Feature Extraction Related to Target Classification for a Radar Doppler Echoes

Milenko S. Andrić, Boban P. Bondžulić, and Bojan M. Zrnić

Abstract — **In this paper, we consider received radar echoes data of moving ground targets and represent the corresponding signals in the time-frequency domain using spectrograms. The objective of the paper is to identify and validate the intrinsic spectrogram-based features characterizing the different classes of targets, and subsequently extract salient features for classification. We will show examples on Radar Echoes Database, containing radar echoes from various targets.**

Keywords — **Classification, Doppler signature, feature extraction, radar echoes database, spectrogram.**

I. Introduction

THE main tasks of ground surveillance radars for security and perimeter protection are detection and classification of moving ground targets. Many current radar-based classification systems employ some type of Doppler or Fourier-based processing, followed by spectrogram and gait analysis to classify detected targets.

The Doppler phenomenon describes the shift in the center frequency of an incident waveform due to the target motion with respect to the radar [1].

Several authors in their studies proved that spectrogram-based features could be used for discrimination purposes either between humans and other moving objects or between different persons [2]-[6]. Human spectrograms can be used to reveal information on the human's behavior and to determine features about the human target being observed, such as size, gender, action, and speed, too.

Research done by Geisheimer and others [2] had shown that the human spectrogram is the sum of Doppler shifted signals reflected from the various parts of the moving body. Using Short Time Fourier Transform (STFT) and the chirplet transform, they extracted various parameters of the human gait from the signal. Research done by van Dorp and others [3] had shown that the radar Doppler signatures, observed in the spectrogram, give detailed information about the movements of the human body parts. The authors focused on the extraction of parameters and described a method for estimating human walking parameters from radar measurements. The application of a continuous-wave radar for the detection and classification of people based on their motion has been demonstrated in [4]. Spectral analysis of the output from the radar using a sequence of STFTs was used to extract to identify some key features of the human walking motion, and to differentiate humans from dogs. Using human gait analysis Greneker [5] designed and tested a suicide bomber detection system based on variations in the spectrogram caused by the presence of a bomb. Authors in [6] used the wavelet transform with time-frequency analysis to extract Doppler features from radar signal returns of helicopter and human targets.

A target classification algorithms using Doppler signature were presented in [7]-[10]. In [7] a Hidden Markov Model (HMM) classifier was implemented for classification between three classes of targets: personnel, tracked vehicles and wheeled vehicles. A fuzzy logic approach to the automatic classification was presented in [8]. Bilik et al [9] developed a Greedy Gaussian Mixture Model (GMM) based classification technique, applicable in classification for low resolution ground surveillance radars. The problem of classification between a walking person, pair of walking persons and slowly moving vehicle was studied in [10]. Time varying velocities and bio-mechanical human locomotion models they used for target classification.

At first glance, spectrogram-based features seem like a promising solution for classification problems. However, the applicability and performances of these features sometimes were not tested in the context of practical systems [11]. Therefore, extensive experiments with various scenarios were carried out in order to obtain a radar echoes database (different targets and environments). In order to identify and validate the main features of the various target classes the STFT analysis is performed.

The remainder of the paper is organized as follows. Section 2 describes the radar echoes database which was obtained with ground surveillance radar. Section 3 presents the spectral analysis of radar Doppler signal. Section 4 presents human motion signatures in Doppler signal. Finally, concluding remarks are given in Section 5.

II. Radar Echoes Database

The spectral analysis conducted in this paper is applied to real data collected in controlled test environments at the premises of Military Academy – Republic of Serbia.

The sensor, used in database collection, is 16.8 GHz ground surveillance pulse-Doppler radar. The radar parameters are: average power – 5 mW, pulse width – 15 μsec, average range resolution - 150 m, elevation resolution – 7.5°, and azimuth resolution - 5°.

Milenko S. Andrić is with the Military Academy, Electronic Systems Department, Belgrade, Serbia, (phone: 381-64-11-60-093; e-mail: asmilenko@beotel.net).

Boban P. Bondžulić is with the Military Academy, Electronic Systems Department, Belgrade, Serbia (phone: 381-64-143-82-79; e-mail: bondzulici@yahoo.com).

