



ELECTRONICS FOR SENSORS & *3rd Joint Workshop*
BIOMEDICAL APPLICATIONS TECHNOLOGIES & SENSORS

Biomedical Applications of Microwave and Millimeter-Wave Radars

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Outline

1

Operating principles



University of Messina

2

FMCW radar typical architecture



Microwave electronics laboratory

3

Range, motion, micro-Doppler sensing

4

Vital-sign sensing



Texas Tech University

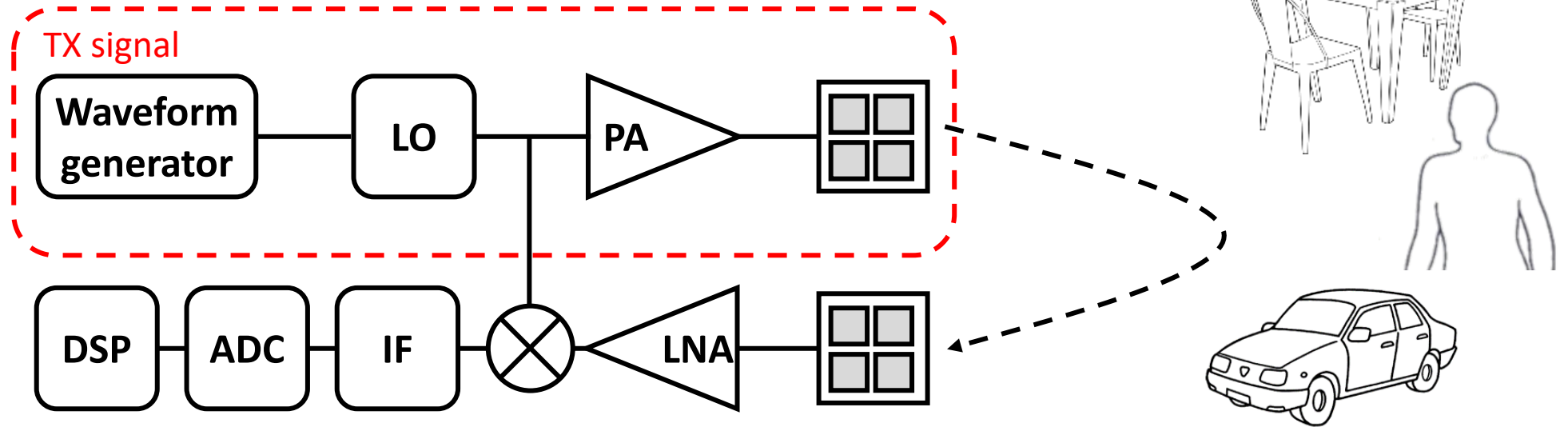


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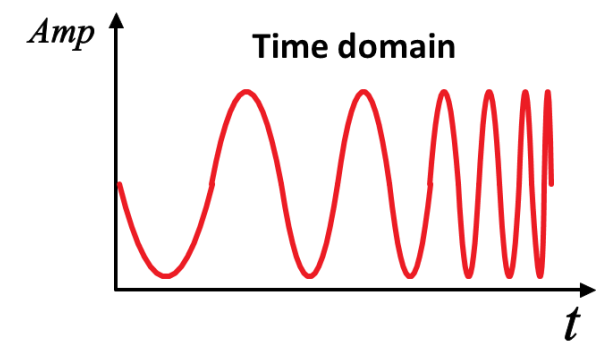
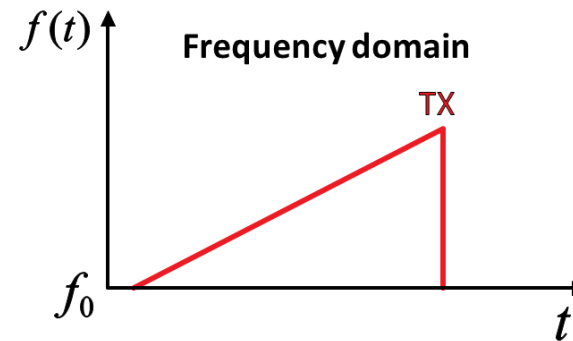
SECTION 1

Operating principles

FMCW transmitted signal

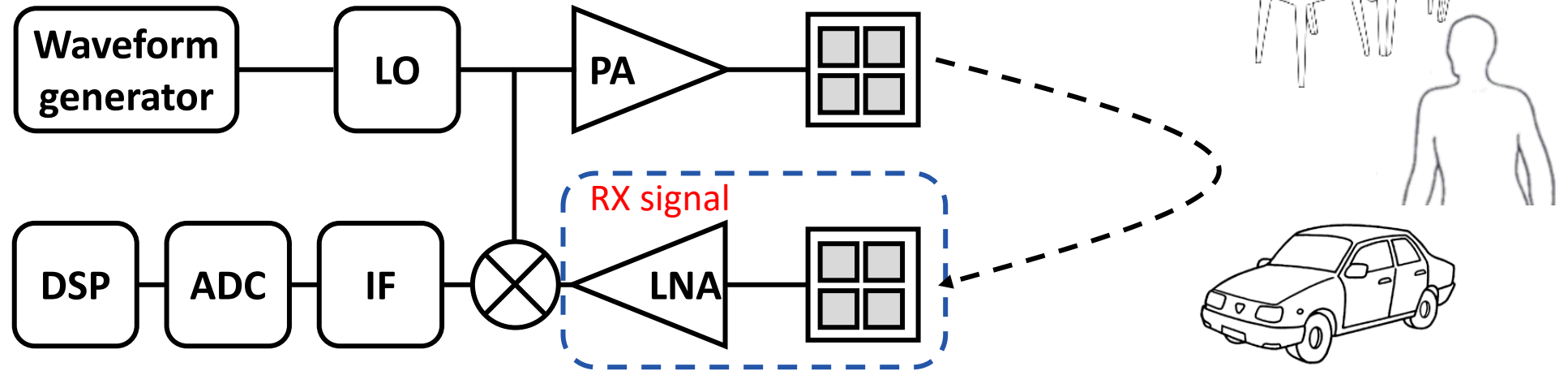


$$s_{tx}(t) = e^{j\left(2\pi f_c t + \pi \frac{B}{\tau_{chirp}} t^2 + \phi_0\right)}$$

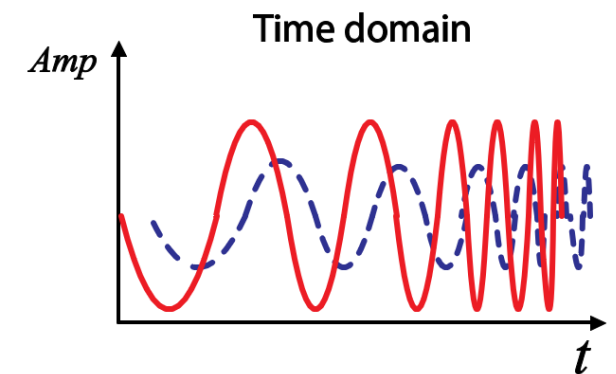
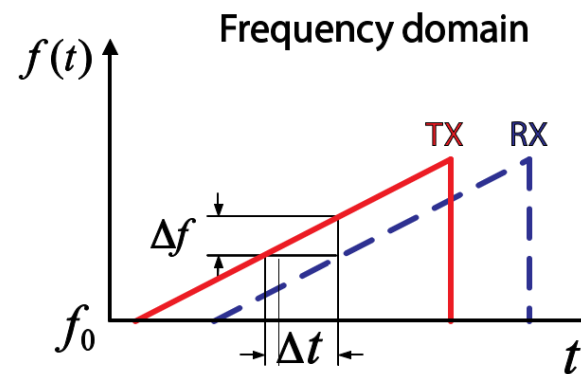


Fundamental of FMCW mechanism

FMCW received signal

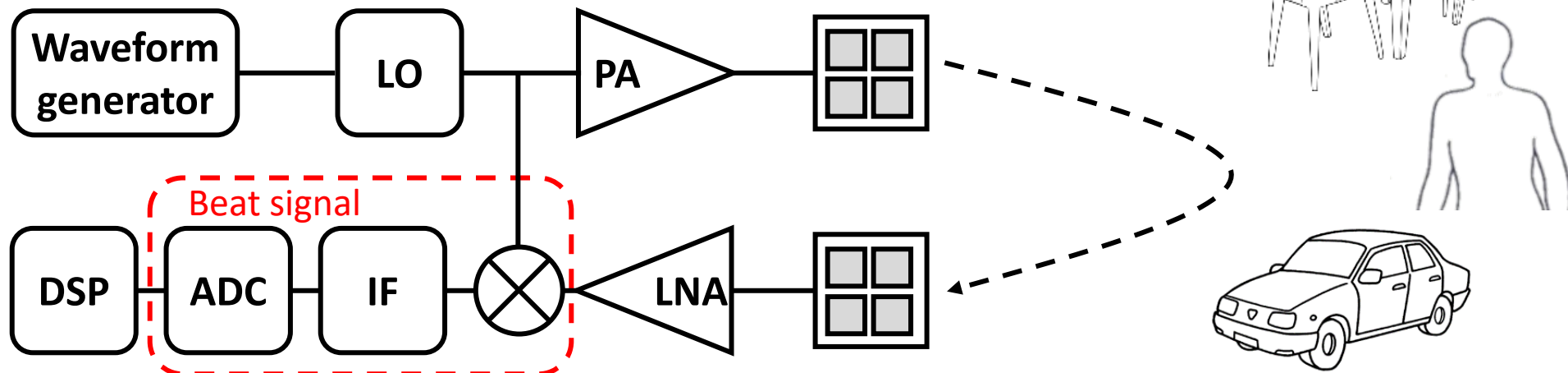


$$S_{rx}(t) \approx e^{j \left(2\pi f_c \left(t - \frac{2R}{c} \right) + \pi \frac{B}{\tau_{chirp}} \left(t - \frac{2R}{c} \right)^2 + \phi_0 \right)}$$



