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Research on Key Technologies of THz Radar Information Processing for Situation Awareness
A Case of Biomedical Application

Ph.D. Candidate: ***Ruochen Wu***

Supervisor: *Antoni Broquetas Ibars*
Co-supervisor: *Jordi J. Mallorqui Franquet*

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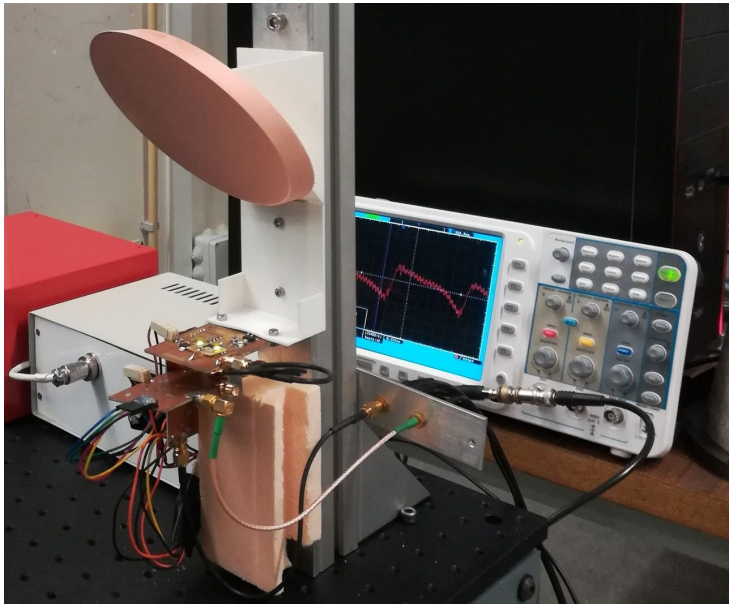
CommSensLab

The non-contact radar can provide respiration and heartbeat measurements.

- Vital sign detection
- Vital signal processing



First prototype of Biomedical Radar

The radar is calibrated using a sphere as a reflector

https://ars.upc.edu/projects/radar-for-medical-applications

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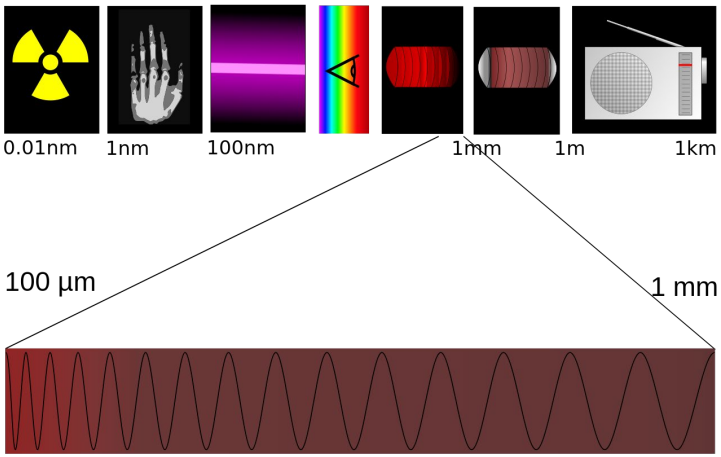
Terahertz (THz)
~ GHz — THz



Band range: 0.1mm ~ 1mm
Frequency range:
0.1THz ~ 10THz

Characteristics:

- 24/7 observation
- Suitable for all weather conditions
- Short wavelength, large bandwidth
  → **High** Doppler resolution
- **NO** ionizing effect on irradiated organisms