Bojan M. Zrnić is with the Ministry of Defence, Defence Technologies Department, Belgrade, Serbia (e-mail: bojan.zrnic@vs.rs).

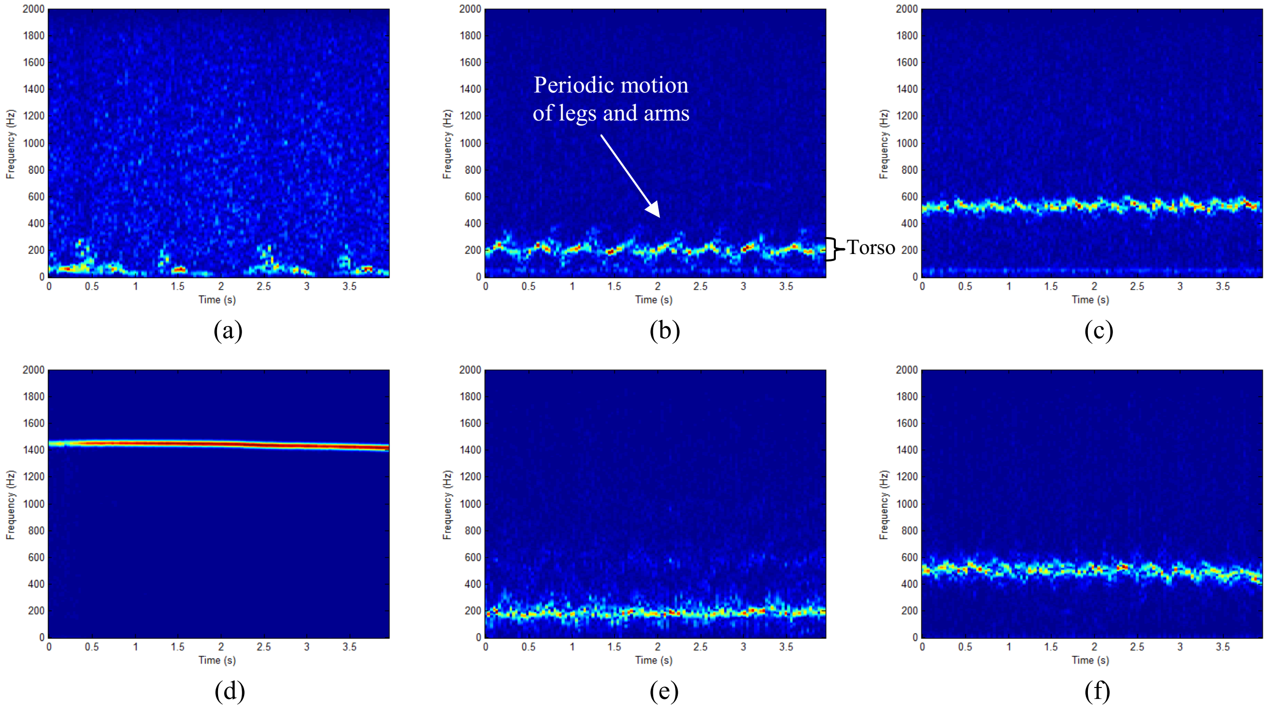


Fig. 1. Spectrograms of radar echo target samples: (a) person crawling, (b) person walking, (c) person running, (d) vehicle, (e) group of persons walking, and (f) group of persons running.

A large database of the raw real Doppler signals was created through more than 80 different scenarios. At least 20 s of each scenario was recorded and sampled at 4 kHz. In total, database of the collected real data for each target class contain 453 records of 4 s duration.

Targets from the following classes were recorded: person and group of persons, vehicle, and vegetation clutter. The targets were recorded in two different environments. The first environment is the road of 4 m width, and 800 m length, and the second environment is the rough terrain, with barriers (slews, woods), and with small vegetation.

Detailed description of database can be found in [12], and database is freely available for download at [13].

