CLASSIFICATION IN L-BAND OF PHYSICAL ACTIVITIES PERFORMED SIMULTANEOUSLY INTO THE FOREST BY A GROUP OF PERSONS

G. Manfredi[§], *I. Hinostroza*[§], *M. Menelle*[†], *S. Saillant*[†], *J.-P. Ovarlez*[*,§] *and L. Thirion-Lefevre*[§]

[§]SONDRA, CentraleSupélec, Université Paris-Saclay, F-91190 Gif-sur-Yvette, France
[†]ONERA, Université Paris-Saclay (DEMR/EGDR), 91120 Palaiseau, France
[*]ONERA, Université Paris-Saclay (DEMR/MATS), 91120 Palaiseau, France

ABSTRACT

The Doppler frequency signature and the cadence frequency of a couple of people moving simultaneously into the forest are presented in this paper. A brisk walk and a run have been analyzed in L-band. The results are based on measured data that have been collected by a bistatic radar working in continuous wave (CW). The purpose of the analysis is to assess the reliability of the short-time Fourier transform (STFT) and of the cadence frequency diagram to distinguish two physical activities performed simultaneously in a forested area and recorded at 1 GHz. Obstructing trees and small movements of the undergrowth largely impacted the spectrogram, making it difficult to interpret. Instead, the cadence frequency looks reliable for detecting the two activities and distinguishing them from the surrounding vegetation.

***Index Terms*—** Cadence frequency, Doppler radar, forest, human detection, remote sensing, Short-Time Fourier Transform (STFT).

1. INTRODUCTION

Detection and classification of human activity is an active research topic. Micro-Doppler analysis, via STFT (also known as spectrogram), is a handy tool for this task [1], especially for a single subject. For more complex movement, additional processing can be done over the spectrogram to obtain a cadence frequency diagram (also known as cadence velocity diagram if speed is shown instead of the frequency Doppler shift). For instance, in [2], for a K-band radar, the authors also used a cadence frequency diagram, besides spectrogram analysis, to discriminate between unassisted and two types of cane-assisted walks of a single subject. In [3], for an X-band radar, besides spectrogram analysis, the cadence frequency diagram is introduced to obtain information on the gait of the walking of a single person and a group of people. It was also shown that the spectrogram of a human gait is very different from the one of a dog. In [4], the authors were more concerned for a lower carrier frequency, 4.2 GHz, and four different activities: walking without any swinging arm, walking with one swinging arm, walking with both arms swinging, and running. Instead of a spectrogram, the authors proposed to use S-transform (from which the STFT is a particular case). In [5], for a Ku-band radar, the authors were interested in discriminating between four cases: a walking person, a running person, a group of people walking, and a group of people running. They showed that spectrogram and cadence frequency diagram analysis outperforms the auto-correlation technique for feature extraction, especially for the cluttered environment. They also showed that the clutter dampens the scattered energy from the subjects.

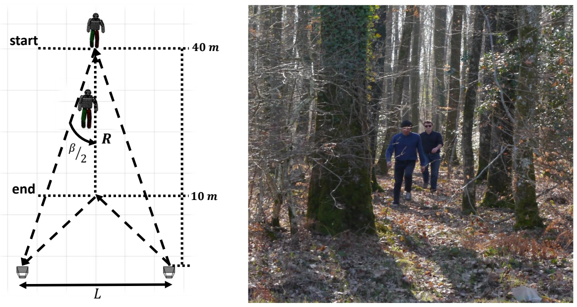
The use of high-frequency carriers is motivated by the consequently high-frequency Doppler shift, which helps in the discrimination of activities. Conversely, lower frequencies, L- or UHF-band, are better adapted for electromagnetic propagation in forested areas, as shown in [6], [7]. Due to the leaves and small branches' size with respect to the working wavelength at those frequencies, their Radar Cross Sections are small compared to the one of the human body. Recently, in [8], for a UHF-band radar, we have presented the Doppler analysis of a single subject walking in a forested area. It was shown that the analysis relying only on the spectrogram is very difficult.

In this work, we investigate at low frequency the use of cadence frequency diagrams additionally to the spectrograms to classify the activities of two people in a forested area. The paper is organized as follows. A description of the employed radar system is presented in Section 2. The spectrogram of the moving targets is described in Section 3. The corresponding cadence frequency diagram is explained and commented in Section 4. Finally, the conclusions are presented in Section 5.

