CHARACTERIZATION OF THE WALKING ACTIVITY WITHIN THE FOREST BY USING A DOPPLER ANALYSIS IN THE UHF-BAND

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 of a man walking into the forest is presented in this paper. The results are based on measured data that have been collected by a bistatic radar working in continuous wave (CW) in the UHF-band. VV and HH polarizations have been employed for our study. The spectrograms have been generated at 1 GHz and 435 MHz by using a Short-Time Fourier Transform (STFT). The purpose of the analysis is to highlight the impact both of the chosen frequencies and of the VV and HH polarizations on the Doppler spectrum of a target moving in a cluttered environment. The Doppler signal has been detected at both used frequencies, but it has appeared strongly fragmented by using the VV polarization nevertheless. The HH polarization instead has proved to be more efficient to detect the Doppler return of the subject moving around the obstructing trees.

***Index Terms*—** Doppler radar, forest, feature extraction, remote sensing, Short-Time Fourier Transform (STFT)

1. INTRODUCTION

Nowadays, the detection of human target moving in highly cluttered environment has renewed a significant interest on the surveillance radar and security operations. The Doppler response of subjects moving in forested areas for instance, is an active research topic with many unsolved problems: the impact of the forest, the mutual interactions between the forest components and the human body, as well as the choice of the proper radar system for the target detection.

Kilic *et al.* [1] analyzed at 5 GHz the mutual coupling between the forest and a moving human body on the Doppler frequency signature. An antenna working in CW and vertical polarized has been used for the analysis in a monostatic configuration. The results are based entirely on numerical tests where the forest as well as the human body have been modeled as being perfectly conductive. Davis [2] has highlighted more efficient radars operating in L-band (1.3 GHz) and in UHF-band (400 MHz) to detect target moving under heavily wooded regions. Pengzheng et Huang [3] provided experimental results for the detection of moving human target in a foliage environment. A clutter suppression technique is presented, and a target trajectory detection and a radial velocity estimation are proposed by using the Hough transform. A bistatic radar horizontally polarized working from 675 MHz to 825 MHz has been employed to this purpose. Dogaru *et al.* [4] studied instead at 300 MHz the coupling effects between the moving body parts by simulated tests. However, neither a surrounding cluttered environments has been considered, nor measurements have been carried out.

The aim of the authors is therefore to analyze the variation of the Doppler frequency signature of a human subject moving within the forest, in the UHF-band and through experimental tests. In detail, the measurements have been carried out observing a man walking among trees. The returned signal has been collected by a bistatic radar at 1 GHz and 435 MHz. Both VV and HH polarization have been used. The spectrograms have been analyzed and four Doppler features have been extracted to characterize the monitored physical activity.

The paper is organized as follows. A description of the employed radar system is presented in the Section II. The processing of the received signal is described in Section III. The Doppler spectrograms are explained and commented in Section IV. Finally, the conclusions are presented in Section V.

2. RADAR SETUP

The measurements have been carried out by using log-periodic and Yagi antennas working at 1 GHz and 435 MHz respectively. The antennas have been placed in bistatic configuration at 1.35 m above the ground and oriented at 90° elevation and 0° azimuth. The bistatic radar has been employed both in VV and HH polarization mode. The radar configuration is depicted in Fig. 1a. The baseline distance L = 16 m has been chosen to guarantee a negligible mutual coupling between the antennas. The target has traveled a distance R = 30 m within the forest (Fig. 1b), starting at 10 m and concluding the activity at 40 m away from the antennas. It follows that, L and R outline a tracking area characterized by a bistatic angle β linearly varying from 77.4° to 22.6°. Two signals have been separately recorded for each used frequency and polarization: $s_{clutter}(t)$ denoting the signal collected without the target and $s_{clutter+target}(t)$ representing the signal backscattered by the moving subject. The measured signal has been filtered, amplified and the $in-phase(I)$ and $quadrature-phase(Q)$ components have been extracted. In the end, the signal has been sampled at f_r = 10 kHz.