III. Spectral Analysis of Audio Doppler Signal

Figures 1(a)-1(c) illustrate the Doppler spectrograms of the target classes: crawling person, walking person, running person, walking group, running group, and light wheeled vehicle. The Doppler frequency is displayed on the vertical axis and time on the horizontal. The amplitude of the reflected signal is color coded with red being the highest intensity and blue the lowest. These spectrograms clearly show a difference between target class characteristics, which can be used for classification.

A crawling person spectrogram, Fig. 1(a), is periodic, but with pauses due to type of motion. When humans walk, the motion of various components of the body including the torso, arms, and legs produce a very characteristic Doppler signature, Fig. 1(b). Doppler spectrogram from a running person is presented in Fig. 1(c). We can see a specific person signature which is characterized with component which oscillates in frequency (characteristic quasi-periodic signal).

The comparative analysis of spectral characteristics of these three target classes shows the difference in central Doppler frequency and the width of spectral line around central Doppler frequency.

The presence of several people simultaneously in the radar field of sight, irrespective of walking/running motion type, involve interferences. Thus, the spectral widths around central Doppler frequency increase (Fig. 1(e), and Fig. 1(f)).

Spectrogram from light-wheeled vehicle (car) is shown on Fig. 1(d). The signature from moving wheeled vehicle has one dominant spectral line at Doppler frequency and narrow band of spectral components around central Doppler frequency because the wheeled vehicle is compact target without moving subreflectors.

As a conclusion, the band of spectral components around central Doppler frequency is the least in the case of wheeled vehicle in comparison with a walking and running person case. In the case consequently when the central Doppler frequencies of a running person and wheeled vehicle with low velocities are similar, may be used to resolve this type of classification conflict the width of spectral band around the central Doppler frequencies.

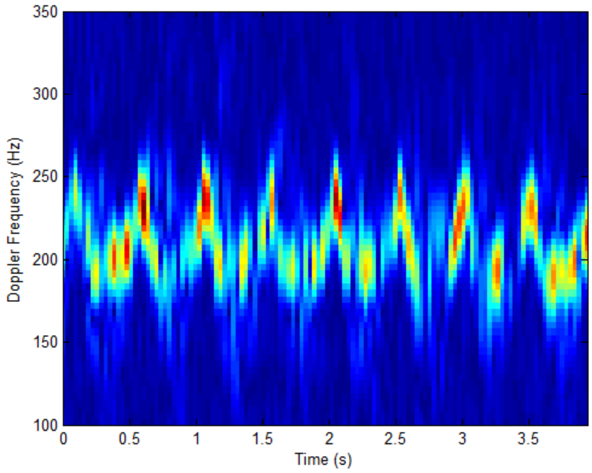
Based on spectral analysis of Doppler signal by spectrogram, central Doppler frequency and width of spectral band around it are possible features for input fuzzy variables.

IV. Human Motion Signatures in Doppler Signal

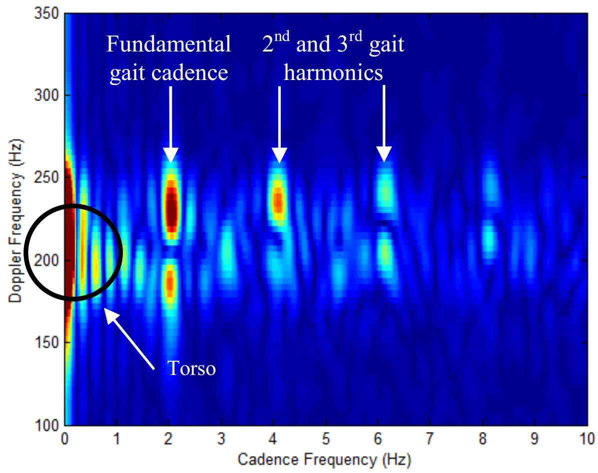
Human locomotion consists of a complex movement of various parts of the body [14]. When a human moves, the different parts of his body (torso, arms, legs) have a particular motion that produces characteristic Doppler signatures (see Fig. 1(b)). The spectral amplitude corresponds to the radar cross section (RCS) of the moving parts. The main contribution comes from the torso. The motion of arms and legs induces modulation on the returned radar signal and generates sidebands about the Doppler frequency, referred to as micro-Doppler signatures. They can provide valuable information about the structure of the moving parts and may be used for classification purposes [15].