Fundamental of FMCW mechanism

FMCW beat signal

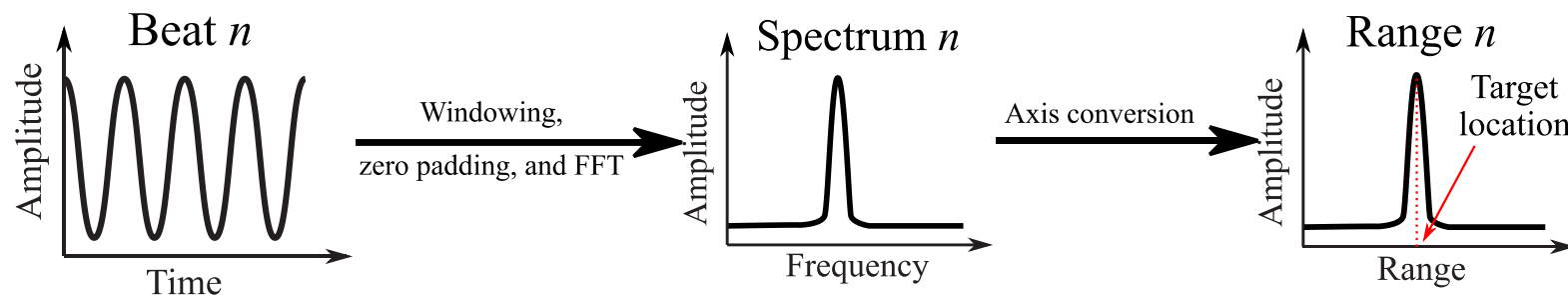


- R : target range

- $x(t)$: target motion extent

$$s_b(t) = \sigma e^{j \left(\frac{4\pi}{c} \frac{B}{\tau_{chirp}} R t + 4\pi \frac{x(t)}{\lambda} + \theta_1 \right)}$$

- Able to detect range
- Range resolution is limited by bandwidth: $c/2B$
- Range precision depends on signal-to-noise ratio



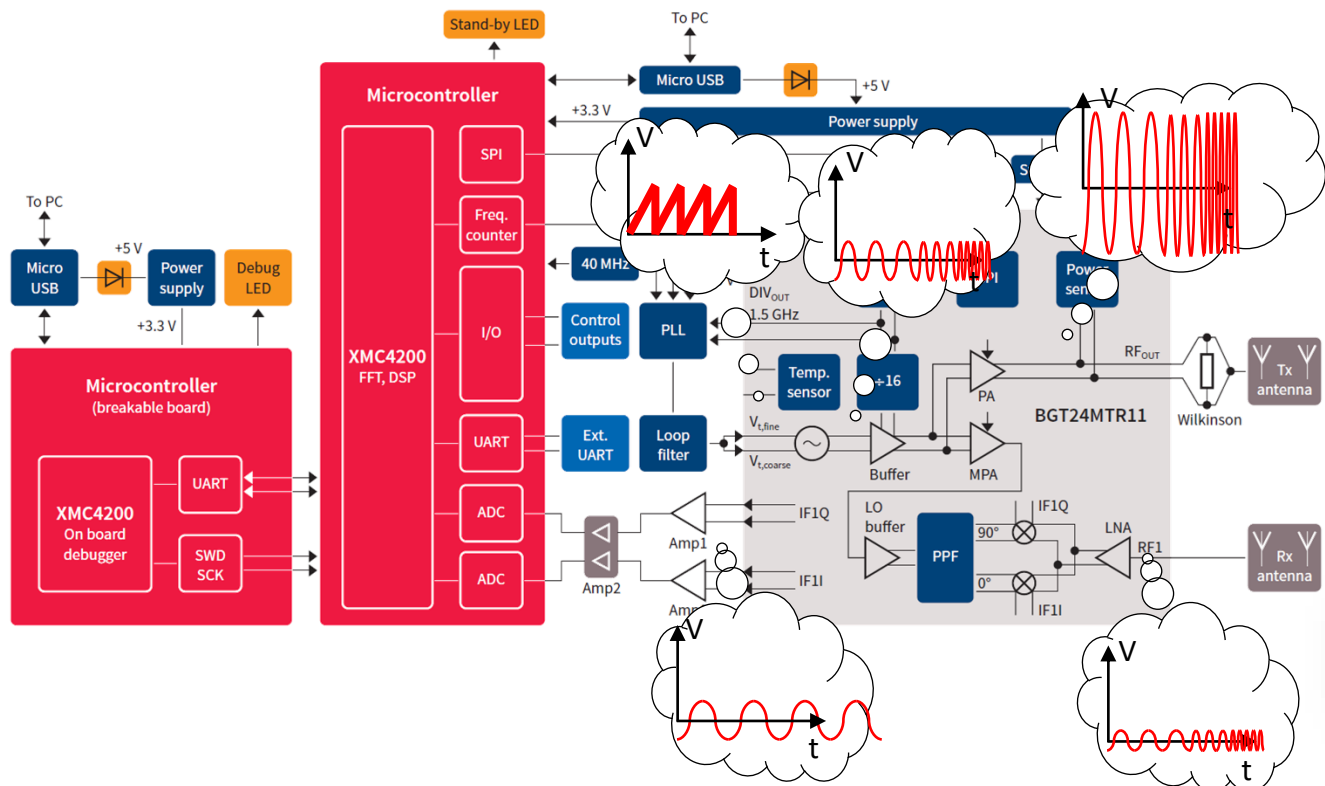


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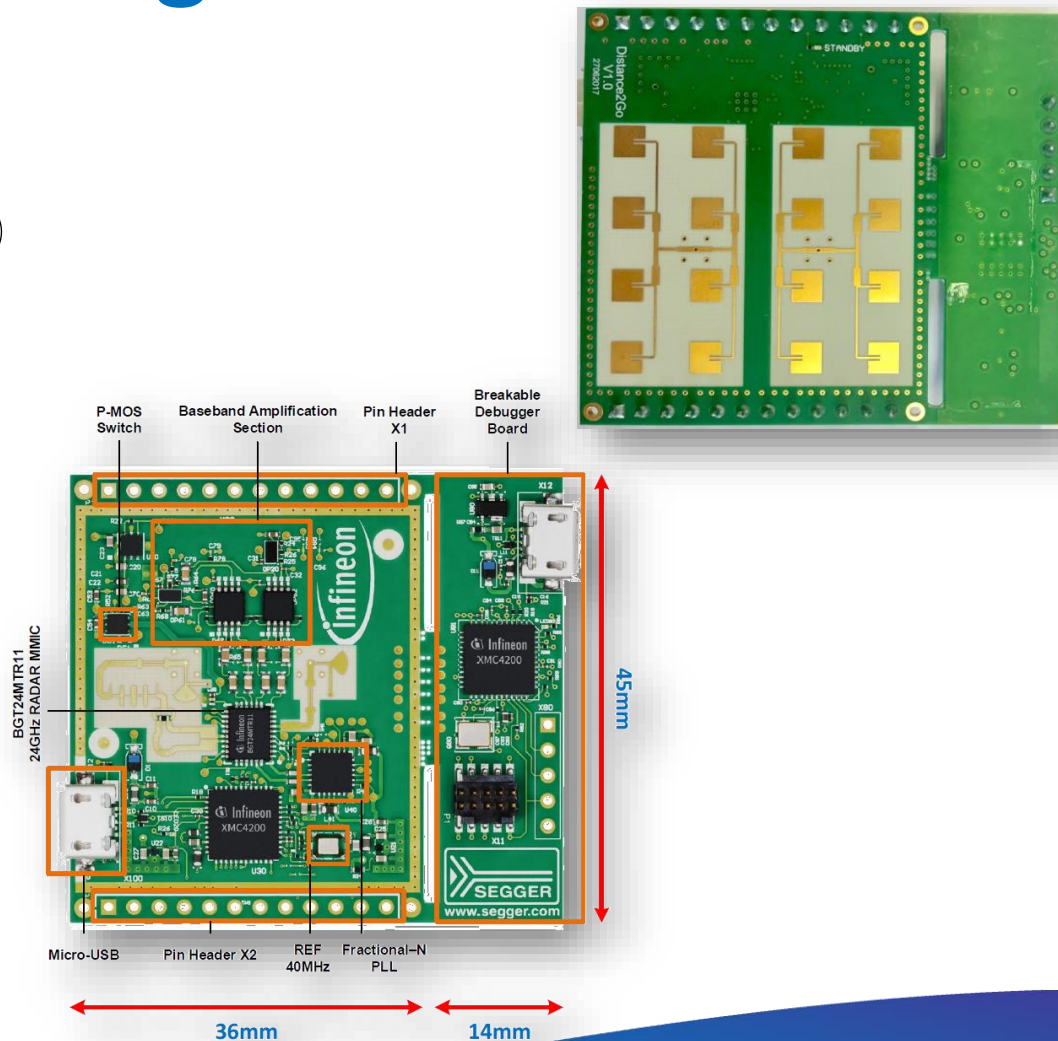
SECTION 2