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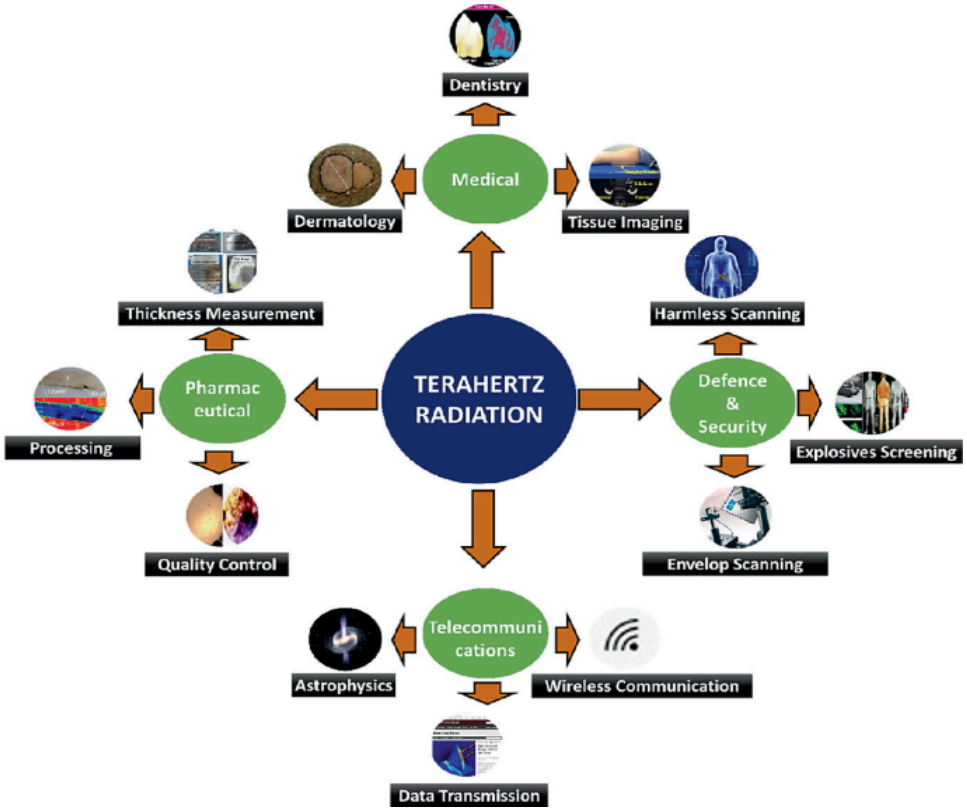