Since the motion of the legs and arms of a walking person is periodic, Otero in [4] used the Fourier transform to extract basic information such as the cadence frequency from the spectral image, which is the step or leg swing rate. For each Doppler bin on the spectrogram vertical axis an FFT was applied over the entire time frame. The result is that the vertical scale is preserved and the horizontal time axis is transformed to the frequency domain.

An example of the radar echo spectrogram for a person walking is shown in Fig. 2(a). Notice the significant spread of the Doppler component caused by the varying motion of the appendages. A sample cadence frequency plot is shown below in Fig. 2(b).



(a)



(b)

Fig. 2. (a) Spectrogram of a person walking, and (b) cadence frequency plot of Fig. 2(a).

The cadence frequency plot highlights the periodic signals present in the spectrogram. The two dominant parameters which characterize the human gait (mean velocity and step rate) can be deduced from suitable portions of the cadence plot. The peak at about zero cadence frequency corresponds to the motion of the torso, with the value of the Doppler frequency (f_{Dtorso}). The next peak corresponds to the fundamental frequency, f_m. Subsequent peaks result from the motion of the other appendages, such as the arms and legs [4],[11].

With the Doppler formula,

$$v = \frac{\lambda \cdot f_{Dtorso}}{2}, \qquad (1)$$

where λ is the sensor wavelength, it can be seen that the walking speed v is proportional to the measured frequency.

By then dividing the walking speed by the cadence frequency yields the length of the stride, l_s,

$$l_s = \frac{v}{f_m}, \qquad (2)$$

In the example of Fig. 2(b) the torso component has a Doppler frequency of about 210 Hz indicating the person was moving with a speed, using (1), of about 1.87 m/s. Due to the spectral spread this curve will include errors if the detected velocity is not identical to the mean velocity of the torso. The modulation of the legs has a fundamental cadence frequency, f_m, of about 2 Hz and the stride length, using (2), is 0.94 m. Because of known dependencies between step frequency and velocity for human gait, it is expected to be useful to combine these both features for target classification.

Otero in [4] was considered the amplitudes of the cadence plot peaks to be indicative of RCS. The RCS of the appendages he determined by summing the amplidudes of the peaks of the fundamental and 2nd and 3rd harmonics that are associated with the periodic motion of the arms and legs. This is then divided by the amplitude of the torso peak in the spectrum. This feature is reffered to as the appendage/torso ratio.

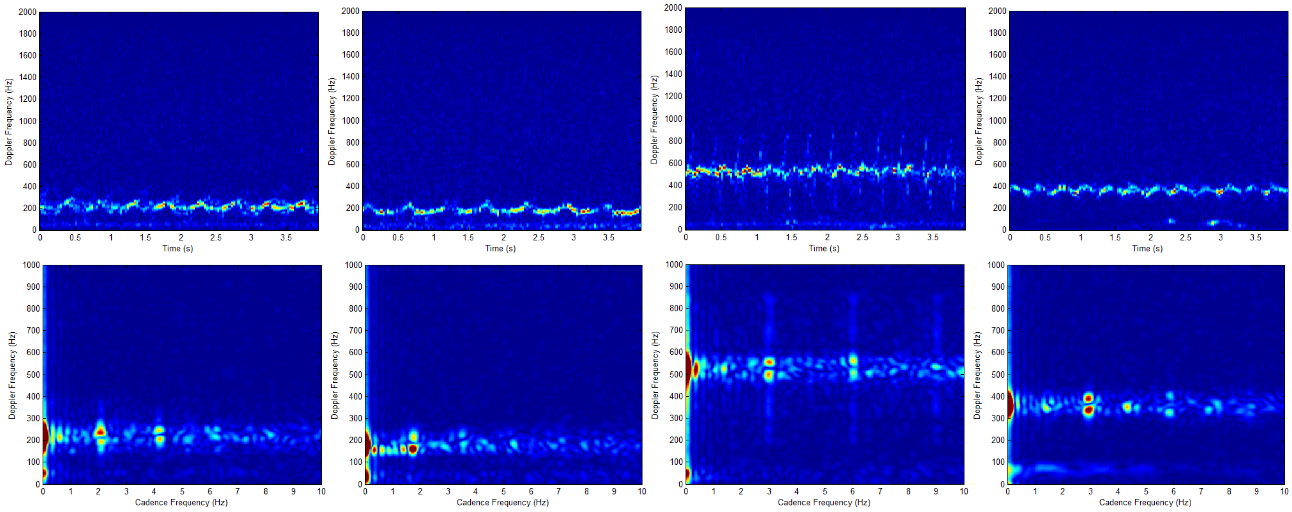
To obtain an valid estimate values of fundamental cadence frequency and appendage/torso ratio noise and clutter have detrimental effect. Clutter is due to unwanted reflections off of objects in the environment that are not targets, such as trees, asphalt roads, buildings, and multi-path target reflections.