FMCW radar typical architecture

FMCW typical architecture & signals

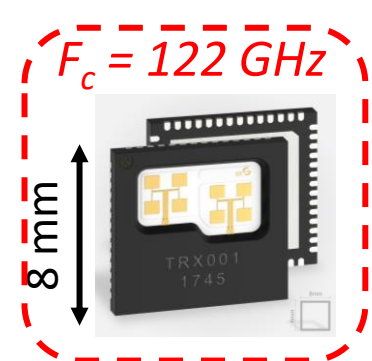
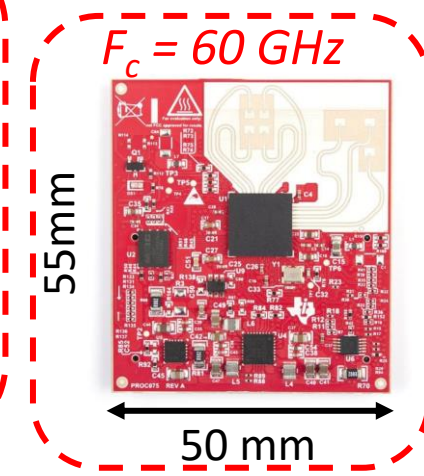
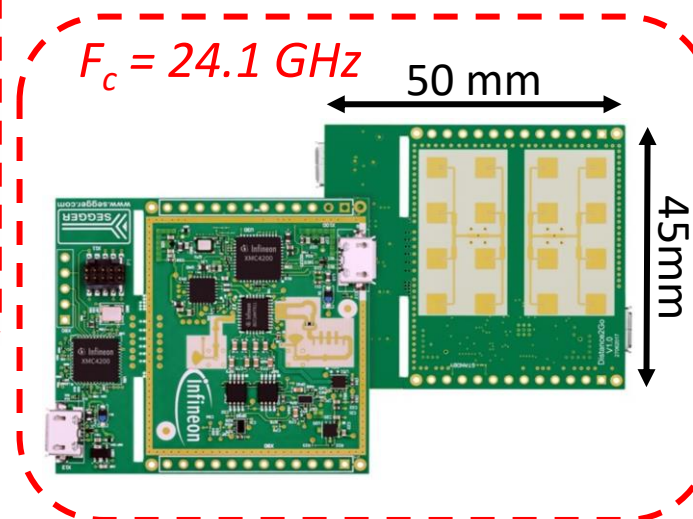
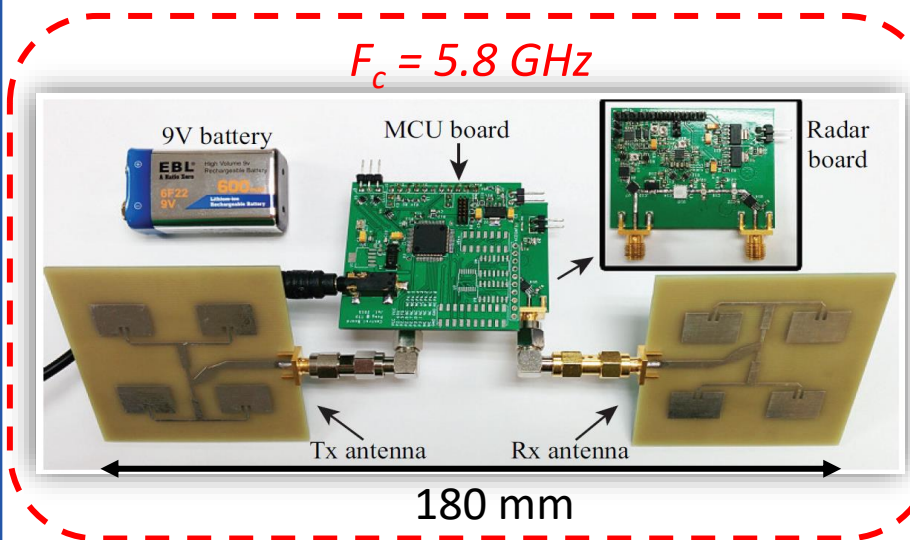


Infineon Distance2Go



Frequency scaling

The higher the frequency, the smaller the wavelength



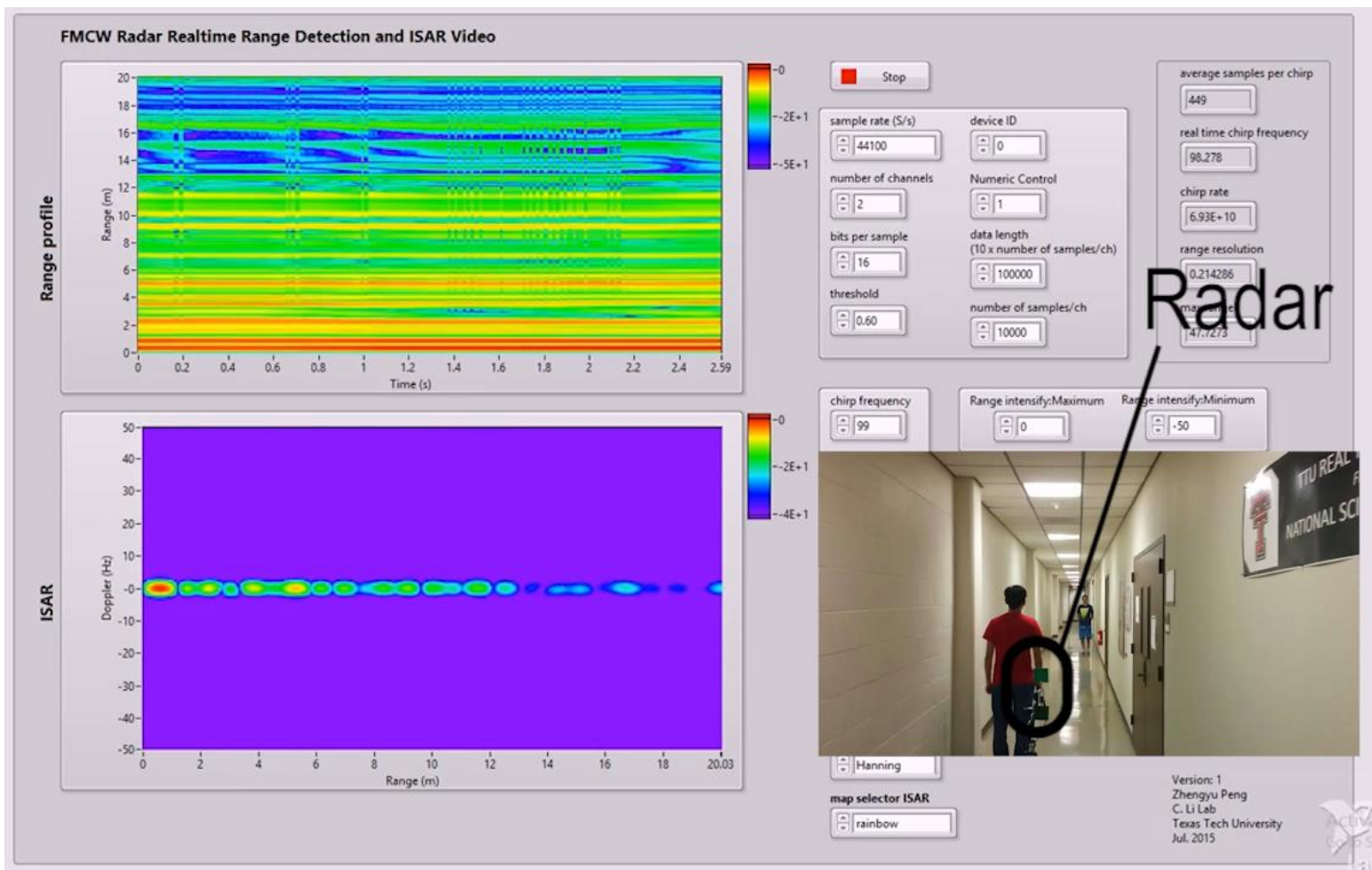


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SECTION 3

Range, motion, micro-Doppler sensing

ISAR Imaging



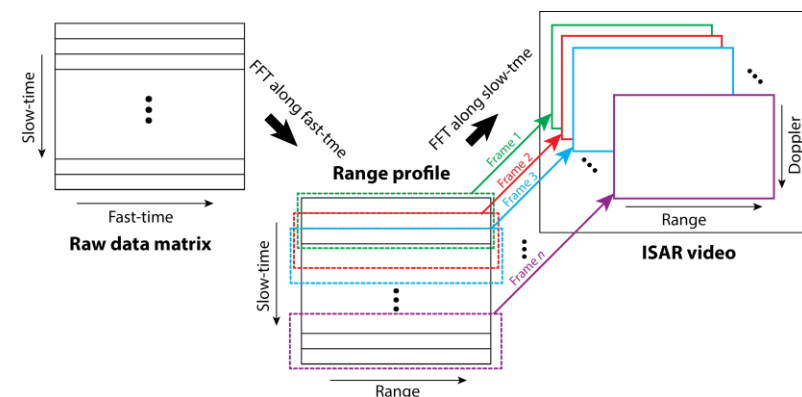
- ✓ For moving objects, the velocity (v) is determined from the phase change across multiple chirps.

