FEATURES EXTRACTION OF THE DOPPLER FREQUENCY SIGNATURE OF A HUMAN WALKING AT 1 GHz

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Aim of the research activity

The study has been carried out with a twofold objective: to analyse at **1 GHz** the Doppler spectrum of a walking person; to highlight what time-frequency analysis between **the short-time Fourier transform (STFT)** [1], **the reassignment spectrogram (RE-Spect)** [2] and **the Wigner-Ville distribution (WVD)** [3] allows the best characterization of the Doppler signature of a human physical activity.

The investigation at low frequency on the time variation of the Doppler spectrum of moving targets is of interest for emerging radar applications devoted to the detection of people in highly cluttered environment.

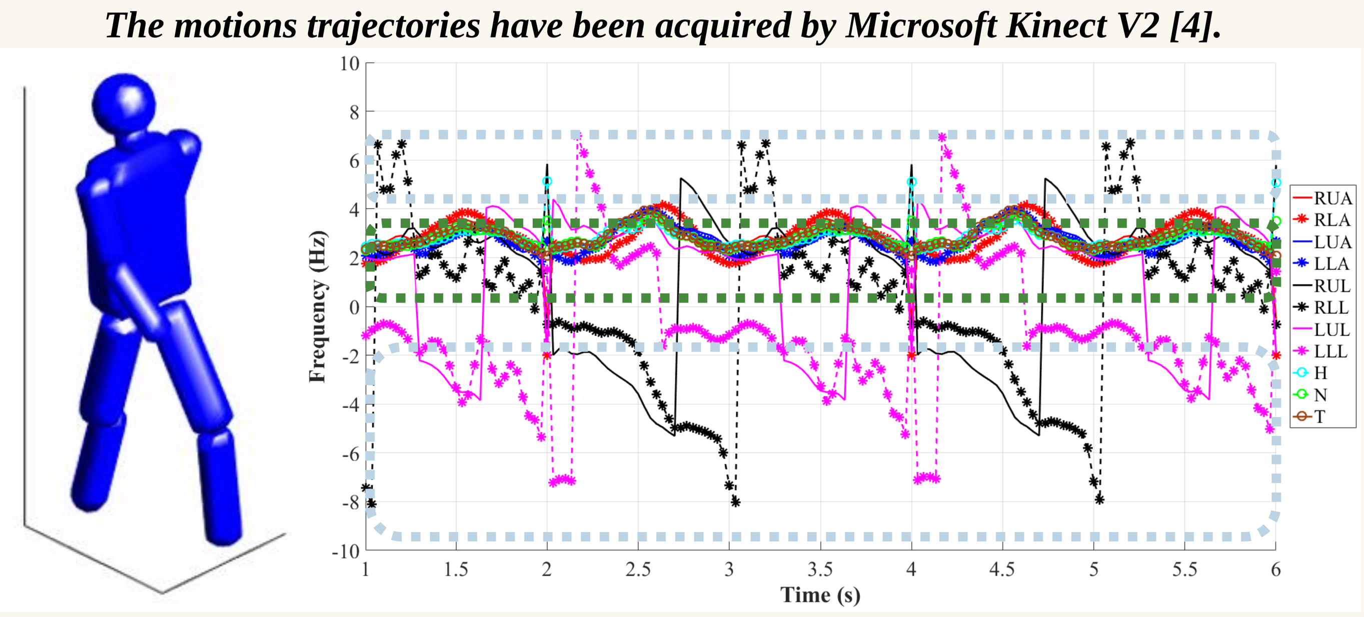
Analytical Doppler frequencies of the human body elements

A human model has been modelled as having 11 body parts to reproduce faithfully the motions of a human walking cycle: head **(H)**, neck **(N)**, torso **(T)**, right arm **(RUA)** left arm **(LUA)**, right forearm **(RLA)**, left forearm **(LLA)**, right thigh **(RUL)**, left thigh **(LUL)**, right leg **(RLL)**, left leg **(LLL)**.

Setup

observation time	6 s
walking cycle	2 s
averaged speed	0,4 m/s
frames	241
sampling frequency	30 Hz
frequency	1 GHz

The motions trajectories have been acquired by Microsoft Kinect V2 [4].