An example of the radar echo spectrograms and appropriate cadence frequency plots for a person and group of persons classes are shown in Fig. 3 and Fig. 4.

Fig. 3 shows that ambient (road and bush) has a great importance in appendage/torso ratio estimation. If the leg swings are hidden with vegetation, higher order harmonics are reduced at cadence frequency plots (see Fig. 3(b) and Fig. 3(d)). Moreover, valid fundamental cadence frequency can be estimate for analyzed situations.

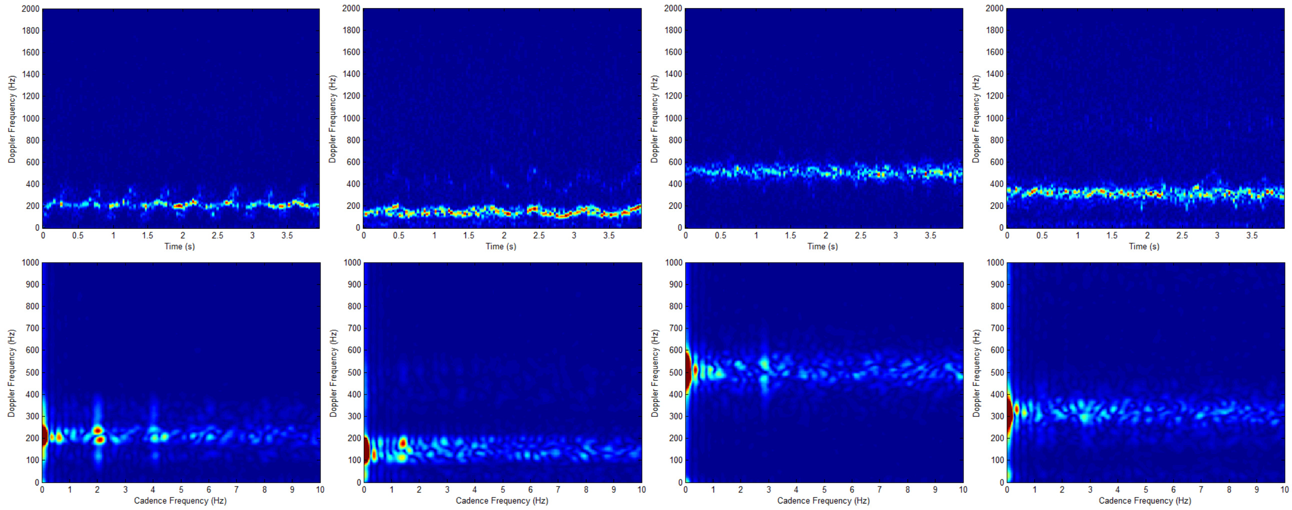
Unfortunately, estimates of these parameters derived from the cadence frequency plot tend to be quite unreliable in the presence of several persons simultaneously in the radar field of sight (see Fig. 4). Fig. 4(a) and Fig. 4(b) shows that in some cases fundamental cadence frequency peak appear since group of people have synchronous motions.

Finally, fundamental cadence frequency provides additional information to differentiate person class from the others. The length of the time window must be chosen to provide enough gait cycles to resolve the cadence frequency for a typical walking/running subject.