$$s_b(t) = \sigma e^{j\left(\frac{4\pi}{c} \frac{B}{\tau_{chirp}} R t + 4\pi \frac{x(t)}{\lambda} + \theta_1\right)}$$

$4\pi \frac{v(t) \tau_{chirp}}{\lambda}$

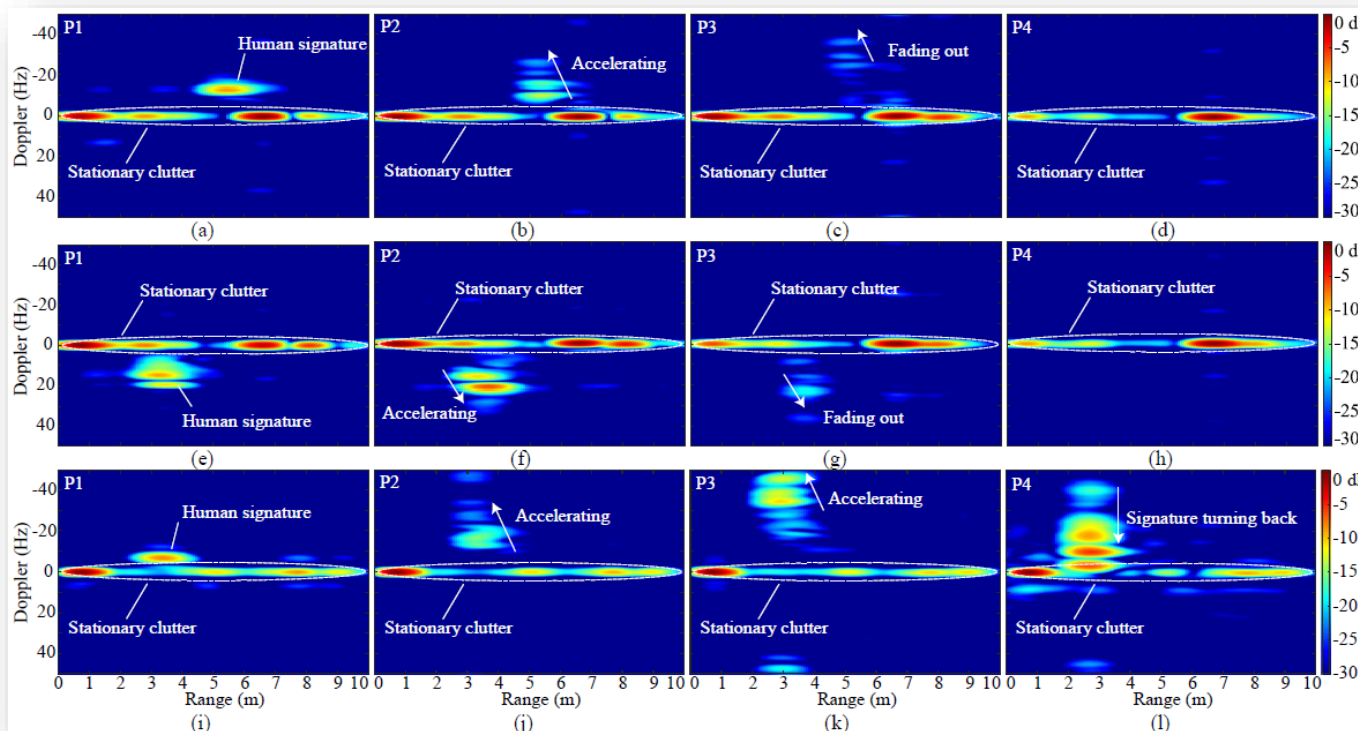
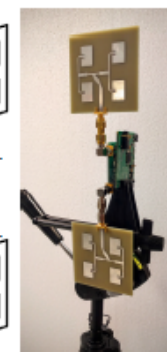
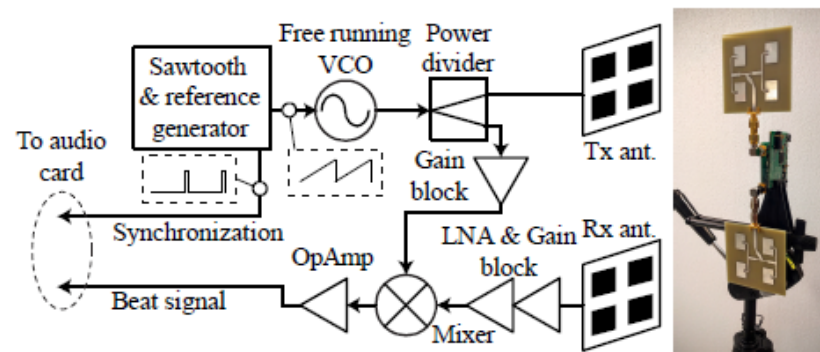
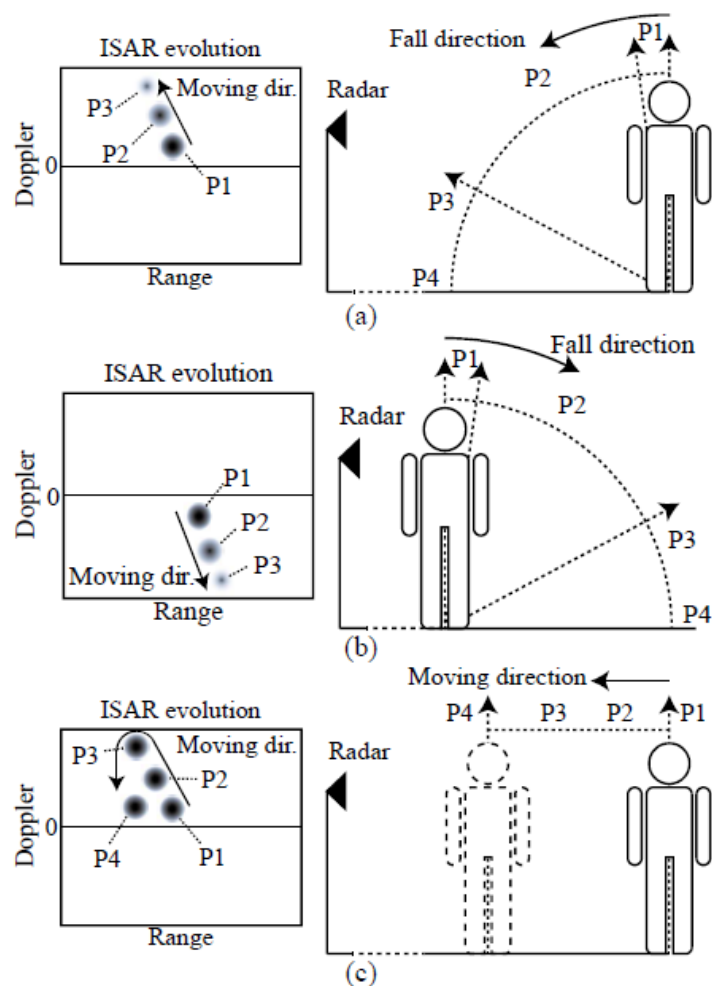
- ✓ A second FFT is performed across chirps to determine the phase change and thus the velocity. The two-dimensional FFT process gives a 2D range-velocity image (FFT heatmap).

- ← ✓ A time-sequence of FFT heatmaps forms an ISAR video.



“A Portable FMCW-Interferometry Radar with Programmable Low-IF Architecture for Localization, ISAR Imaging and Vital-Sign Tracking,” *IEEE T-MTT*, vol. 65, no. 4, 2017.

Fall detection



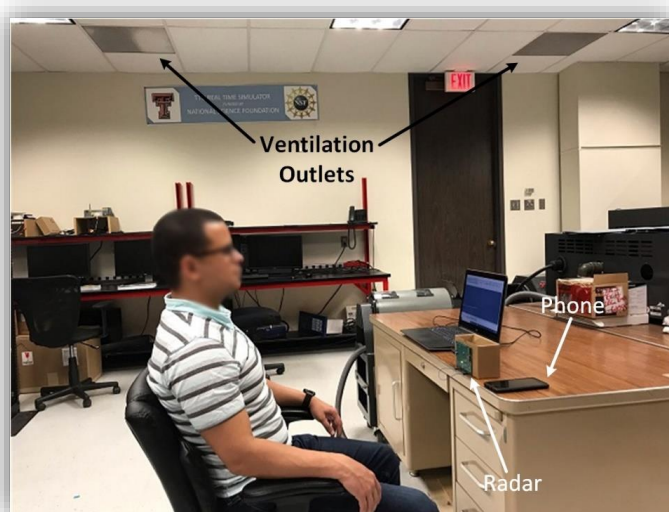
Z. Peng, J. Muñoz-Ferreras, R. Gómez-García and C. Li, "FMCW radar fall detection based on ISAR processing utilizing the properties of RCS, range, and Doppler," IEEE MTT-S IMS, San Francisco, CA, 2016, pp. 1-3.