2. MEASUREMENT SETUP

The measurement setup has already been presented in the previous work [8]. Following, we summarize the basic parameters.

The electromagnetic signal reflected from the moving human targets has been retrieved using log-periodic antennas



(a) (b)

Fig. 1: Measurement setup: (a) parameters of the bistatic configuration, (b) couple of persons moving among the trees.

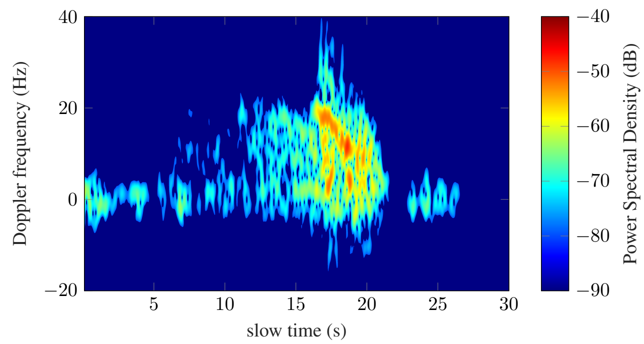


Fig. 2: Spectrogram of a couple of persons walking and running among the trees at 1 GHz.

working at 1 GHz. The antennas have been placed in bistatic configuration at 16 m from each other (baseline L) to guarantee a negligible mutual coupling between them. The radars have been employed in VV polarization mode. The radar configuration is depicted in Fig. 1a.

A brisk walk and a run have been measured in 30 s with the following methodology. The subjects were asked to stay still for 6 s after the beginning of the measurement. Then, they performed the two motor activities simultaneously within the forest forward the antennas. The targets have traveled a distance R = 30 m among the trees (Fig. 1b), starting at 40 m and concluding the activities 10 m away from the antennas. Thus, they stopped in a still position until the end of the measurement. The tracking area is characterized by a bistatic angle β, which linearly varies from 22.6° to 77.4°.

3. SPECTROGRAM IN L-BAND OF A COUPLE OF PERSONS MOVING INTO THE FOREST

A STFT has been used to analyze the Doppler frequency signature of the moving targets

$$S(t,f) = \left| \int_{-\infty}^{\infty} s(u)h^*(u-t)e^{-i2\pi f u}du \right|^2 \quad (1)$$

$s(u)$ is the signal in the $in-phase(I)$ and $quadrature-phase(Q)$ components sampled at f_r = 10 kHz. $h(\cdot)$ is the smoothing Hanning window, and $S(t,f)$ the spectrogram distribution [9]. The sliding Hanning window has a length of 0.5 s that provides a frequency resolution Δf = 2 Hz.

The fast walk and the run have been performed in approximately 15 s, and the corresponding Doppler signature is shown in Fig. 2. The spectrum looks strongly distorted, and the moving targets' contributions are detectable exclusively when they are close to the radar, as observed in the time interval 16 s - 20 s. The strongest signal (orange decreasing trend) is related to the main reflecting area of the targets, i.e. the torso, whereas the cyan spikes around 40 Hz represent the forward and backward motions of the limbs. The walking and running persons' Doppler signatures are weaker in magnitude or undetectable in the time interval 6 s - 12 s. An explanation is that most human body parts are shadowed by the trees present in the path. Thus, the obstructing trees affect the back-scattering signal, and consequently, it does not allow the proper interpretation of the Doppler spectrum. Besides, the spectrum highlights Doppler contributions around 1 Hz in the time interval 0 s - 5 s and 22 s - 26 s when the cooperating targets are in standing still. These can be related to undergrowth movements because the measurement was performed in the presence of wind.

The presence of obstacles and low vegetation, the low working frequency, and the involved interferences caused by the subjects' motions do not provide identifiable frequency signatures in the spectrum. Conventional techniques based on Doppler features extraction [10, 11] fail to detect two specific physical activities. For instance, analyzing the Doppler frequencies of the highest intensity signal in the spectrogram shown in Fig. 2, a decrease from 20 Hz to 5 Hz is observed from 16 s to 18 s. These frequencies identify a deceleration from 3.3 m/s to 1 m/s approximately using the bistatic radar equation [12] and the parameters presented in Section 2. The detected deceleration could be associated with the final phase of a run, but two activities performed simultaneously cannot be detected. It is also important to point out that the use of a CW mode does not provide for range information, which is generally used to distinguish between synchronous activities [13].