(a) (b) (c) (d)

Fig. 3. Spectrograms (upper row) and appropriate cadence frequency plots (bottom row) for a person target class: (a) walking ot the road, (b) walking on the bush, (c) running on the road, and (d) running on the bush.



(a) (b) (c) (d)

Fig. 4. Spectrograms (upper row) and appropriate cadence frequency plots (bottom row) for a group of persons target class: (a) walking ot the road, (b) walking on the bush, (c) running on the road, and (d) running on the bush.

V. Conclusion

The application of a pulse-Doppler radar for the classification of moving ground targets has been demonstrated. The spectral analysis conducted in this paper is used to extract very basic information that could be used for classification; thus, the observations remained as suggestions requiring further research.

Further work would be needed to create a multi-class classifier that can discriminate different target classes.

References

[1] E. Avci, I. Turkoglu, and M. Poyraz, "A new approach based on wavelet nero genetic network for automatic target recognition with X-band Doppler radar," *Journal of Electrical & Electronics Engineering*, vol. 6, no. 2, 2006.

[2] J.L. Geisheimer, W.S. Marshall, and E. Greneker, A Continuous-Wave Radar for Gait Analysis, in *Proc. 35th Asilomar Conference on Signals, Systems, and Computers*, vol. 1, pp. 834-838, 2001.

[3] P. van Dorp, and F.C.A. Groen, "Human Walking Estimation with Radar," *IEE Proc.-Radar Sonar Navig.*, vol. 150, no. 5, 2003.

[4] M. Otero, "Application of a continuous wave radar for human gait recognition," in *Proc. of SPIE*, vol. 5809, pp.538-548, 2005.

[5] G. Greneker, "Very low cost stand-off suicide bomber detection system using human gait analysis to screen potential bomb carrying individuals," in *Proc. of SPIE*, vol. 5788, pp. 46-56, 2005.

[6] T. Thayaparan, S. Abrol, E. Riseborough, Lj. Stankovic, D. Lamothe, and G. Duff, "Analysis of radar micro-Doppler signatures from experimental helicopter and human data," *IET Radar Sonar Navig.*, vol. 1, no. 4, pp. 289-299, 2007.

[7] M. Jahangir, K.M. Ponting, and J.W. O'Loghlen, "Robust Doppler classification technique based on Hidden Markov models," *IEE Proc.-Radar Sonar Navig.*, vol. 150, no. 1, pp. 33-36, Feb. 2003.

[8] M. Andrić, Ž. Đurović, and B. Zrnić, "Ground Surveillance Radar Target Classification Based on Fuzzy Logic Approach," presented at the 2005 EUROCON Conference, Belgrade, Serbia.

[9] I. Bilik, J. Tabrikian, and A. Cohen, "GMM-based target classification for ground surveillance Doppler radar," *IEEE Trans. Aerospace and Electronic Systems*, vol. 42, pp. 267-278, 2006.

[10] I. Bilik, and J. Tabrikian, "Radar target classification using Doppler signatures of human locomotion models," *IEEE Trans. Aerospace and Electronic Systems*, vol. 43, no. 4, pp. 1510-1522, 2007.

[11] S.Z. Gurbuz, W.L. Melvin, and D.B. Williams, "Detection and Identification of Human Targets in Radar Data," in *Proc. of SPIE Defence and Security Symposium*, Orlando, Fl, USA, April 2007.

[12] M. Andric, B. Bondzulic, and B. Zrnic, "The Database of Radar Echoes from Various Targets with Spectral Analysis," presented at the 10th Symposium NEUREL, Belgrade, Serbia, September 23-25, 2010.

[13] The Database of Radar Echoes from Various Targets [Online]. http://cid-3aaf3e18829259c0.skydrive.live.com/home.aspx, 2010.

[14] C. Hornsteiner, and J. Detlefsen, "Characterisation of human gait using a continuous-wave radar at 24 GHz," *Advances in Radio Science*, vol. 6, pp. 67-70, 2008.

[15] L. Vignaud, A. Ghaleb, J. Le Kernec, and J.-M. Nicolas, "Radar high resolution range & micro-doppler analysis of human motions," presented at the International Radar Conference – RADAR, 2009.