Millimeter-wave vocal fold analysis

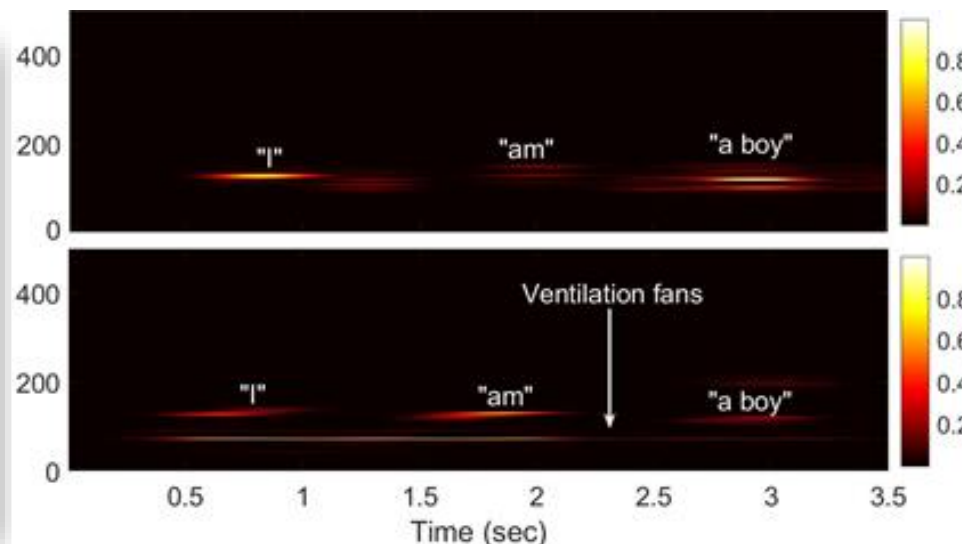
I/Q channels phase and amplitude imbalance due to circuit non-idealities destroys the signal orthogonality, particularly for small wavelengths.



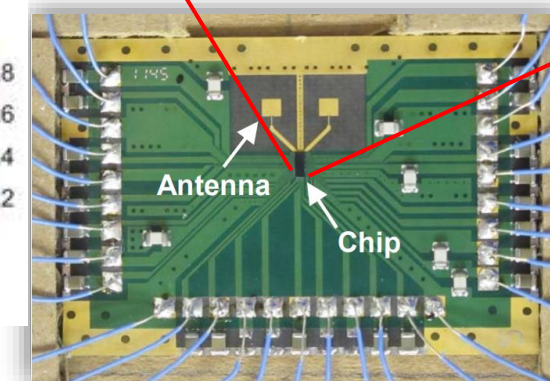
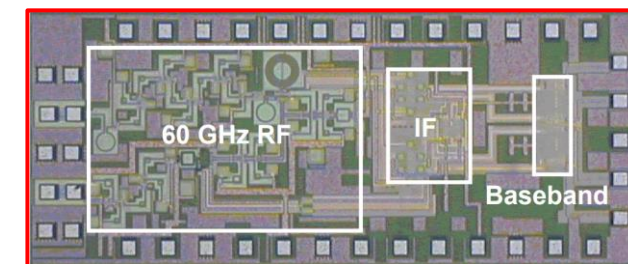
I/Q correction is required



Experimental setup for speech sensing (125-GHz radar-on-chip)



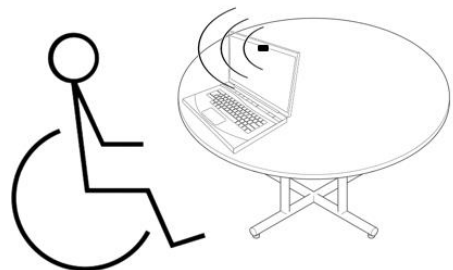
Spectrogram detected by radar and microphone, respectively.



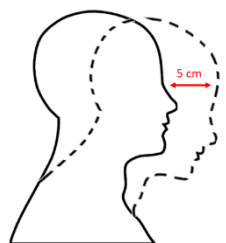
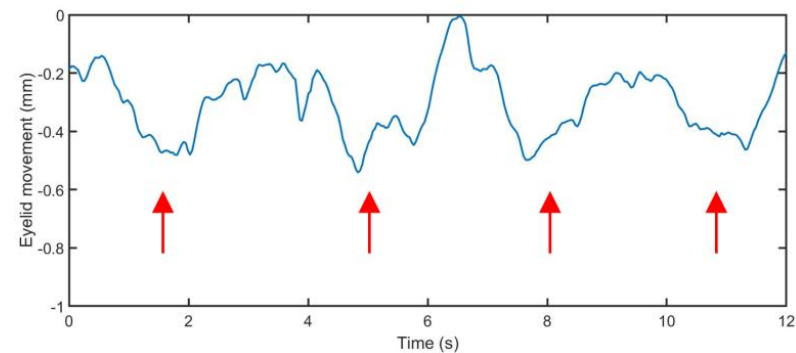
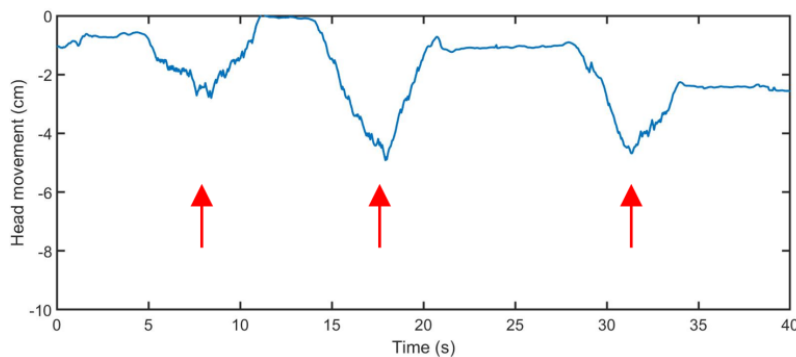
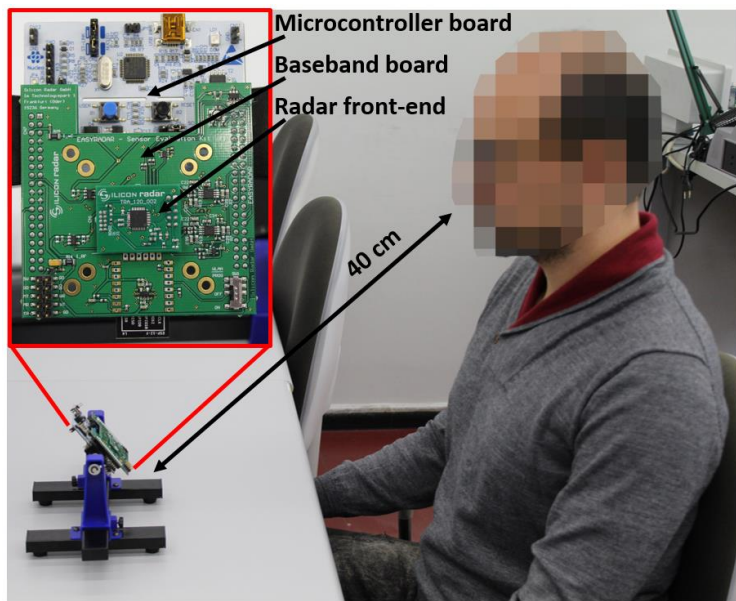
T. J. Kao, A. Y. Chen, Y. Yan, T. Shen and J. Lin, "A flip-chip-packaged and fully integrated 60 GHz CMOS micro-radar sensor for heartbeat and mechanical vibration detections," *IEEE RFIC Symp.*, Montreal, QC, 2012, pp. 443-446.

D. Rodriguez and C. Li, "Sensitivity and Distortion Analysis of a 125-GHz Interferometry Radar for Submicrometer Motion Sensing Applications," *IEEE T-MTT*, vol. 67, no. 12, pp. 5384-5395, Dec. 2019.

