Project” was to investigate whether the Impulse Radio Ultra Wideband Radar (IR-UWB) sensor can detect the Obstructive Sleep Apneas (OSAs)
- Important biosignals/vital signs: Respiration and Heartbeat during sleep
- On the one hand: IR-UWB recording
- On the other, the gold standard: Polysomnography (PSG) recordings of respiration and heartbeat signals

IR-UWB radar examinations

- Radar’s position: ~0.5m of the patients’ chest
- The radar sensor records the chest’s displacement → Respiration
- Further, it can detect the heart’s smaller motions → Heartbeat



source: https://novelda.com/articles/uwb-sensing/ultra-wideband-sensing

Preprocessing Steps

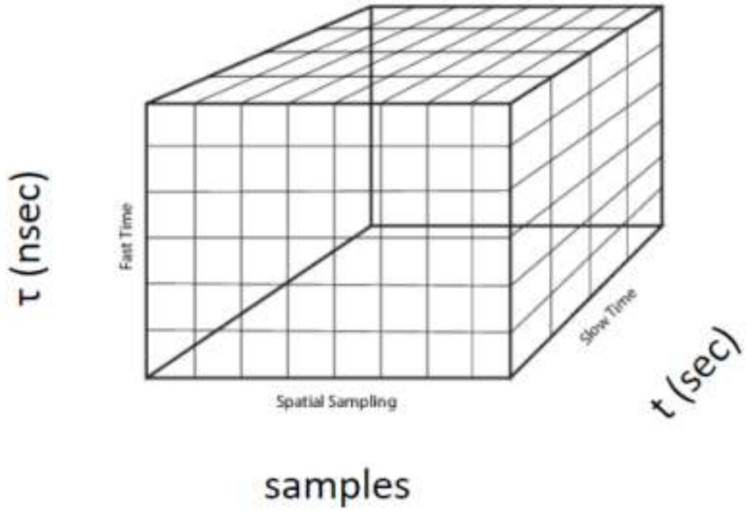
- Many preprocessing steps were required before the sensor’s signals be suitable for OSA detection
  - Processing of radar-based output
  - Denoising
  - Motion detection and elimination
  - Accurate extraction of respiratory and heartbeat signals
  - Estimation of respiratory and heartbeat frequencies
  - Comparison with the Polysomnography (PSG) measurements

Radar Sensor Mathematical Background

- Radar sensor recordings:
  - 2D matrices
  - The Fast Time τ (msec) → Bins
  - The spatial sampling → Samples
- The radar output for the “optimal bin”:

$$\mathbf{x}_{f_r,f_h}(t) = \frac{1}{\sqrt{K}} \sum_{k=0}^{K-1} \mathbf{u}(t - kT_s - t_k(f_r, f_h))$$

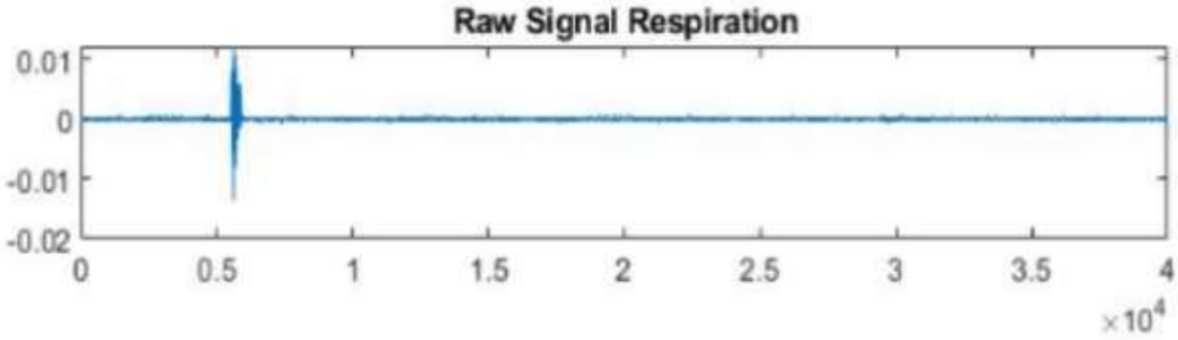
$$t_k(f_r, f_h) = \frac{d_0}{v} + \frac{a_r \sin(2\pi f_r t)}{v} + \frac{a_h \sin(2\pi f_h t)}{v}$$



In terms of our analysis, the optimal bin was selected from the estimation of *maximum variance* per 2D *segment* → Corresponds to the maximum chest displacement → “Best available recording”