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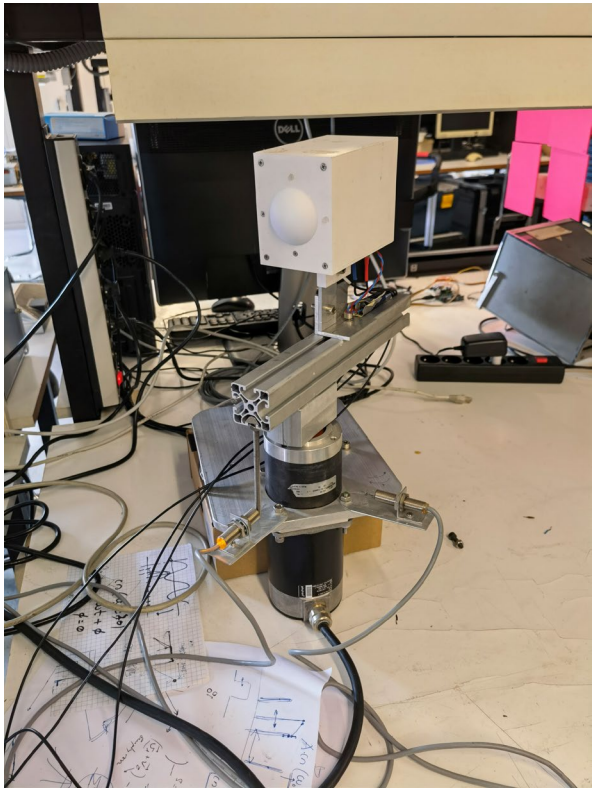
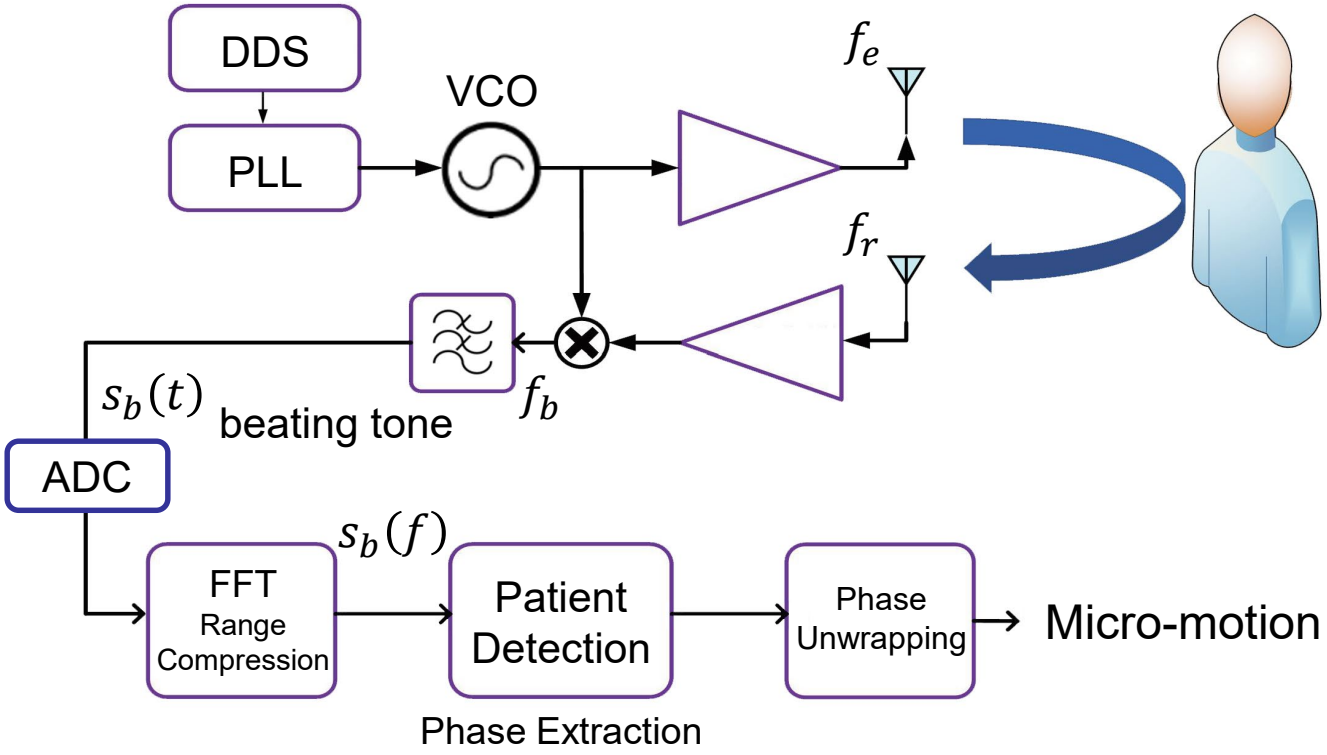
FMCW Radar
Prototype of Radar

