LETTER
Identification of Pedestrian and Bicyclist through Range Micro Doppler Signatures

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SUMMARY Identification of urban road targets using radar systems is usually heavily dependent on the aspect angle between the target velocity and line of sight of the radar. To improve the performance of the classification result when the target is in a cross range position relative to the radar, a method based on range micro Doppler signature is proposed in this paper. Joint time-frequency analysis is applied in every range cell to extract the time Doppler signature. The spectrograms from all of the target range cells are combined to form the range micro Doppler signature to allow further identification. Experiments were conducted to investigate the performance of the proposed method, and the results proved the effectiveness of the method presented.

key words: urban road target, identification, range micro Doppler signature

1. Introduction

According to the global status report on road safety from the World Health Organization (WHO), 26% of road fatalities occur amongst pedestrians and bicyclists all over the world and the percentage of bicyclist fatalities has increased in last a few years [1]. This makes the identification of vulnerable urban road targets (pedestrian and bicyclist) of high significance. Compared to other sensing techniques (such as camera and Lidar), radar is a reliable approach which can maintain its performance under adverse weather conditions (like smoke, fog and sand/dust storm). For a radar based identification system, micro Doppler signature is the typical approach used to distinguish non-rigid targets (such as pedestrians because it contains a comprehensive information of all the moving body segments [2], [3]. However, this signature is compromised by the aspect angles between target velocity and line of sight of the radar, especially when this angle approaches 90° or 270° (when target’s velocity is normal to the line of sight of radar) [4], [5]. Under this situation, it is very hard to achieve a high identification performance by only using information from the time-frequency domain. Hence, some further processing is required and more information is also needed to be added to the traditional micro Doppler signature [6], [7].

Actually, when a bicyclist’s moving direction is normal to the line of sight of radar, the only radial velocity of cyclist to radar is the left/right movement of the torso due to the bicyclist’s motion being fully constrained to the bicycle during cycling [8]. But for a pedestrian, besides the left/right movement of torso, both arms also produce different radial movement which can be potentially adopted to distinguish him/her from a bicyclist. When a micro Doppler signature is recorded with a single frequency continuous wave radar, a spectrogram based technique is often dominated by the component with the largest radar cross section (RCS) magnitude (such as from a torso) and make the Doppler component from other small RCS body parts hard to detect. This may reduce the information that is useful for further identification.

In this paper, a method based on range micro Doppler is proposed and applied with a Stepped Frequency Radar (SFR) system. In the proposed method, joint-time-frequency analysis is applied in each range bin where the target is present to extract more detail information from the small RCS segments. Then the spectrograms obtained from multiple range cells are combined to form the range micro Doppler signature of a target to allow further identification. Principal Component Analysis (PCA) is chosen as the feature extractor and Support Vector Machine (SVM) is adopted as the classifier to test the proposed method. The classification by using a traditional micro Doppler signature is presented for comparison.

2. Range Micro Doppler Signatures

An identification method through range micro Doppler is proposed in this paper and its block diagram is shown in Fig. 1.

As shown in Fig. 1, Inverse Fast Fourier Transform (IFFT) is applied for the raw radar data to get the time range data matrix. Then, joint time frequency analysis is adopted in every range cell where the target is present to extract the time frequency information. Short Time Fourier Transform (STFT) is adopted in this paper to obtain the micro Doppler signature. STFT can be described with Eq. (1).

$$\mu D(\tau, f) = \int_{-\infty}^{+\infty} s(t)w(t - \tau) \exp(-j2\pi ft)dt$$  (1)

where $s(t)$ is the received signal, and $w(t)$ is the window in time domain. In the experiment, all the data was processed by using a 0.1 s Hamming window with 75% overlap to extract the micro Doppler signature.
Range micro Doppler signature can be created by concatenating micro Doppler signatures from target range cells.

\[ R_{\mu D} = [\mu_{D_1}(\tau, f), \mu_{D_2}(\tau, f), \cdots, \mu_{D_N}(\tau, f)] \]  

(2)

where \( \mu_{D_i}(\tau, f) \) represents the spectrogram from \( i \)th range cell and \( i = 1, 2, \cdots, N \) represent all of the range cells where the target can be detected.

To test the identification performance of the proposed method, features are extracted from range micro Doppler signatures through PCA. PCA is a typical unsupervised statistical procedure which can be used as a feature extractor. This method can reduce the data dimensions whilst keeping most of the important information. Then, the extracted features were classified with SVM (Radial Basis Function kernel was adopted). Eight-fold cross validation method is employed to reduce the errors among different data sets.

3. Experimental Setup and Data Collection

A stepped frequency radar system operating at 24 GHz which was driven by a Rohde&Schwarz VNA (Vector Network Analyzer) and separate transmitting/receiving antennas was used in the experiment. The parameters of the radar system are shown in Table 1.

The sweep repetition frequency of the system was 400 Hz which means the maximum speed that could be measured in experiment was 1.25 m/s. This was enough for the left/right movement of pedestrian and bicyclist. Given the width of a typical human shoulder being was between 0.4 and 0.5 m, the bandwidth of the system was chosen to be 500 MHz (corresponding to 0.3 m range resolution) which means that the pedestrian and bicyclist occupy 2 range cells. The experiment scenario is shown in Fig. 2.