4. CADENCE FREQUENCY ANALYSIS

In a previous work [3], Otero presented that walking and running are characterized by a constant Doppler shift caused by the torso and a cadence frequency linked to the arms and legs' swinging movement periodicity. Furthermore, Andric *et al.* [5] related the Doppler speed and the cadence frequency to find the stride length, uniquely characterizing human physical activity.

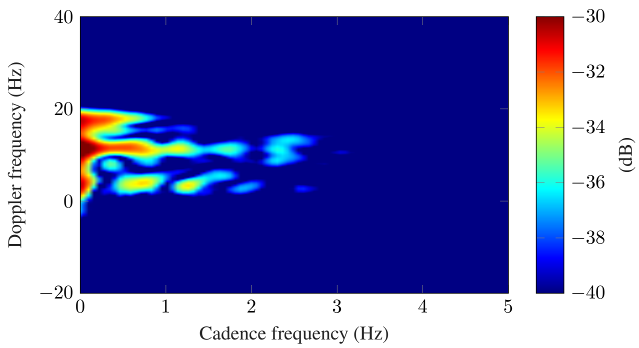


Fig. 3: Cadence frequency diagram of a couple of persons walking and running among the trees at 1 GHz.

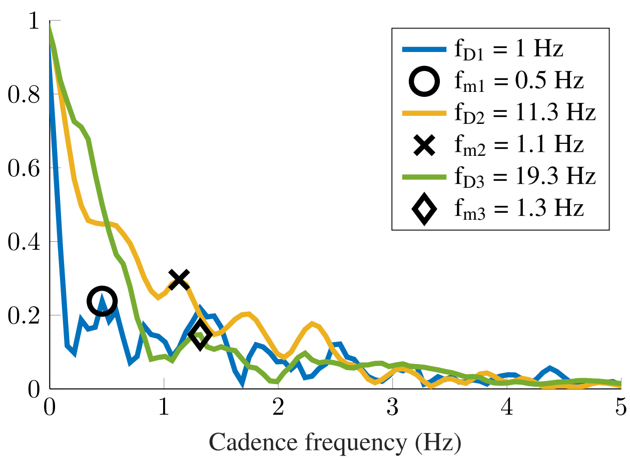


Fig. 4: Cadence frequencies represented by the circle, cross and diamond markers, corresponding to the Doppler bins 1 Hz, 11.3 Hz and 19.3 Hz respectively.

Therefore, we verified the reliability of a cadence frequency analysis of the spectrogram to detect and distinguish the fast walk and the run performed into the forest and measured at low frequency.

A discrete Fourier transform (DFT) has been carried out for each Doppler bin over the entire measurement time [2]. The result is presented in Fig. 3. The Doppler frequencies in the vertical axis are preserved and the horizontal axis is transformed from the time domain to the frequency domain. Three main Doppler frequencies f_D are highlighted in the diagram shown in Fig. 3: f_{D1} = 1 Hz, f_{D2} = 11.3 Hz and f_{D3} = 19.3 Hz. The corresponding cadence frequencies f_m have been extracted, normalized, and depicted in Fig. 4 for each identified f_D. f_{D1} = 1 Hz determines a speed v_{D1} of 0.15 m/s, and a cadence frequency f_{m1} of 0.5 Hz characterizes it. f_{D1} could be caused by the displacement of branches and bouncing leaves from the ground as the two targets pass between the trees. f_{D2} = 11.3 Hz, on the other hand, refers to a speed v_{D2} = 1.7 m/s, with a cadence frequency f_{m2} = 1.12 Hz. The frequency f_{D3} = 19.3 Hz identifies a Doppler speed v_{D3} = 2.9 m/s, and is characterized by a cadence frequency f_{m3} = 1.25 Hz. v_{D2} and v_{D3} are the typical speeds of a walk and a run, analyzed in [10, 14]. Besides, by relating the Doppler velocities to the cadence frequencies [5], the stride lengths of 1.18 m and 2.3 m are calculated and are in quite agreement with walking and running stride values already analyzed in the literature [15].

Therefore, the diagram proves to be suitable for detecting groups of people moving simultaneously, despite the physical activities are measured at low-frequency in CW and performed in a cluttered environment.