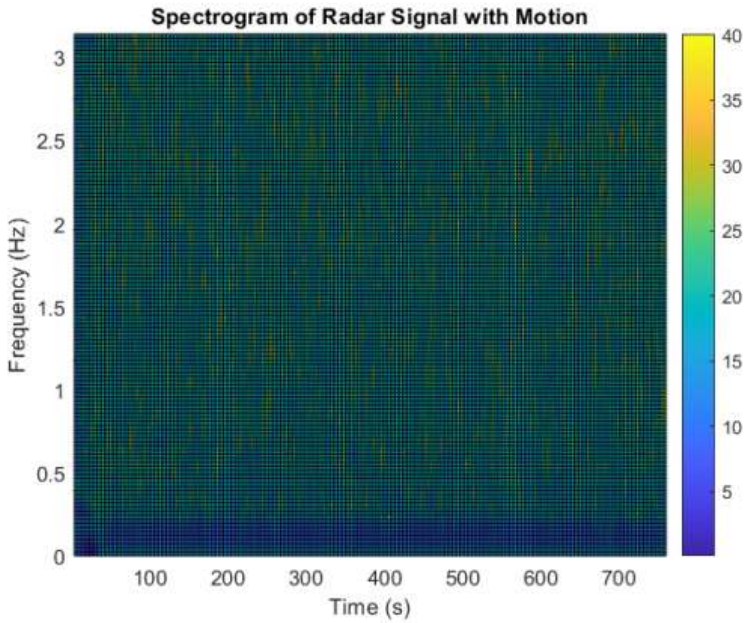
Motion Detection & Denoising (1/2)

- Having extracted a unique sensor's recording by concatenating the signal's segments, each of which was selected from the optimal bin, we pass through the denoising procedure
- As the patients may move during their sleep → corresponds to high recorded fluctuations in the signal → Can further lead to misdiagnosis



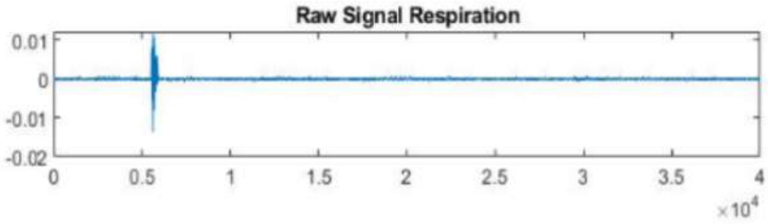
Motion Detection & Denoising (2/2)

- The motion activity estimation was based on the spectrogram extraction per signal segment of 120 sec
- Our goal was to detect and avoid the low frequency motion events of the spectrogram (i.e., the dark blue elements)
- Set thresholds for detecting the intense motion events
- **These thresholds should not confuse apnea and motion events**
- Our algorithm is analytically described in the paper

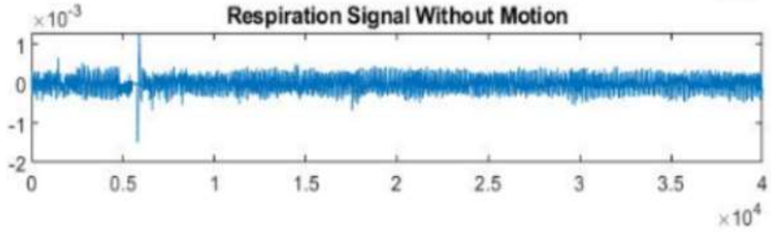


Activity Signal Example

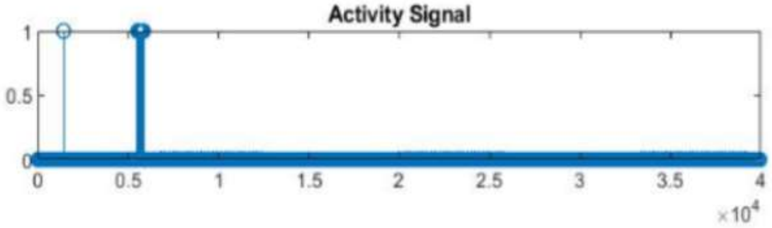
(a) the raw sensor's signal, after the optimal bin selection
(b) the signal with reduced motion
(c) activity signal: corresponds to "1" when intense motion has been detected, otherwise "0"



(a)



(b)



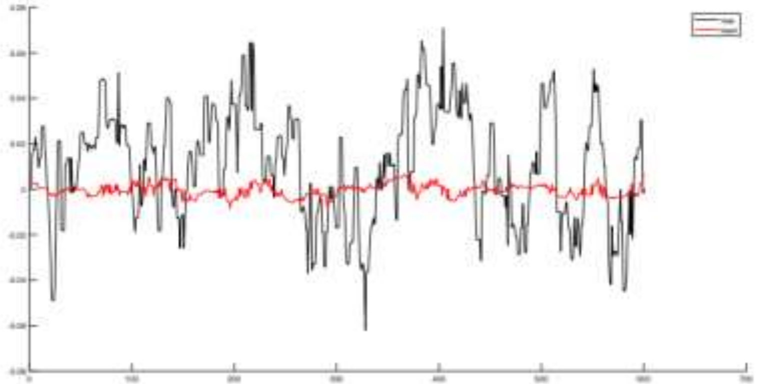
(c)