Workspace in the Hardware Laboratory of TSC Department



Prototype of 120GHz radar

FMCW Radar
Block Diagram



$$f_b = -\frac{\Delta f}{T_{Chirp} c} r$$

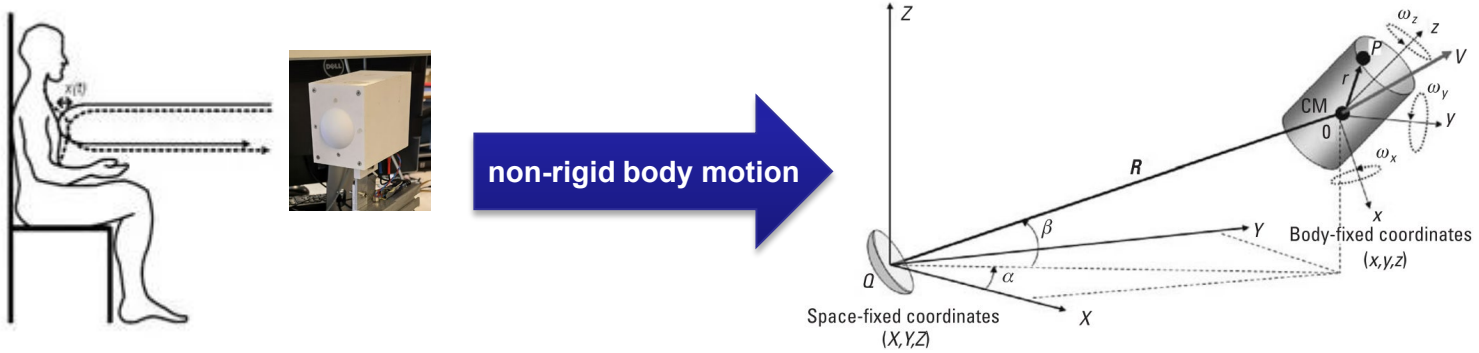
$$\phi_b = -2\pi f_0 \frac{2r}{c} = -2kr$$

$$s_b(t) = A_b \cos(\phi_b - 2\pi f_b t) \prod \left\{ \frac{t}{T_{Chirp} - t_r} \right\}$$

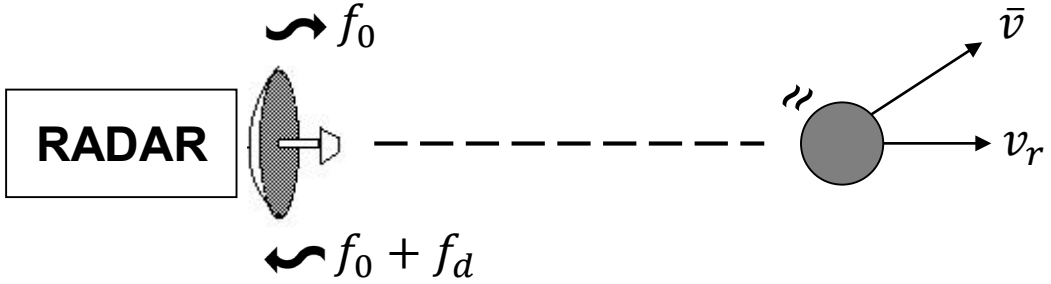
$$\downarrow$$

$$\frac{1}{2} A_r A_t$$

Micro-Doppler (I)



- Doppler effect: Doppler frequency **SHIFT** occurs when there is relative motion between the radar and the target
- Micro-motion: other tiny movements of the target itself

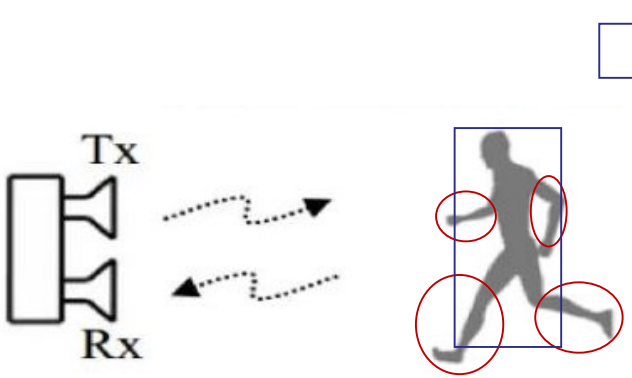


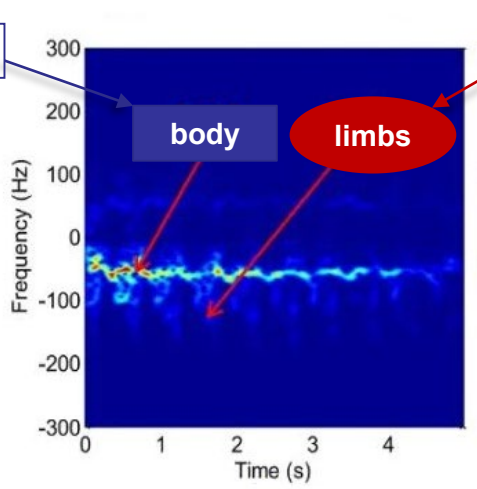
$$f_d = \frac{-2}{\lambda} v_r$$

Micro-Doppler (II)