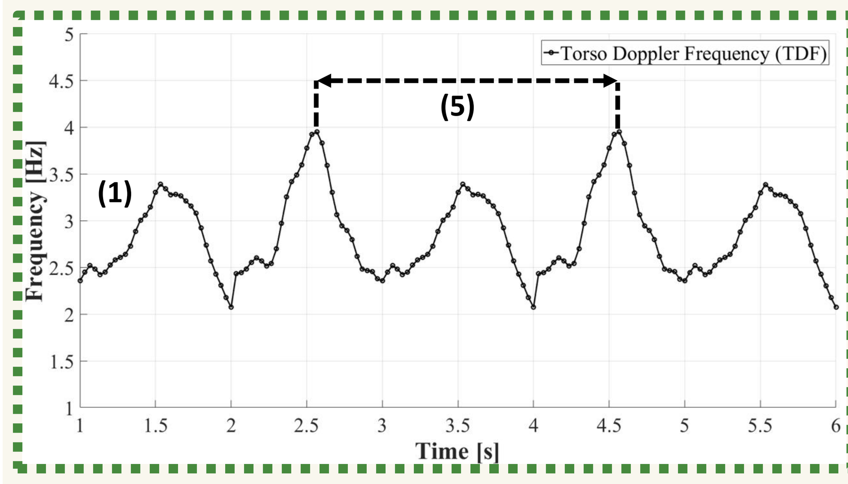
Analytical Doppler frequencies of a human body at 1 GHz.

The features **(2)**, **(3)** and **(4)** are identified by using the Doppler frequency envelopes **HFE** and **LFE.** At each time bin, **HFE** is made up by the highest frequencies and **LFE** by the smallest ones.

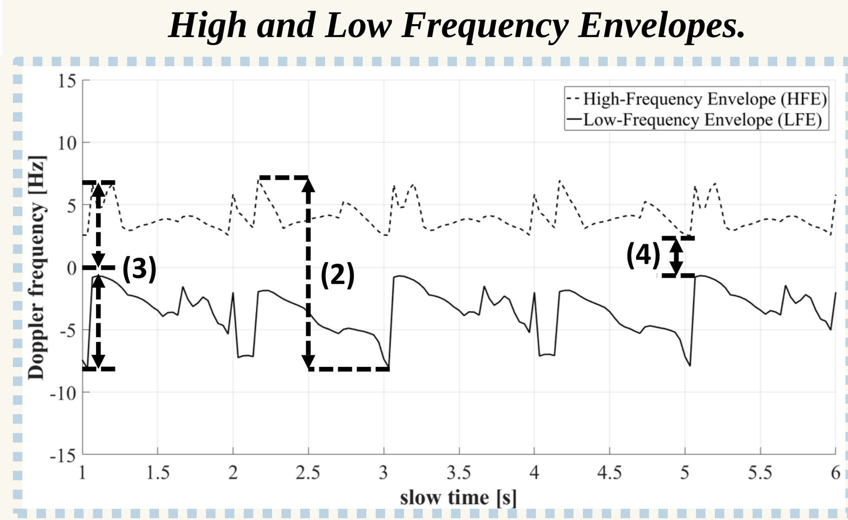
Analytical Doppler features

(1)	**2,86 Hz**
(2)	**15,08 Hz**
(3)	**0,56 Hz**
(4)	**3,16 Hz**
(5)	**2 s**

Torso Doppler Frequency.



High and Low Frequency Envelopes.



Five features have been chosen to characterize the Doppler shifts of the physical activity at 1 GHz [5]:

- **(1)** The **Torso Doppler frequency**, related to the speed of the human subject.
- **(2)** The **Total Doppler BW**, related to the speeds of the limbs motions.
- **(3)** The **Offset** which outlines the forward and backward motions of the limbs.
- **(4)** The **Bandwidth (BW) without micro-Doppler**.
- **(5)** The **Period** of the limbs motions.