Extraction of Respiratory and Heartbeat Signals

- The respiratory signal, which corresponds to the chest displacement, can be captured in a more effective manner than the heartbeat

- This leads to a prominence of the respiratory signal versus the heartbeat

- Regarding the heartbeat signal, we passed the raw sensor’s signal through a lowpass filter (in 0.9Hz), then from a highpass filter (in 0.5 Hz) and finally, through a median filter (of order 20)



Black: respiratory signal
Red: Heartbeat signal

Respiratory and Heartbeat Frequencies Estimation

RESPIRATION RATE

- Split the signal into segments of 120 sec duration
- Unless motion exists, we apply the ***power spectrum*** estimation
- Select the frequency with the maximum energy
- After that, we estimate the respiration rate (i.e., respirations/minute)
- If motion exists, we replace this segment's respiratory rate with the mean value over the left and right neighboring rates

HEARTBEAT RATE

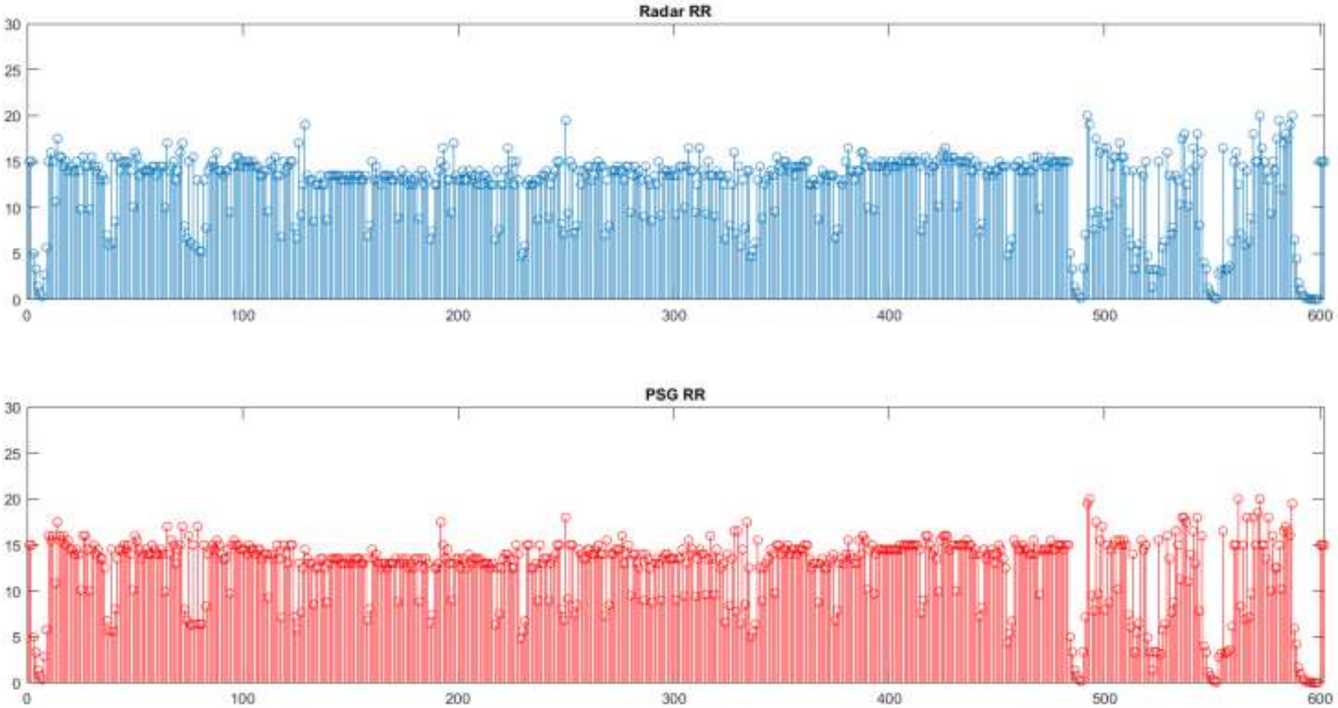
- Split the signal into segments of 120 sec duration
- Unless motion exists, we apply the ***peak detection*** method
- Counting the peaks per segment, we estimate the heartbeat frequency
- If motion exists, we replace this segment's heartbeat rate with its left-right neighboring rates

Respiration and Heartbeat Rates Evaluation

- Pearson’s Correlation was estimated between the rates derived from the radar sensor and those estimated from the PSG
- 28 patients were examined and evaluated
- The importance of high Pearson’s correlations corresponds to probably more accurate OSA detection (and further, sleep stages)