Victor C. Chen

- Rigid body
  - Human – body
  - Helicopter – propeller
  - Pendulum
  - …
- Non-rigid body
  - Human – limbs, vital sign…
  - …





Radar echo of body motion: **Doppler** information

Radar echo of wobbling limbs: **micro-Doppler** information

Different targets will cause different micro-motion modulations that result in the radar echo due to their own physical properties.

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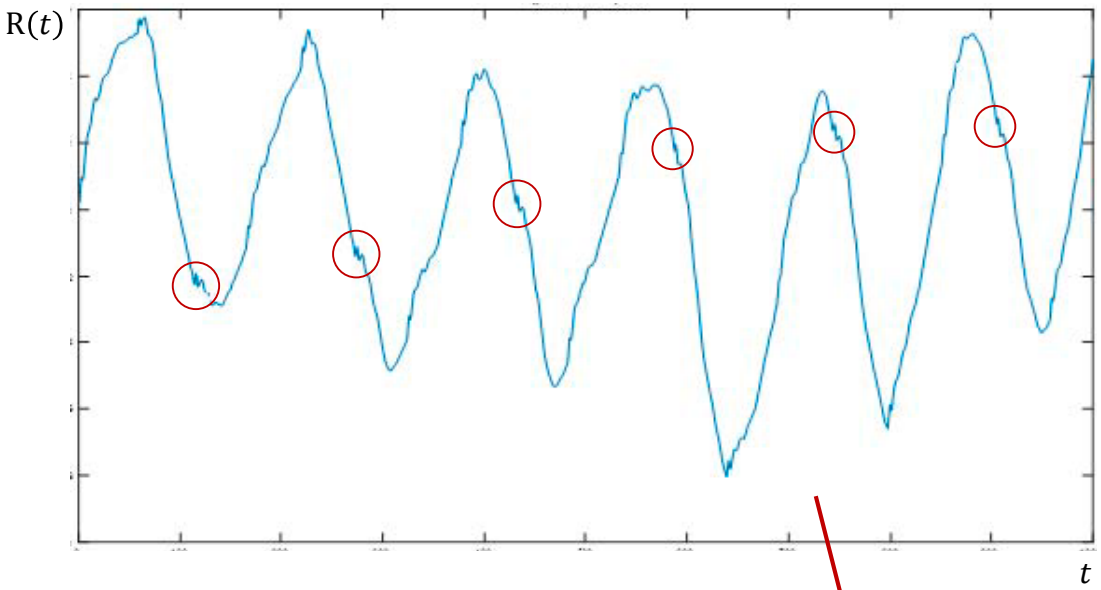
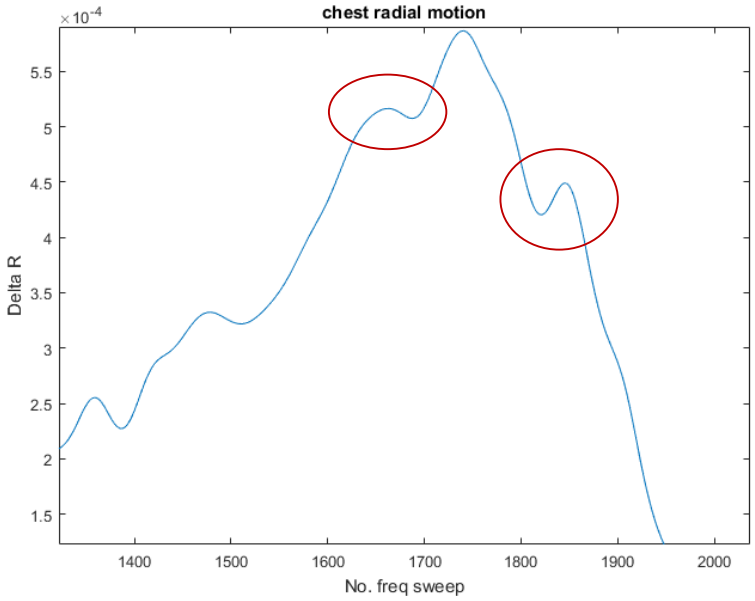
Vital Signal Analysis
Heartbeat Signal Detection (I)