Time-Frequency analysis of a walking man

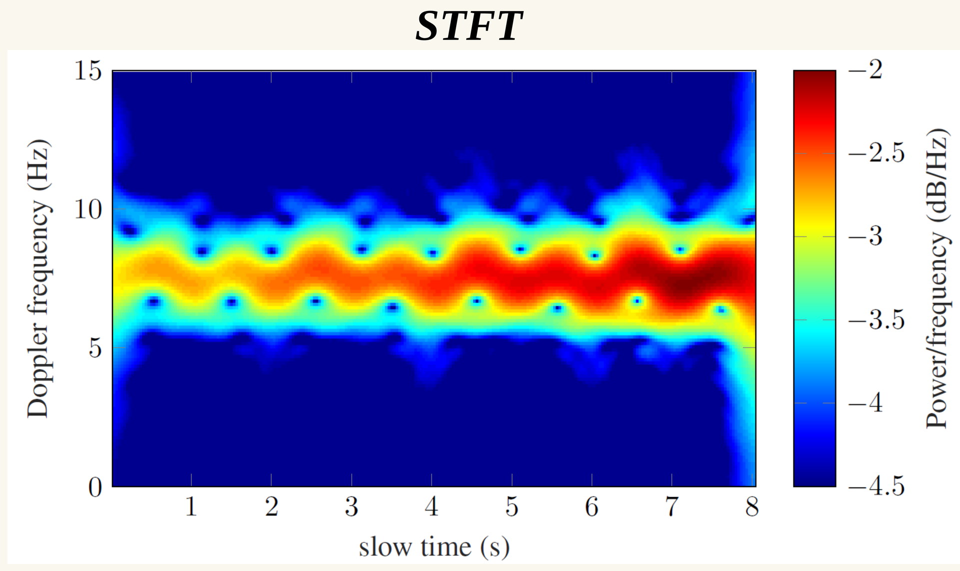
- The dielectric properties of the human model:
  $\boldsymbol{\varepsilon_r}$ = 50, $\boldsymbol{\sigma}$ = 1 S/m.
- The reflected EM field has been provided by a **physical optics (PO)-based analytical model**

Simulation Setup

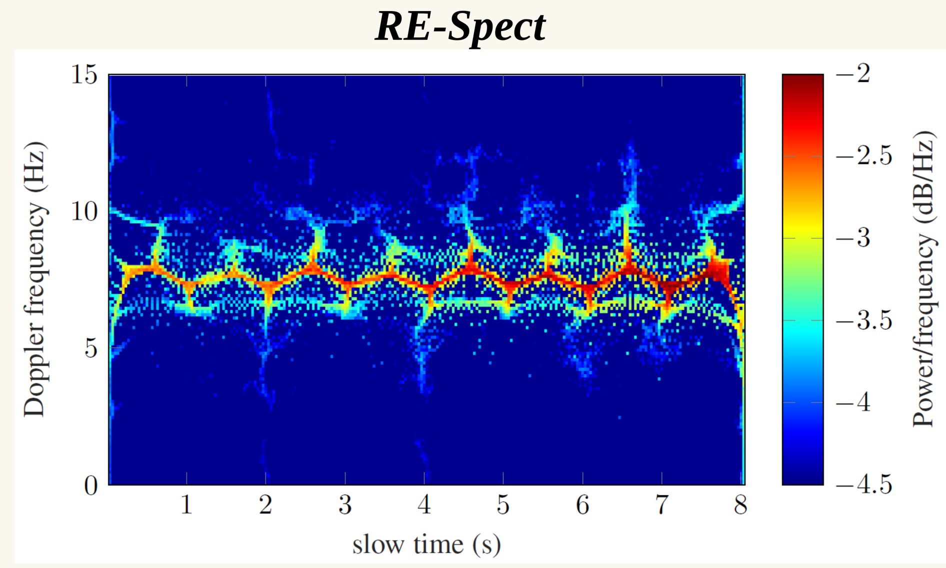
horn Antenna	LB-770-10
gain	10 dB
power	0 dBm
frequency	1 GHz
bandwidth	0 Hz (CW)
polarization	VV
azimuth angle	0°
elevation angle	0°
sampling frequency	0 Hz
CPI	3 ms

Doppler spectrograms at 1 GHz of a walking man.