To collect stable a micro Doppler signature, experiments were conducted when a human target was walking or cycling on the spot. Given there is no change in range domain, the motions produced by target human moving on the spot, in the cross position to radar, can be assumed to have the same micro Doppler signature as when such targets are ‘actual’ moving. The distance between the human target and radar was 15 meters. A bike stponder was used in the experiment to lift the bicycle’s back wheel to make it possible for a human to cycle on the spot. Experiment subjects included three different human beings with different heights, body shapes and genders. During the data collection, 3 target human were walking or cycling one by one on the spot with different velocities towards two cross directions. Each individual sample was recorded for 20 s, and the moving repetition times per person per direction was 20.

4. Classification Result and Discussion

An example of micro Doppler signatures of a pedestrian and bicyclist in the cross position are shown in Fig. 3.

As Fig. 3 shows, the power of bicyclist’s spectrogram is potential to be higher than the pedestrian, but this is not a reliable feature which can be influenced by target human’s body shape as well as bicycle’s size and material. Hence, all the signatures used in the classification were normalized to their maximum power. As comparison, an example about the micro Doppler signatures in different range cells of two targets are shown in Fig. 4. In this example, both targets were present within two range cells during experiments.

As it is shown in Fig. 4 (a) and (b), the micro Doppler signatures of pedestrian from two range cells are different. With the application of STFT in different range bin, more information corresponding to small RCS segments can be extracted (as labelled in Fig. 4 (b)). The signatures of bicyclist within two range cells, Fig. 4 (c) and (d), are similar to each other. As we mentioned previously, during cycling, the
entire bicyclist is constrained by the bicycle and there is only one left/right movement. This will make the micro Doppler signatures from the target range cells similar to each other. So the concatenation of micro Doppler signatures from different range cells has the potential to contain more information about the targets and could be used to improve the classification performance.

In the experiment, all the range micro Doppler signatures were combined from the micro Doppler signatures within range bin 50 and 51 (as shown in Fig. 4). The principal component cumulative energy was set to be 0.9 for feature extraction. The SVM classifier was trained with default initial parameters and the parameters optimization were conducted through grid search.

The classification results with the proposed method with 1 s length are shown in Table 2, as comparison, the results through micro Doppler signatures are also shown. Table 2 includes the mean accuracies, corresponding standard deviations (STD), maximum and minimum accuracies.

A good improvement (more than 10%) of the mean identification accuracies through range micro Doppler signature compared with the micro Doppler signature can be observed in Table 2. However, with the mean accuracy increases, STD also increases. This is potentially due to the instability of the micro Doppler signature in every range cell where targets were present during the experiment.

More experiments were conducted to investigate the classification performance with increasing signal dwell time, the results are shown in Fig. 5. The signal dwell time was increased from 0.5 s to 2 s with an increment of 0.5 s to investigate the influence of signal dwell time on the final accuracy. To keep the PCA feature dimensions similar to each other with different the different.

The results are shown in Fig. 4.

Figure 5 indicates that the classification accuracies through range micro Doppler signature are higher than that through micro Doppler signature. The performance of the proposed method is better than the compared methods with all the tested dwell signal lengths. Figure 5 also indicates that both method achieved a relative stable performance when the dwell time increased to 1 s or 1.5 s, this is understandable based on the fact that a normal gait circle time of pedestrian/bicyclist is around 1 s. Similarly, the proposed method produces higher STD values with all signal dwell lengths and further research will be done to find the optimization parameters such as range resolution to enhance its stability.

5. Conclusion

An identification method by using a range micro Doppler signature is proposed to enhance the recognition accuracy when targets are in the cross position of the radar. The range micro Doppler signature is generated by the combination of spectrograms within all the range cells where a target is present. The experimental results show the potential of the proposed method and more investigation of the range micro Doppler signature will be done in future research.

References

[1] Global status report on road safety, World Health Organization,
http://www.who.int/violence_injury_prevention/road_safety_status/2015/en/

[2] V.C. Chen, F.Y. Li, S.-S. Ho, and H. Wechsler, “Micro-Doppler effect in radar: phenomenon, model, and simulation study,” IEEE Trans. Aerosp. Electron. Syst., vol.42, no.1, pp.2–21, Jan. 2006.

[3] V.C. Chen, The micro-Doppler effect in radar, Artech House, London, UK, 2011.

[4] Y. Kim and H. Ling, “Human activity classification based on micro-Doppler signatures using a support vector machine,” IEEE Trans. Geosci. Remote Sens., vol.47, no.5, pp.1328–1337, May 2009.

[5] F. Fioranelli, M. Ritchie, and H. Griffiths, “Classification of un-armed/armed personnel using the NetRAD multistatic radar for micro-Doppler and singular value decomposition features,” IEEE Geosci. Remote Sens. Lett., vol.12, no.9, pp.1933–1937, June 2015.

[6] Z.A. Cammenga, G.E. Smith, and C.J. Baker, “Combined high range resolution and micro-Doppler analysis of human gait,” 2015 IEEE Radar Conference (RadarCon), Arlington, USA, pp.1038–1043, May 2015.

[7] R. Rytel-Andrianik, P. Samczynski, D. Gromek, M. Wielgo, J. Drozdowicz, and M. Malanowski, “Micro-range, micro-Doppler joint analysis of pedestrian radar echo,” 2015 IEEE Signal Processing Symposium (SPSymo), Debe, Poland, pp.1–4, June 2015.

[8] B. Rodriguez-Hervas, M. Maile, and B.C. Flores, “Study of the microdoppler signature of a bicyclist for different directions of approach,” SPIE Defense+Security, International Society for Optics and Photonics, Maryland, USA, 2015.