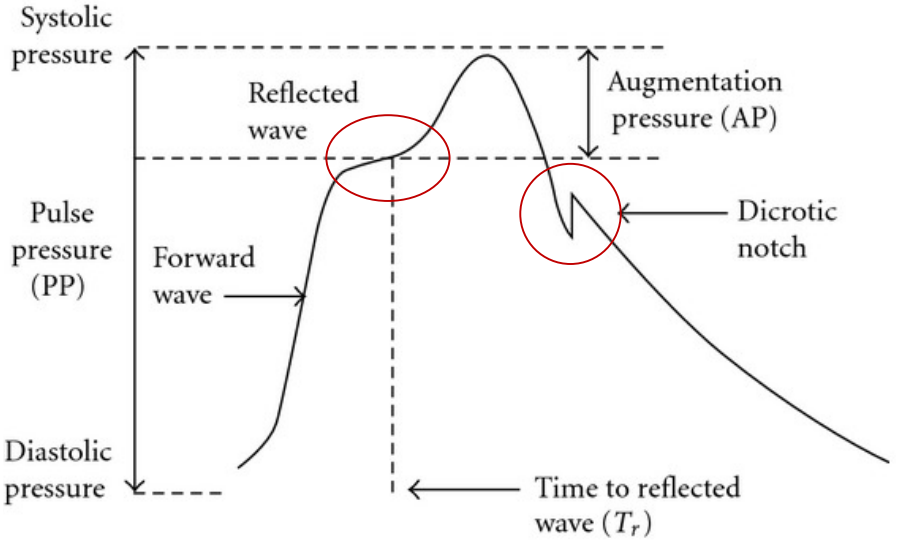


The breathing signal with some small ripple perturbations belonging to heartbeats.

Vital Signal Analysis
Heartbeat Signal Detection (II)



Zoom of the heartbeat signal



Aortic pulse pressure waveform detected using a contact sensor (Stoner L, Young JM, Fryer S. Assessments of arterial stiffness and endothelial function using pulse wave analysis. Int J Vasc Med.)