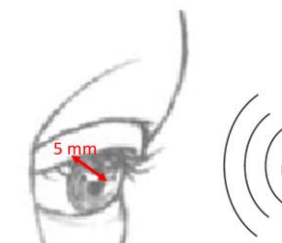
Head motion and eyes blinking detection



mm-Wave Radars for Assisting People with Neurodegenerative Disorders

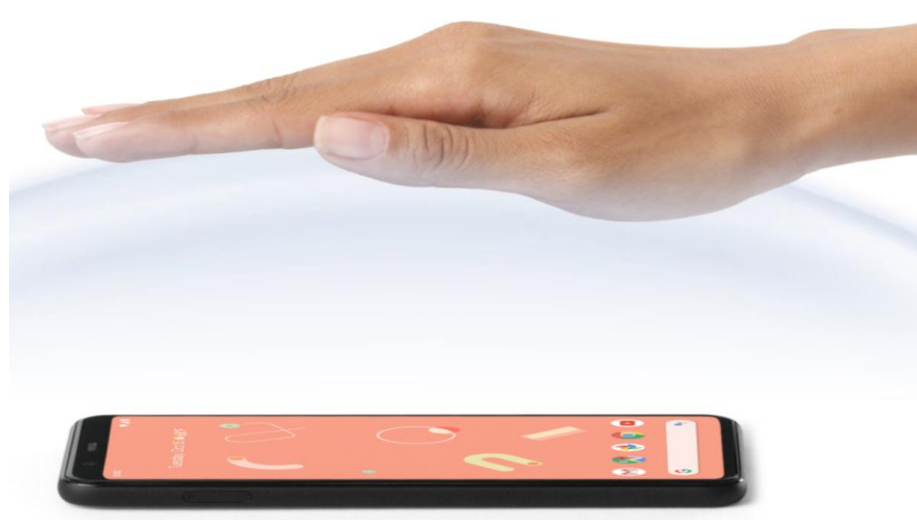
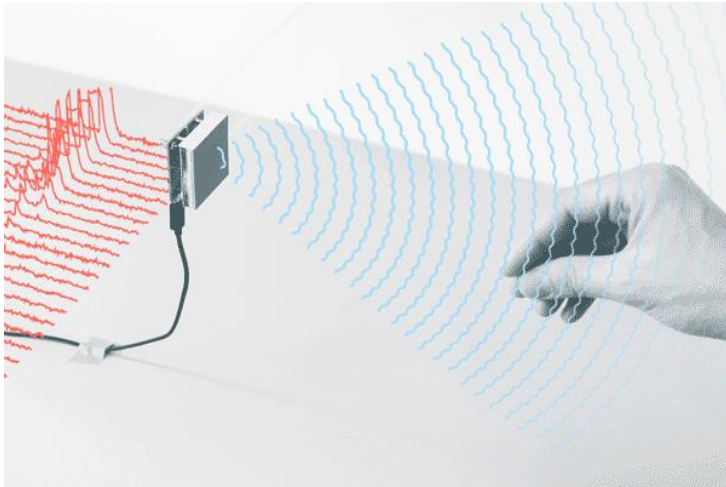


Head motion detection



Eyelid detection

Recent industrial efforts – Google Soli, Pixel 4



“Get things done.
No touch required.”



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SECTION 4

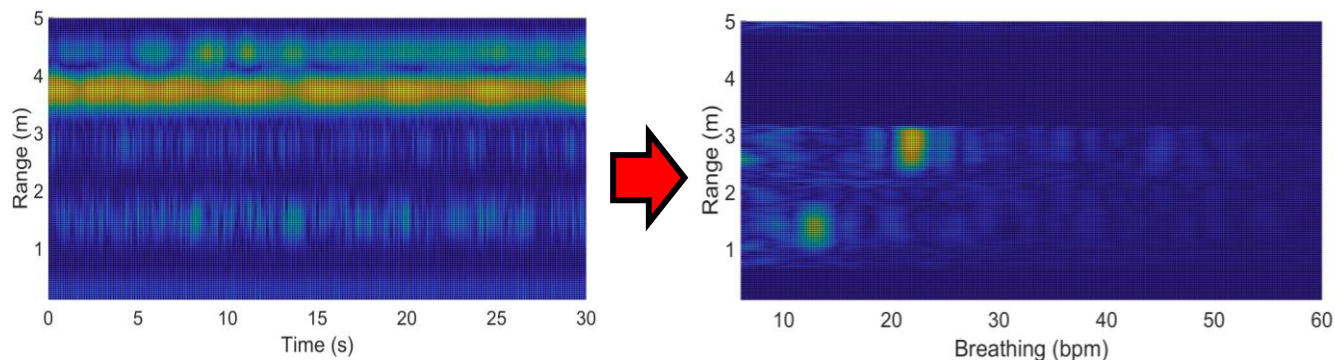
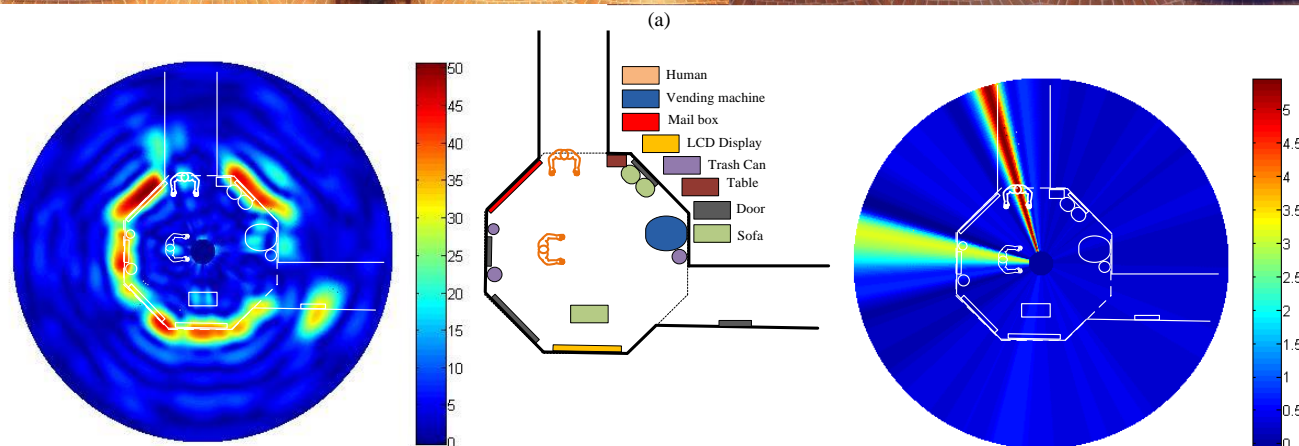
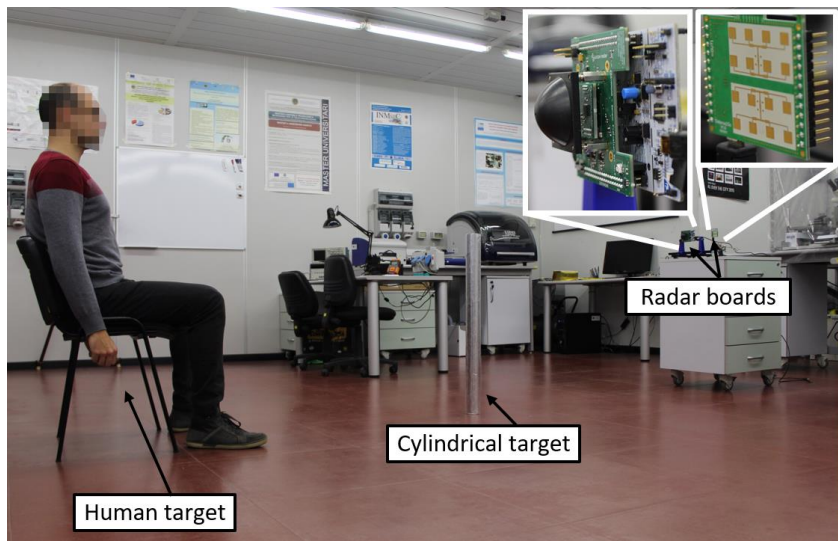
Vital-sign sensing

Vital-sign sensing

Example from a very young researcher...



Human-nonhuman discrimination



Successful human isolation: two people at 1.5 m and 2.9 m and a desk at 6 m.