5. CONCLUSIONS

In this paper, a reliability assessment in the L-band of the STFT and the cadence frequency diagram to detect multiple targets moving within the forest has been presented. To this purpose, measured data concerning a fast walk and a run have been collected using a bistatic radar working at 1 GHz.

The STFT shows a spectrum strongly fragmented. The backscattered signal is weaker in magnitude or undetectable when the trees partially or totally shadow the subject. Besides, small movements of the undergrowth are detected at the beginning of the path, making the interpretation of the spectrogram a tricky task. The spectrum is spread and distorted, and specific Doppler signatures of the two physical activities are not observed.

Conversely, the frequency periodicity diagram provides the identification of distinct Doppler frequencies. The analysis of the corresponding Doppler speeds and the stride lengths allows distinct detection of the measured movements distinguishing them from each other and those surrounding vegetation. It follows that a cadence frequency analysis is reliable to characterize movements performed simultaneously by a group of subjects, even if they are measured at low frequency in forested areas with a bistatic radar employed in CW.

This investigation may be of interest for the emerging radar applications devoted to human detection and activity classification in a cluttered environment using support vector machine (SVM), or convolutional neural networks (CNN).

6. REFERENCES

[1] V. C. Chen, *The Micro-Doppler Effect in Radar*, Artech House, 2019.

[2] A. K. Seifert, A. M. Zoubir, and M. G. Amin, "Radar-based human gait recognition in cane-assisted walks," in *2017 IEEE Radar Conference (RadarConf)*. IEEE, 2017, pp. 1428–1433.

[3] M. Otero, “Application of a continuous wave radar for human gait recognition,” in *Signal Processing, Sensor Fusion, and Target Recognition XIV*. International Society for Optics and Photonics, 2005, vol. 5809, pp. 538–548.

[4] X. Ma, R. Zhao, X. Liu, H. Kuang, and M. A. A. Al-Qaness, “Classification of Human Motions Using Micro-Doppler Radar in the Environments with Micro-Motion Interference,” *Sensors*, vol. 19, no. 11, pp. 2598, 2019.

[5] M. Andrić, D. Bujaković, B. Bondžulić, S. Simić, and B. Zrnić, “Analysis of radar Doppler signature from human data,” *Radioengineering*, vol. 23, no. 1, pp. 11–19, 2014.

[6] M. E. Davis, “FOPEN radar design for sparse forest surveillance,” in *2016 IEEE Radar Conference (RadarConf)*, 2016, pp. 1–6.

[7] J. Zhang, T. Jin, Y. He, L. Qiu, and Z. Zhou, “Human micro-Doppler signature extraction in the foliage-penetration environment,” in *2016 21st International Conference on Microwave, Radar and Wireless Communications (MIKON)*. IEEE, 2016, pp. 1–5.

[8] G. Manfredi, I. Hinostroza, M. Menelle, S. Saillant, J.P. Ovarlez, and L. Thirion-Lefevre, “Characterization of the walking activity within the forest by using a Doppler analysis in the UHF-BAND,” in *IGARSS 2020-2020 IEEE International Geoscience and Remote Sensing Symposium*. IEEE, 2020.

[9] 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.

[10] 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, May 2009.

[11] G. Manfredi, J.P. Ovarlez, and L. Thirion-Lefevre, “Features extraction of the Doppler frequency signature of a Human walking at 1 GHz,” in *IGARSS 2019-2019 IEEE International Geoscience and Remote Sensing Symposium*. IEEE, 2019, pp. 2260–2263.

[12] N. J. Willis, *Bistatic radar*, vol. 2, SciTech Publishing, 2005.

[13] D. Tahmoush and J. Silvious, “Visualizing and displaying radar micro-Doppler data,” in *Radar Sensor Technology XV*. International Society for Optics and Photonics, 2011, vol. 8021, p. 80210A.

[14] M .Grimmer, K. Schmidt, J. E. Duarte, L. Neuner, G. Koginov, and R. Riener, “Stance and swing detection based on the angular velocity of lower limb segments during walking,” *Frontiers in neurorobotics*, vol. 13, pp. 57, 2019.

[15] B. C. Elliott and B. A. Blanksby, “Optimal stride length considerations for male and female recreational runners.,” *British journal of sports medicine*, vol. 13, no. 1, pp. 15, 1979.