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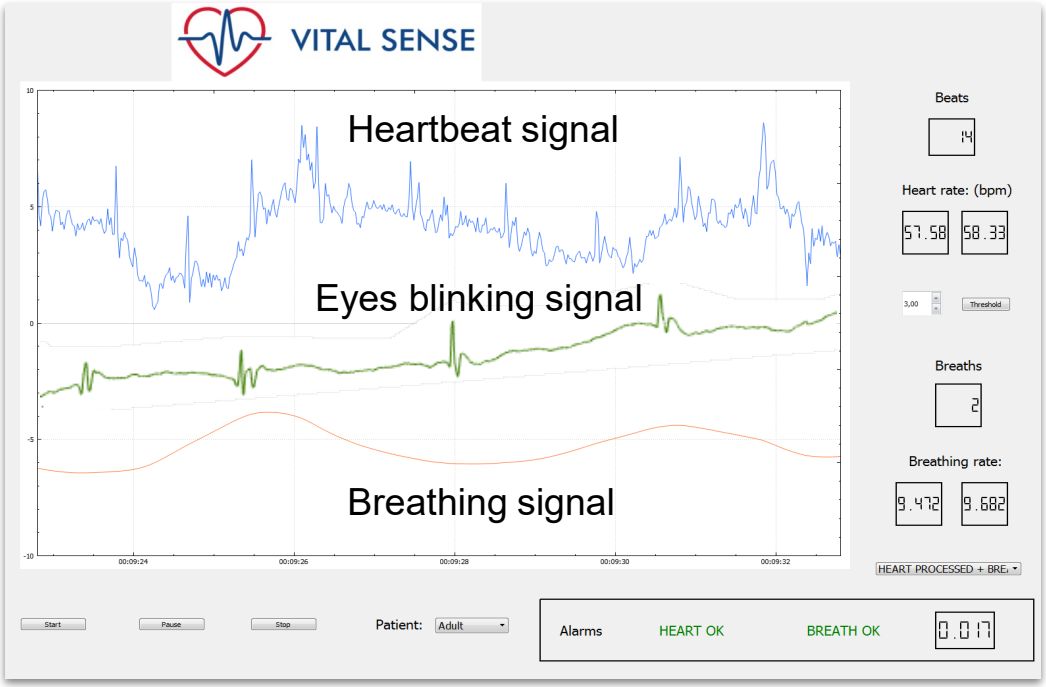
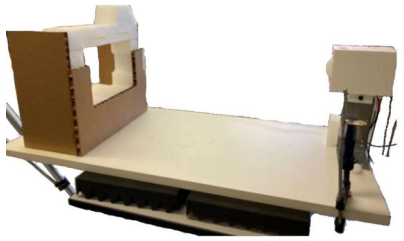
Vital Signal Analysis



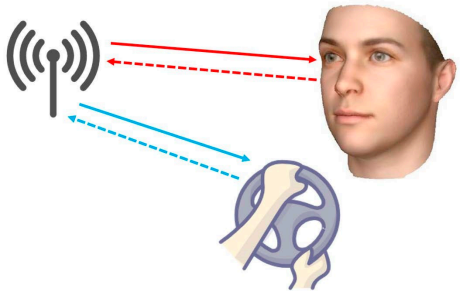
Real Time Vital Parameters monitoring with 120GHz Radar

Eyelid detection:

Case 1: Clinical Assignment



Case 2: Driving Behavior



J. Hu et al., "BlinkRadar: Non-Intrusive Driver Eye-Blink Detection with UWB Radar," 2022 IEEE 42nd International Conference on Distributed Computing Systems (ICDCS), Bologna, Italy, 2022.

Breathing/hearbeat signals:

$$s(t) = R_0 + A_b \sin(2\pi f_b t) + A_h \sum_{n=0}^{\infty} p_h(t - nT_h) + N$$

Eyelid signal:

$$s_e(t) = A_e \sum_{n=0}^{\infty} p_e(t - nT_e) + N + A_m M(t)$$

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Problems and Objectives

- Promblems:
  - Heartbeat signal: difficult to distinguish
  - Eyelid signal: easy to lose signal data in complex situations
- Applications:
  - Clinical diagnosis (hospital…)
  - Fatigue detection (driver…)
  - Person/behavior recognition (fall…)
  - Emotion recognition (happy…)

  …
- Collaboration:
  - UPC – Hospital Sant Joan de Déu Barcelona

  …
- Ph.D. dissertation:
  - Radar optimization
  - **Signal situation awareness** technology
  - Micro-motion signal detection
  - Vital target recognition

Algorithms

- Time-frequency Analysis
  - Essence of micro-Doppler extraction: echo signal processing
  - Detection of the time-varying frequency in the target echo
  - Extraction of the superimposed micro-motion signal components
- Empirical Mode Decomposition (EMD)
  - Decomposition of the frequency modulation mode of the micro-motion characteristic signal into different modulation modes
- Artificial Neural Network (ANN/NN)
  - Learn based on signal sample data
  - Interaction between neurons - Correlation of signal samples: included in the network structure
  - Process: data normalization, denoising, numbering, training, and classification
- Support Vector Machine (SVM)
  - Find the optimal hyperplane for binary classification
  - High signal classification/recognition rates with fewer data samples

References

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MANY THANKS FOR YOUR ATTENTION!

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