3. DATA PROCESSING

A clutter suppression has been carried out as following

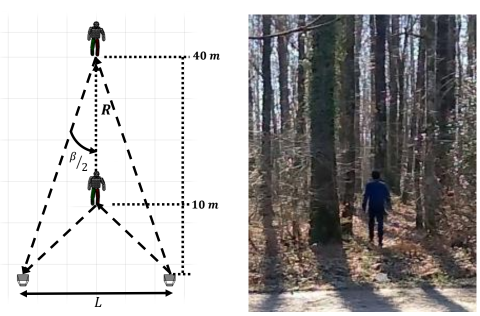
$$s(t) = s_{target+clutter}(t) - s_{clutter}(t) \tag{1}$$

We neglect the possible mutual coupling between the human body and the surrounding environment. Thus, we assume that the resulting signal $s(t)$ corresponds to the signal backscattered by the target alone. Then, a STFT has been used to analyze the Doppler frequency signature of the moving human target

$$S(t,f) = \left| \int_{-\infty}^{\infty} s(t)h(t-\tau)e^{-i2\pi ft}dt \right|^2 \tag{2}$$

$s(t)$ is the signal in I and Q components, $h(\cdot)$ the smoothing Hanning window, and $S(t,f)$ the power spectral density (PSD) of the data. A coherent processing interval (CPI) = 0.5 s has been chosen. It follows a frequency resolution Δf = 2 Hz. In addition, a threshold = -80 dB has been applied in order to reduce the noise clutter.

Four Doppler features have been extracted from the spectrogram: 1) the torso Doppler frequency, 2) the period, 3) the total Doppler bandwidth (BW), and 4) the offset. A detailed description concerning the meaning and the calculation of the features has been presented in a previous work [5]. The Doppler characteristics have been used to classify the frequency signature of the walk.



(a) (b)

Fig. 1: Measurement setup: (a) outdoor scene, (b) parameters of the bistatic configuration.

4. MEASUREMENTS

The Doppler frequency modulations of the walk in a forested area are presented in this section. The comparison between the VV and HH polarizations has been carried out at 1 GHz and 435 MHz respectively, analysing the spectrograms and the corresponding Doppler features.

4.1. Doppler analysis of the walk within the forest at 1 GHz

The first analysis focuses on the variation of the Doppler spectrum of the walking target at 1 GHz. The spectrogram relative to the VV polarization is shown in Fig. 2a and the corresponding Doppler features listed in absolute value in the first column of the Table 1. The subject has walked among the trees for approximately 28 s travelling 30 m. Thus, a speed of 1.07 m/s is supposed. The walk away the antennas has caused the negative Doppler frequencies centered around -8 Hz. The spectrogram highlights an intensity pattern zigzag shaped in the time interval 0.3 s - 8 s. The pattern is related to the swaying torso from which the strongest signal is reflected. The torso Doppler frequency 1) equal to 5.29 Hz implies a speed of 0.7 m/s [6]. The disagreement between the detected and the supposed speed could be attributed to the fragmentation of the Doppler spectrum which occurs in the time interval 10 s - 28 s. An explanation is that, the human body parts are partially or totally shadowed by the surrounding trees. It follows that, the Doppler signature is weaker in magnitude or it is undetectable, as observed in the time interval 21 s - 24 s. The extracted total BW 3) and the offset 4) of 23.95 Hz and 11.98 Hz respectively, are related to the motions of the arms and legs [7]. Their corresponding Doppler frequencies are represented by the cyan spikes shown in Fig. 2a at the lower and upper edges of the main pattern.