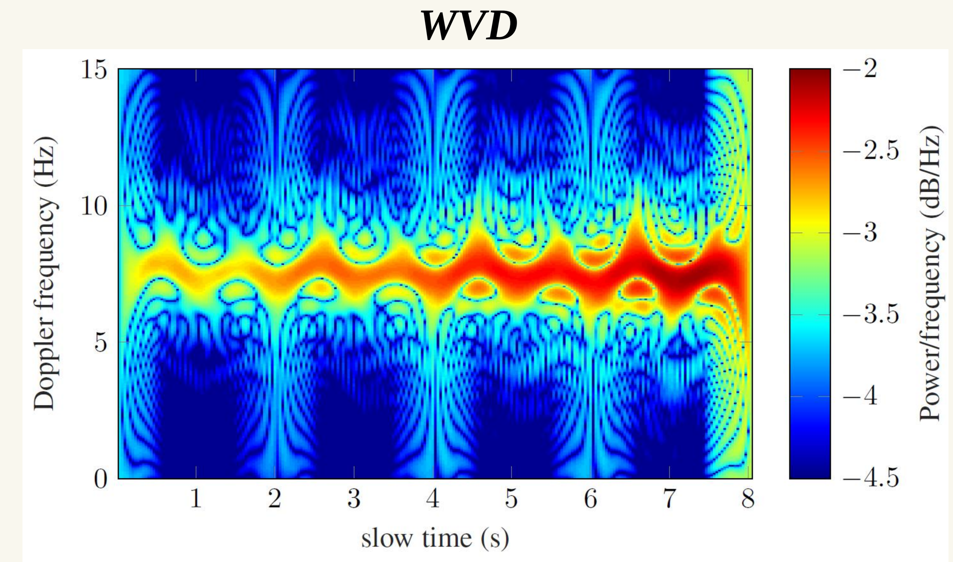
STFT



RE-Spect



WVD



STFT: Doppler features

Features	Hanning	Hamming	Gauss	Kaiser	Flapttop
(1)	2.84 Hz	2.84 Hz	2.84 Hz	2.83 Hz	2.81 Hz
(2)	9.02 Hz	9.5 Hz	9.5 Hz	9.37 Hz	10.4 Hz
(3)	3.21 Hz	3.21 Hz	3.21 Hz	3.26 Hz	3.21 Hz
(4)	4.10 Hz	3.98 Hz	3.75 Hz	4.33 Hz	5.03 Hz
(5)	1.97 s	1.97 s	2 s	1.97 s	2.1 s

RE-Spect: Doppler features

Features	Hanning	Hamming	Gauss	Kaiser	Flapttop
(1)	2.81 Hz	2.81 Hz	2.81 Hz	2.81 Hz	2.83 Hz
(2)	14.88 Hz	12.53 Hz	14.88 Hz	14.88 Hz	14.29 Hz
(3)	2.74 Hz	2.97 Hz	2.74 Hz	2.74 Hz	2.56 Hz
(4)	0.94 Hz	0.82 Hz	0.58 Hz	0.82 Hz	0 Hz
(5)	2 s	2.03 s	2 s	2 s	2.1 s

WVD: Doppler features

Features	Hanning	Hamming	Gauss	Kaiser	Flapttop
(1)	2.81 Hz	2.81 Hz	2.82 Hz	2.82 Hz	2.82 Hz
(2)	14.94 Hz	14.94 Hz	14.94 Hz	14.94 Hz	14.94 Hz
(3)	2.77 Hz	2.77 Hz	2.77 Hz	2.77 Hz	2.77 Hz
(4)	3.34 Hz	3.46 Hz	2.64 Hz	2.64 Hz	3.05 Hz
(5)	1.93 s	1.93 s	1.93 s	1.93 s	1.93 s

The Doppler features have been compared with the analytical ones presented above.

Conclusions

- Numerical tests have been carried out analysing at 1 GHz the Doppler spectrum of a walking man.
- Three joint time-frequency techniques have been applied to the backscattered response of the moving target provided by a PO-based analytical model.
- Five Doppler features have been extracted both to characterize the frequency signature and to discriminate the best time-frequency analysis
- The pseudo WVD proved to be the best time-frequency function to detect and characterize the physical activity of a real subject.

Ongoing research activity

Experimental tests observing a subject walking within the forest

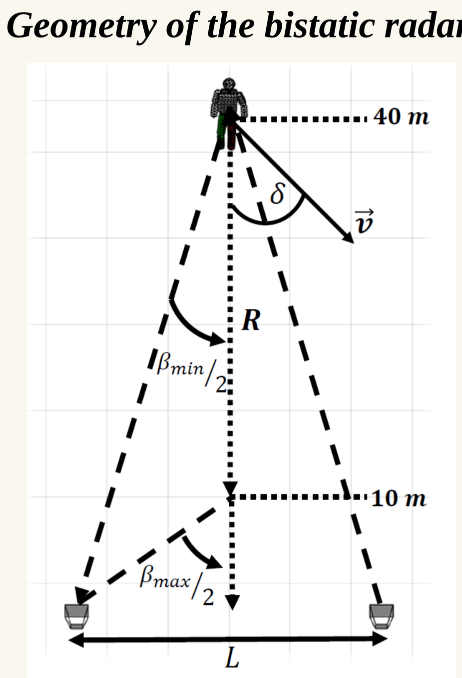
GOAL:

- **Analysis at low frequency (UHF-band) of the impact of a highly cluttered environment on the Doppler spectrum of a moving target.**

Measurement Setup

frequency	1 GHz (CW)
antenna	Yagi
polarization	VV
power	0 dBm
sampling frequency	10 kHz

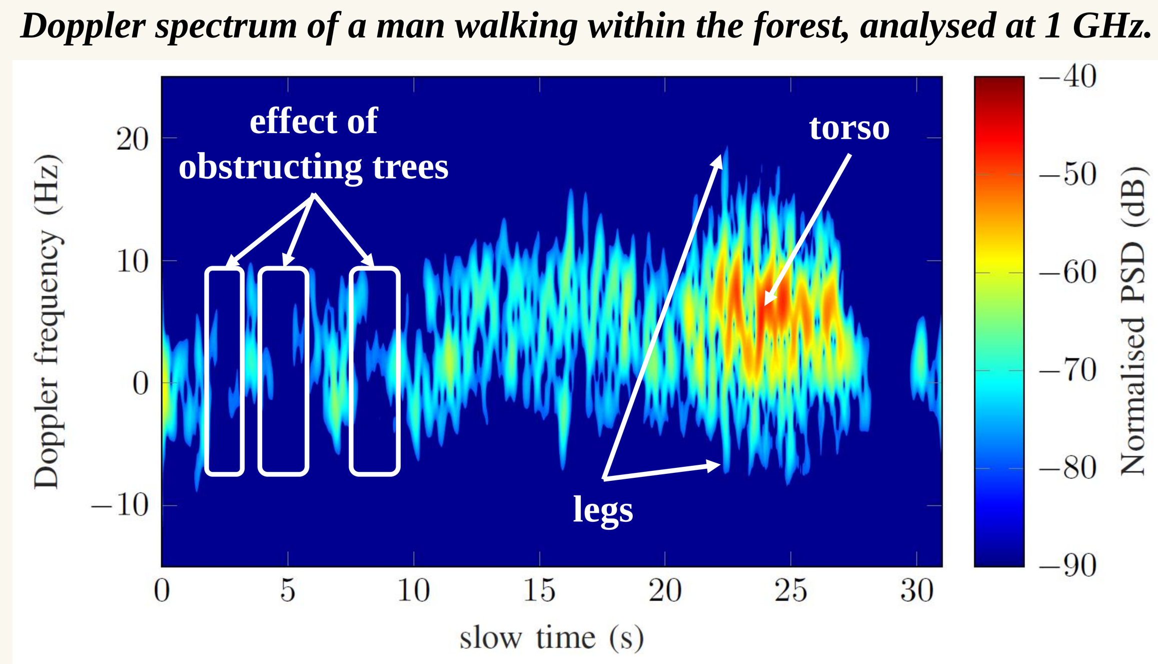
Geometry of the bistatic radar.



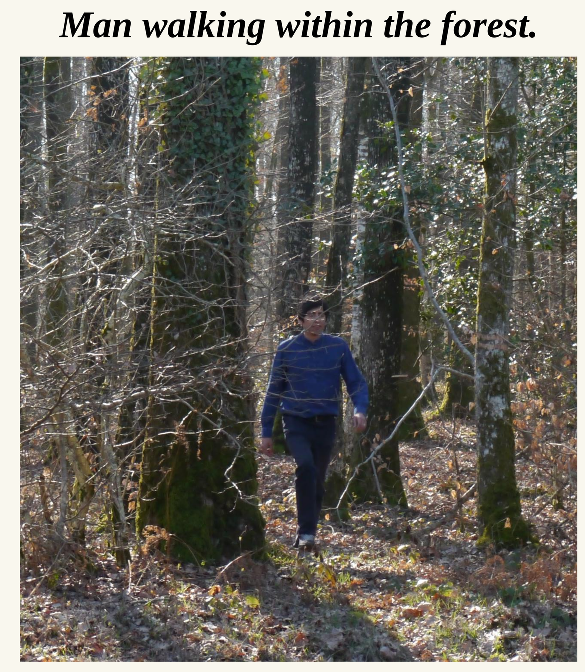
L = 16 m.