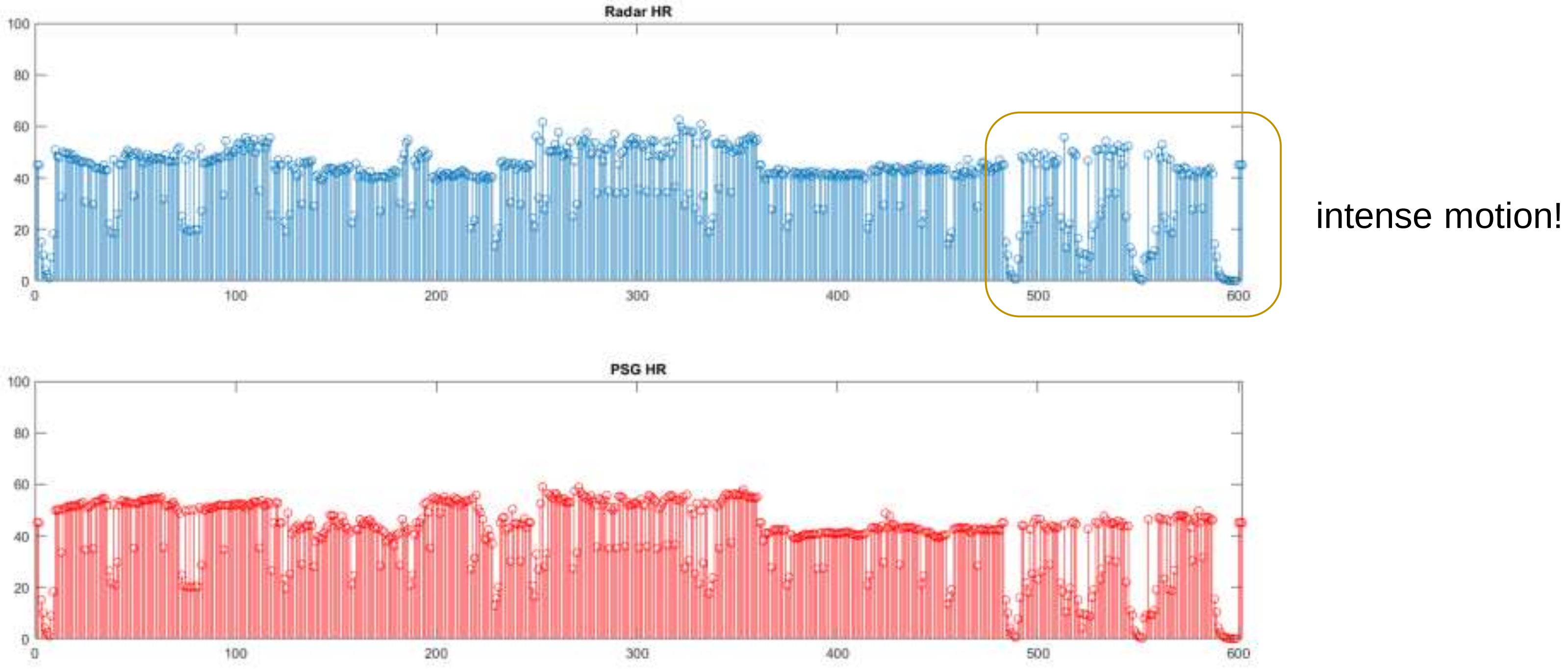
Patient ID	Respiratory	Heartbeat
1	0.99	0.88
2	0.95	0.91
3	0.96	0.98
4	0.97	0.71
5	0.93	0.81
6	0.95	0.96
7	0.98	0.95
8	0.99	0.67
9	0.93	0.83
10	0.98	0.89
11	0.93	0.90
12	0.99	0.97
13	0.98	0.46
14	0.99	0.69
15	0.99	0.99
16	0.94	0.97
17	0.97	0.98
18	0.91	0.96
19	0.95	0.97
20	0.95	0.98
21	0.94	0.96
22	0.93	0.97
23	0.96	0.88
24	0.79	0.95
25	0.91	0.95
26	0.88	0.93
27	0.98	0.98
28	0.99	0.99
Average	0.95	0.90

Respiration Rates Example



5 randomly selected examinations, comparison between the radar and PSG respiration rates

Heartbeat Rates Example



5 randomly selected examinations, comparison between the radar and PSG heartbeat rates

Conclusions & Future steps

- The IR-UWB radar can capture the respiration and heartbeat signals in an effective manner
- Further, the corresponding rates proved to be comparative to the ones estimated from the gold standard, the PSG
- In the future, we aim to exploit the signals derived from these two sources and investigate if the OSA detection is also so comparative as the vital signs' acquisition from the radar sensor

Thank you very much!
Any questions?