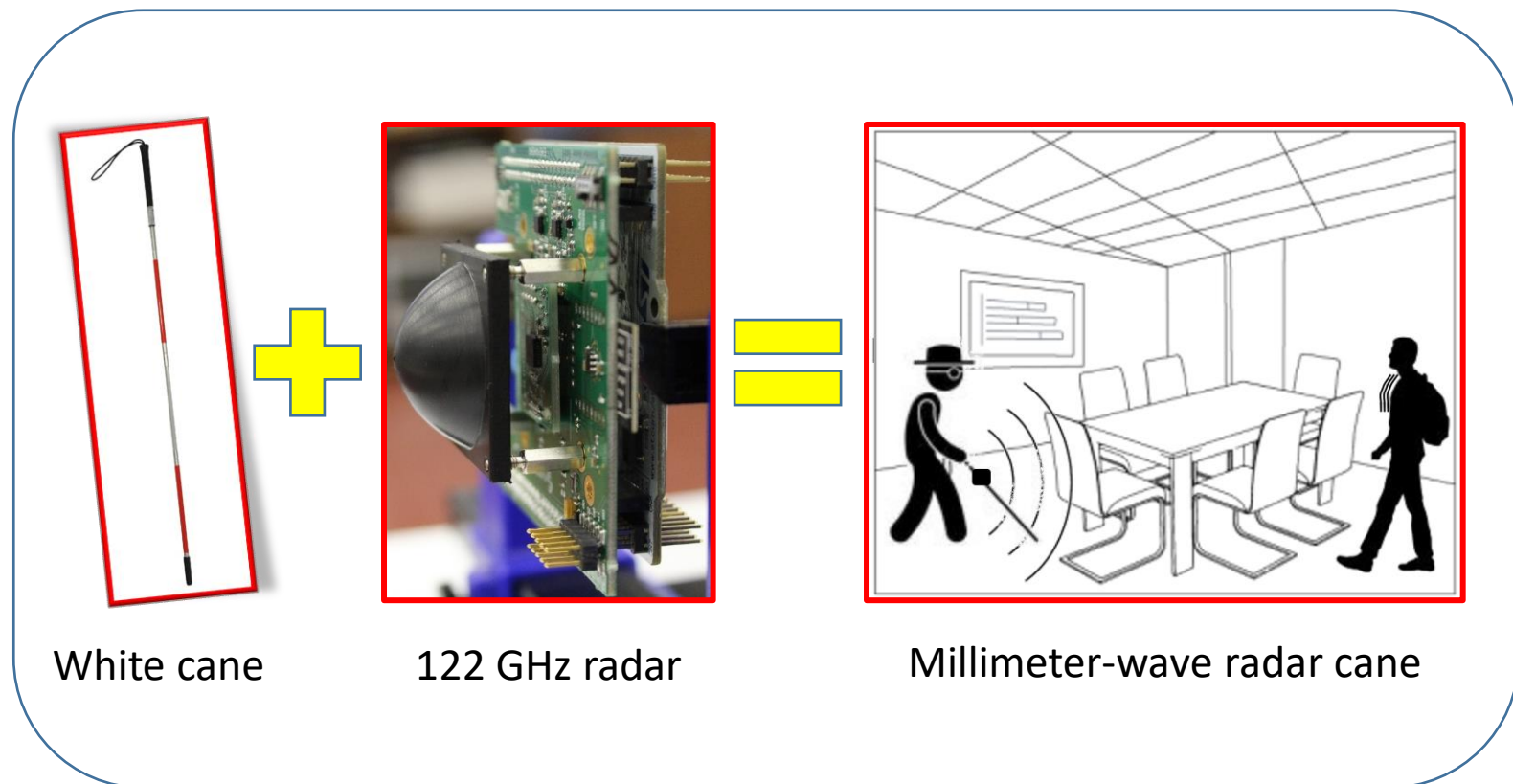
Millimeter-wave cane

- ✓ User-friendly system able of detecting potential obstacles
- ✓ Compact dimensions
- ✓ Higher precision
- ✓ Absence of privacy concerns
- ✓ Additional information on the target
 - ✓ Breathing rate detection for human targets discrimination

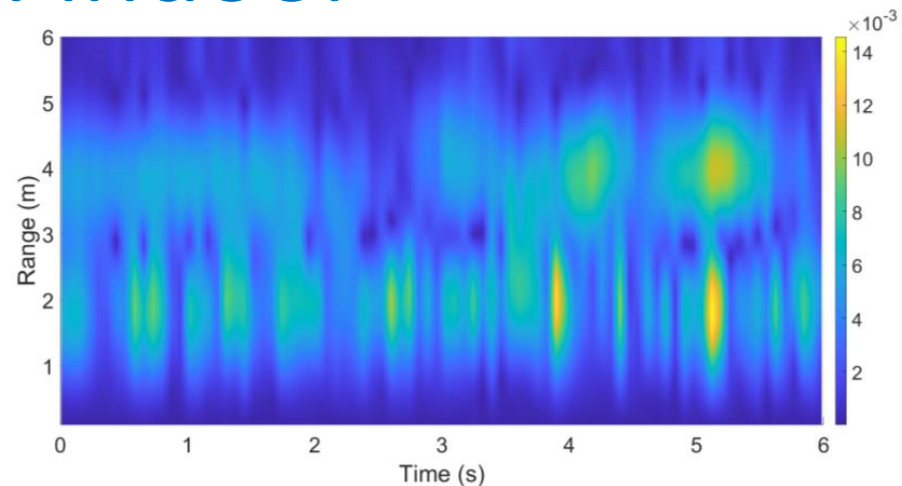
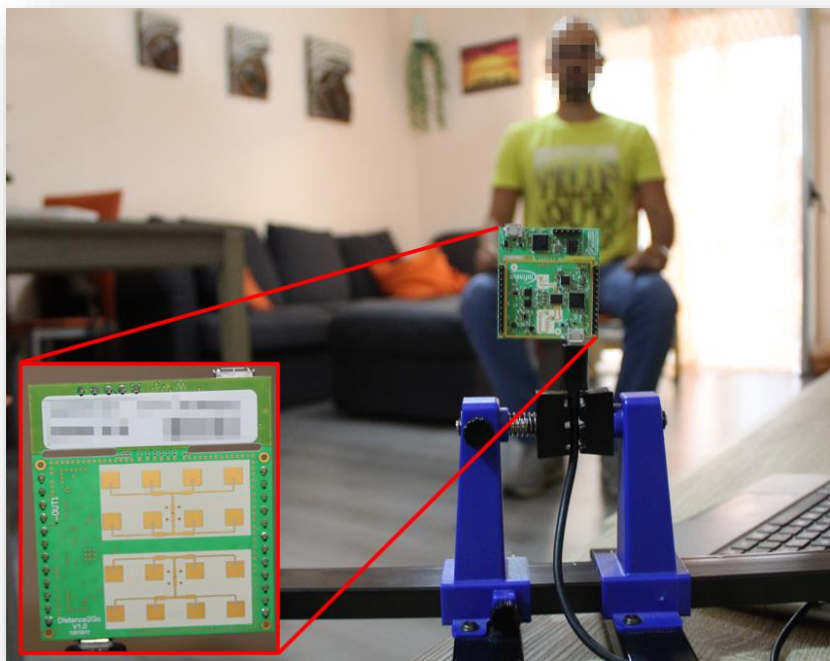


But...

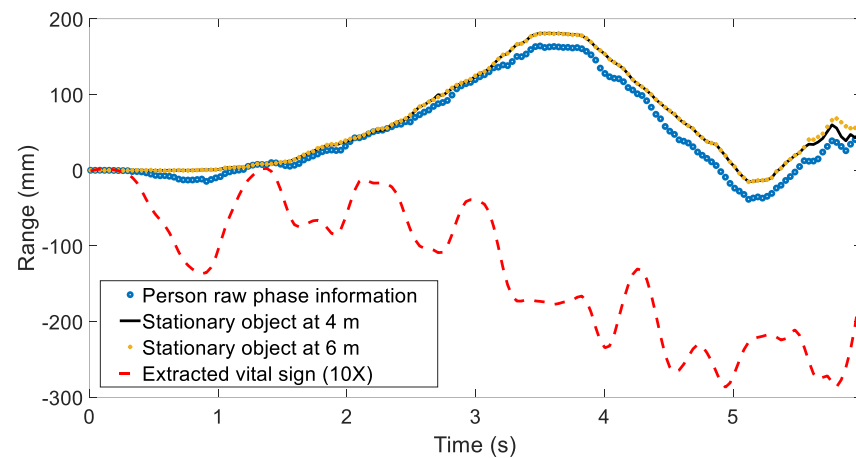
- ✓ Radar self-motion on the cane
- ✓ Range migration issues



Large radar movements: indoor

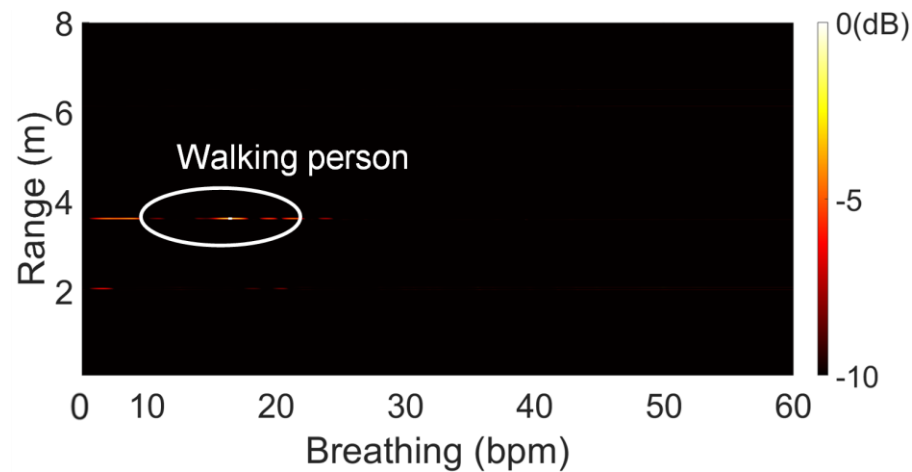
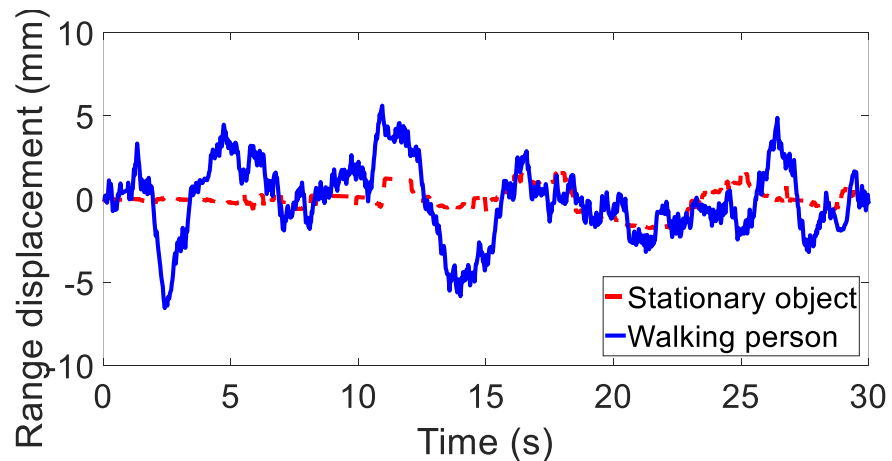
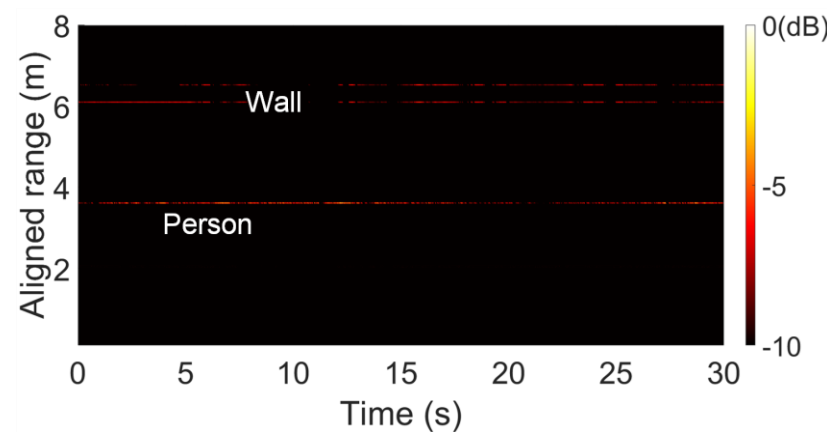
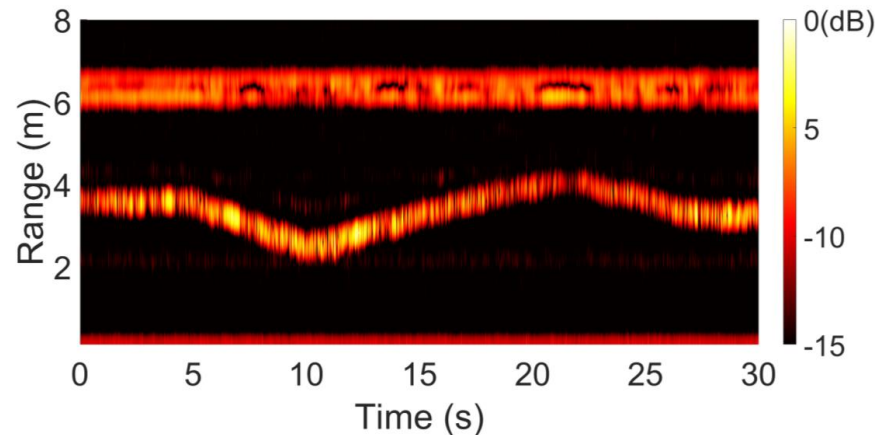
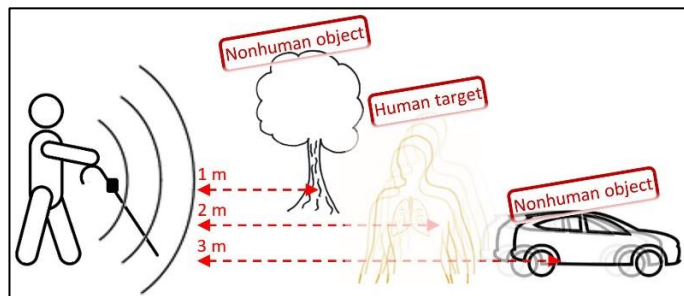