$22,7° \leq \beta \leq 77,4°$

Doppler spectrum of a man walking within the forest, analysed at 1 GHz.

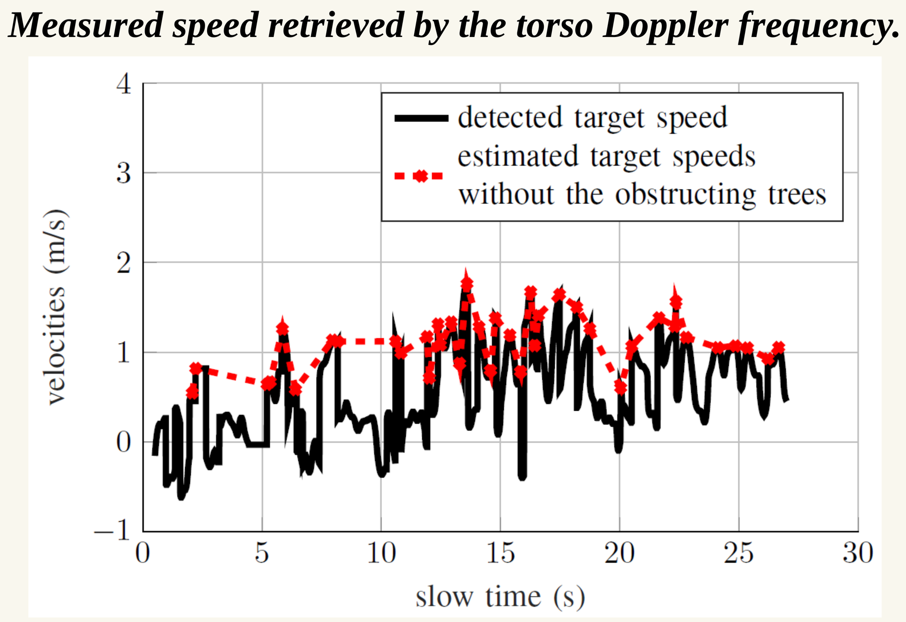


Man walking within the forest.



Averaged speed = 1,08 m/s.

Measured speed retrieved by the torso Doppler frequency.



Measured and simulated Doppler features.

Features		1 GHz
1) Torso Doppler	measured	3.48 Hz
	simulated	5.5 Hz - 9.5 Hz
2) Period	measured	0.42 s
	simulated	0.4 s - 0.7 s
3) Total BW	measured	28 Hz
	simulated	18.6 Hz - 28.3 Hz
4) Offset	measured	14.19 Hz
	simulated	9.2 Hz - 12.5 Hz

The human body parts are shadowed by the trees. Consequently, a fragmentation of the Doppler spectrum is highlighted.

References

[1] V. C. Chen and S. Qian, "Joint Time-Frequency transform for Radar range-Doppler imaging," IEEE Transactions on Aerospace and Electronic Systems, vol. 34, no. 2, pp. 486–499, 1998.

[2] I. Reinhold, J. Starkhammar, and M. Sandsten, "The scaled reassigned spectrogram adapted for detection and localisation of transient signals," in Signal Processing Conference (EUSIPCO), 2017 25th European. IEEE, 2017, pp. 907–911.

[3] R. Tan, H. S. Lim, A. B. Smits, R. I. A. Harmanny, and L. Cifola, "Improved micro-Doppler features extraction using Smoothed-Pseudo Wigner-Ville distribution," in Region 10 Conference (TENCON), 2016 IEEE. IEEE, 2016, pp. 730–733.

[4] M. Capecci, M. G. Ceravolo, F. Ferracuti, S. Iarlori, V. Kyrki, S. Longhi, L. Romeo, and F. Verdini, "Physical rehabilitation exercises assessment based on hidden semi-markov model by Kinect v2," in Biomedical and Health Informatics (BHI), 2016 IEEE-EMBS International Conference on. IEEE, Feb 2016, pp. 256–259.

[5] Y. Kim and H.Ling, "Human activity classification based on micro-Doppler signatures using a support vector machine," IEEE Transactions on Geoscience and Remote Sensing, vol. 47, no. 5, pp. 1328–1337, 2009.