The walk has been measured at the same frequency by using the HH polarization. The results are shown in Fig. 2b and in the second column of the Table 1. The cooperating target has walked 30 m in approximately 27 s with an average speed of 1.1 m/s. The spectrogram exhibits a periodic trend saw-tooth shaped, well detected for the total observation time. The calculated torso Doppler 1) equal to 6.29 Hz denotes a speed of 0.95 m/s which is in quite agreement with

Table 1: Measured Doppler features of a subject walking within the forest, analyzed at 1 GHz. Comparison between the VV and HH polarizations

Features	VV	HH
1) Torso Doppler	5.29 Hz	6.29 Hz
2) Period	0.53 s	0.54 s
3) Total BW	23.95 Hz	24.88 Hz
4) Offset	11.98 Hz	12.44 Hz

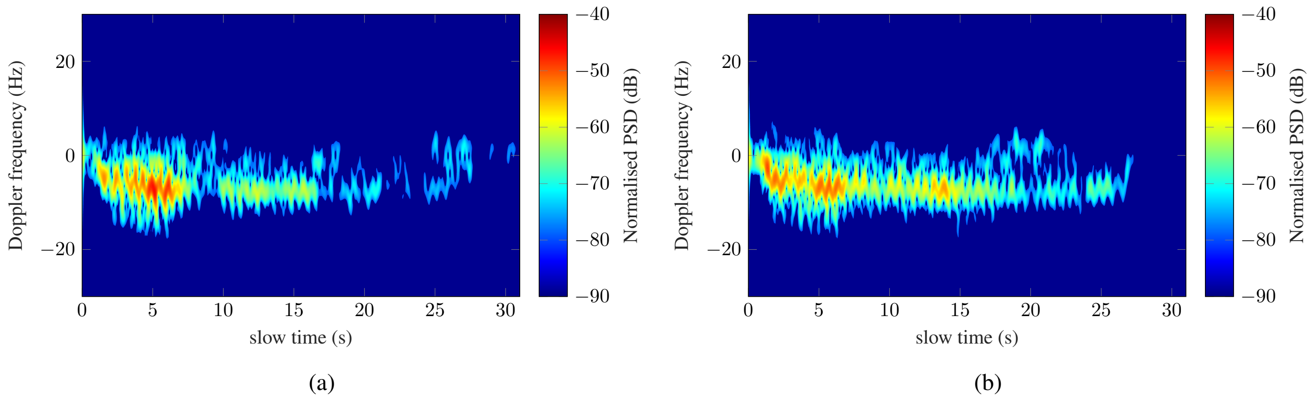


Fig. 2: Doppler frequency signature of a man walking in a forested area analyzed at 1 GHz: (a) VV polarization, (b) HH polarization.

that employed by the target. Indeed, the signal backscattered by the moving subject seems always detectable by using a HH polarization, even in the presence of obstructing trees. It follows that, the Doppler spectrum is not distorted, as conversely observed in Fig. 2a, and the classification of the monitored activity improves. The values of the total BW 3) and the offset 4) are close with those relative to the VV polarization, observing a difference less than 1 Hz. In the end, a period 2) of approximately 0.5 s has been calculated for both polarizations, which is representative of a walking activity as already presented in previous classifications [7–9].

4.2. Doppler analysis of the walk within the forest at 435 MHz

The variation of the Doppler spectrum of the walk has been analyzed then at 435MHz. The spectrogram relative to the VV polarization is shown in Fig. 3a. The subject has covered 30 m in approximately 28 s with a speed of about 1.08 m/s. The frequency signature of the monitored target is centered around -2.5 Hz. The spectrogram is characterized by a total BW 3) and an offset 4) of 16.3 Hz and 8.15 Hz respectively. These features depend on the forward and backward motions of the limbs which are well detected in the time interval 3 s - 8 s, and highlighted by the spikes with an intensity around -68 dB. The torso Doppler 1) equal to 2.45 Hz corresponds to a speed of 0.85 m/s which is lower than the estimated one. The error may be linked again to the fragmentation of the Doppler return due to the obstructing trees, observed in Fig. 3a starting from 16 s. This issue strongly affects the classification of the monitored activity. In addition, the Doppler spectrum changes starting from 12 s respect to the one depicted in Fig. 2a at 1 GHz. It may be linked to the mutual coupling between the body parts that cannot be neglected any more at the chosen frequency. It follows that, the Doppler shifts of the limbs superimpose the zigzag pattern produced by the chest, becoming no longer distinguishable from each other.