Range profile

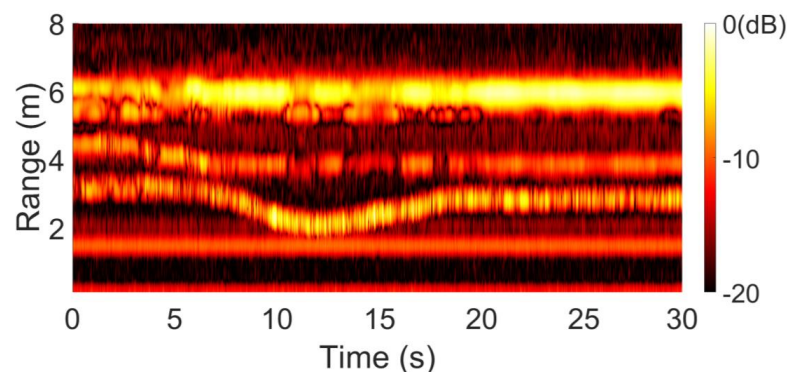
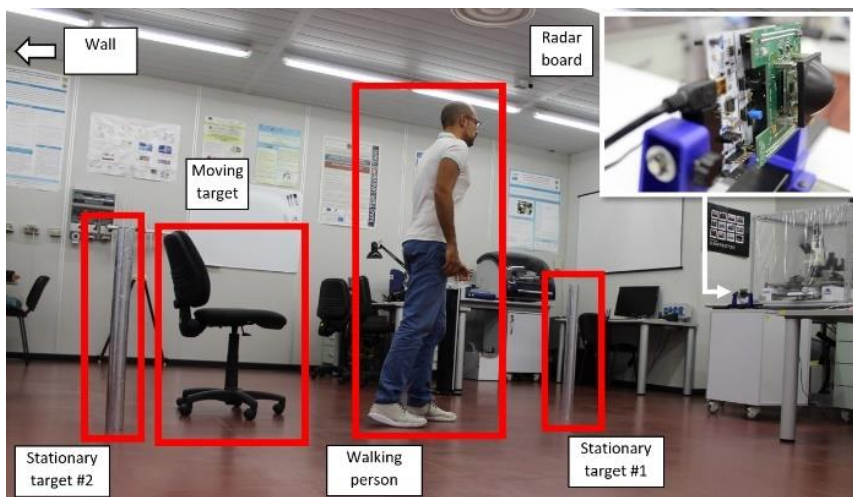


Range displacements

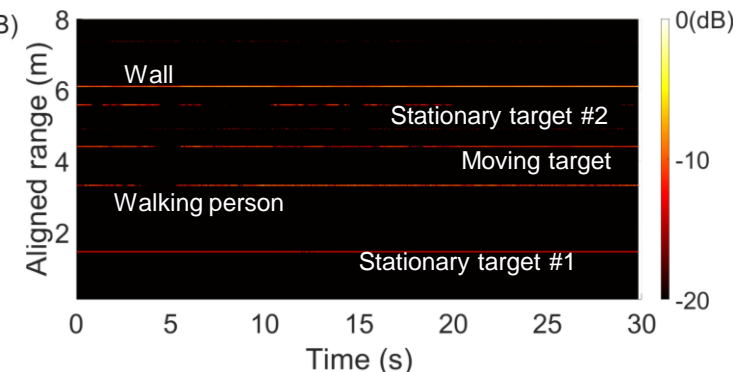
Range migration



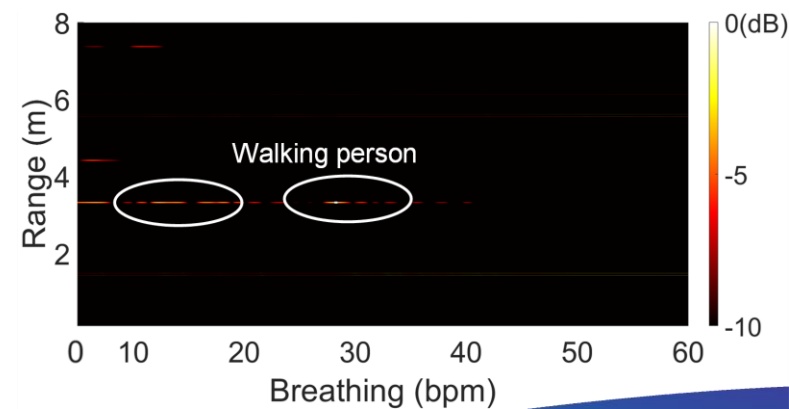
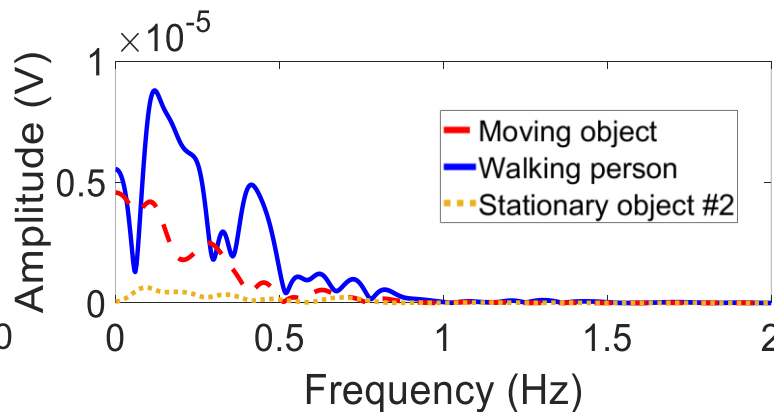
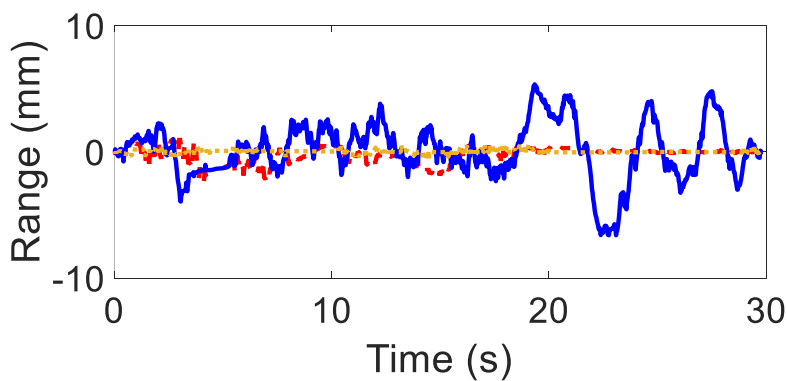
Range migration



Range profile



Aligned range



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Thank you for your attention!