Table 2: Measured Doppler features of a subject walking within the forest, analyzed at 435 MHz. Comparison between the VV and HH polarizations

Features	VV	HH
1) Torso Doppler	2.45 Hz	2.61 Hz
2) Period	0.69 s	0.66 s
3) Total BW	16.3 Hz	12.91 Hz
4) Offset	8.15 Hz	6.45 Hz

The new scattering phenomenology occurs at low frequency also by using the HH polarization. The spectrogram is depicted in Fig. 3b and the Doppler features listed in the second column of the Table 2. The subject has completed the walk in approximately 31 s, hence travelling 30 m with an average speed of 0.95 m/s. The Doppler contribution of the moving subject has been detected for the total observation time except at the instant 17 s. The absence of distortions on the Doppler spectrum allowed to calculate the feature 1) equal to 2.61 Hz. It denotes a speed of 0.9 m/s that perfectly matches with the supposed one. The Doppler contributions due to the swings of the legs (at first observed through the spikes weak in magnitude) are superimposed to those of the swaying chest (strongest signal). It follows that the total BW 3) and the offset 4) equal to 12.91 Hz and 6.45 Hz are lower that ones calculated for the VV polarization, listed in the first column of the Table 2. A period of around 0.65 s has been detected at 435 MHz for both VV and HH polarizations.

5. CONCLUSIONS

In this paper the variation of the Doppler spectrum of a human subject walking within the forest has been presented. The measured data have been collected by using a bistatic radar working in the UHF-band and in VV and HH polariza-

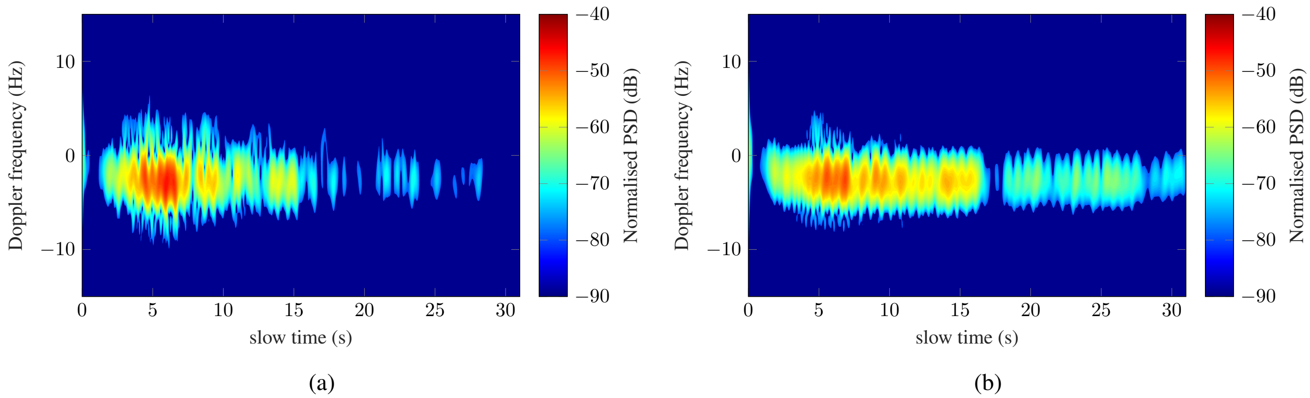


Fig. 3: Doppler frequency signature of a man walking in a forested area analyzed at 435 MHz: (a) VV polarization, (b) HH polarization.

tions. The spectrograms have highlighted that at 1 GHz, the Doppler contributions due to the swinging limbs are still distinguishable from those due to the motion of the chest both in VV and HH polarizations. Conversely, at 435 MHz the frequency shifts are superimposed due to the mutual coupling between the body parts, revealing a homogeneous Doppler signature. The Doppler spectrum results are strongly fragmented and distorted at VV polarization both at 1 GHz and 435 MHz. We suppose that the Doppler return is weaker in magnitude or undetectable when the subject is partially or totally shadowed by the obstructing trees. The Doppler signature is instead detectable during the whole observation time by using HH polarization, which proves hence to be more suitable for the detection of the speed. In the end, no significant differences between the VV and HH polarization arose for the characterization of the total BW, the offset and the period.

6. REFERENCES

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