Polarimetric MDS of pedestrian

Wenwu Kang, Yunhua Zhang and Xiao Dong

Radar observation and signature identification of human motions have a variety of applications in social security and rescue operations. Both simulation and real radar experiment are conducted to investigate the polarimetric micro-Doppler signatures (MDSs) of a pedestrian. In the simulation, the motion-captured dataset developed by Carnegie Mellon University motion graphic laboratory is first used, then both Feldberechnung bei Korperm mit beliebiger Oberflaeche (FEKO) and MATLAB are used to calculate the radar scattering of pedestrian’s arms, based on which, horizontal-horizontal (HH) and horizontal-vertical (HV) polarimetric MDSs are analysed. Simulation results clearly show that in the time–frequency diagram, HH micro-Doppler (m-D) of arms is rising, whereas HV m-D is falling, which is verified by practical Ka-band radar experiment on a pedestrian. The work shows that by using polarimetric radar the m-D signature of human motion can be much well detected and identified which can be further explored for classification of different people.

Introduction: The detection and identification of human activities by radar have attracted wide attention from both academic and industry communities in recent years, which can have a lot of applications, especially in the fields of social security and rescue operations. Human motions can cause Doppler frequency modulation, and thus Doppler frequency shifts are generated which are known as micro-Doppler (m-D) frequency [1]. Micro-Doppler signatures (MDSs) can be explored through time-frequency (TF) analysis, e.g. short-time Fourier transform (STFT). At present, most researches on human MDS were conducted using single polarised radar (horizontal-horizontal (HH) or VV), which just provide limited polarimetric information on MDS. A polarimetric radar system transmits and receives signals via a horizontally or vertically linearly polarised wave. The different polarimetric information reflects different MDS of human motions, thus dual polarised or fully polarised radars should be capable of acquiring more accurate MDS of human motions.

In recent years, a few of studies on polarimetric MDS have been reported [2–6]. Human gaits at different aspect angles were analysed without considering the arms via simulation based on the four-path model in [2]. Polarimetric multi-static m-D classification of a human with a metallic pole and without a metallic pole was performed in [3]. The measurements results of wind turbines taken by two radar systems of S-band and X-band were presented in [4]. Classification of birds and unmanned aerial vehicles (UAVs) was studied based on radar polarimetry in [5]. Experimental polarimetric MDS analysis of small drones was reported in [6]. In this experiment, an interesting phenomenon was observed: the co-polarised antenna receives better signals when the aspect angle is 0°, whereas the cross-polarised antenna receives better signals when the aspect angle is 90°.

In this Letter, we focus on polarimetric MDS acquisition and analysis about pedestrian aiming at obtaining much more information on human motions than single polarisation. First of all, we establish a simulation model regarding a pedestrian and perform electromagnetic scattering simulation using commercial software such as Feldberechnung bei Korperm mit beliebiger Oberflaeche (FEKO) and then investigate the MDS through TF analysis, and finally, real radar experiment is conducted to verify the simulation. First, the simulation models are set up via using FEKO. Secondly, the space coordinates of a pedestrian at different times are obtained by motion capture equipment from the Carnegie Mellon University (CMU) motion graphic laboratory [7], and backscattering of a pedestrian at different positions was calculated using multilevel fast multipole method algorithm based on integrated into FEKO software. Thus, the polarimetric radar signatures of a pedestrian can be simulated. Finally, TF analysis on HH and horizontal-vertical (HV) data is conducted via STFT. Both simulation and real radar experiment show an interesting phenomenon, i.e. relatively strong backscattering of HH and HV appear at different times. In the TF diagram, the m-D of arms is rising for HH, whereas the m-D of arms is falling for HV.

Electromagnetic scattering models: To calculate the backscattering from a pedestrian during moving, the position coordinates need to be calculated first. The motion capture data from CMU motion graphic laboratory are used [7]. Fig. 1 shows the coordinate of a pedestrian at an instantaneous time. If the distance between a pedestrian and radar is short, it can be assumed that radar beam only illuminates a part of the pedestrian. Furthermore, in practise the radar situates at a certain height, so only the torso and arms of a pedestrian are considered in our simulation. The electromagnetic scattering model of a pedestrian is set up by using FEKO software. Fig. 2a shows the pedestrian’s lower arm model (the upper arm is neglected because it moves with a very small amplitude compared with the lower arm), which is simply represented by an ellipsoid which is formed by revolution of an ellipse about the long axis, and the long and short axes are, respectively, 0.05 and 0.15 m. Considering the posture change of torso, head, neck, and shoulder are small, these parts are treated as a whole. Fig. 2b shows the pedestrian’s main body model, where the shoulder and neck are represented by two cylinders. The radius and height of the cylinder representing shoulder are 0.05 and 0.4 m, respectively. The radius and height of the cylinder representing neck are 0.05 and 0.10 m, respectively. The torso is also modelled by an ellipsoid, the radiiuses are 0.15 m in the X direction, 0.10 m in the Y direction, and 0.25 m in the Z direction. Finally, the head is modelled by a sphere with a radius of 0.1 m.

Simulations: The radar is assumed to be placed 1.2 m above the ground. Limited by the available computer resource, only the scattering of the main body model is simulated and at a single frequency of 2 GHz. The transmitting antenna is a single polarisation antenna in horizontal polarisation, whereas the receiving antenna is a dual-polarisation antenna of horizontal and vertical polarisations, so we can obtain HH and HV results. The concrete simulation procedure is depicted as follows:

Step 1: Through the post-processing of the motion-captured dataset, 343 pedestrian positions in 2.86 s time span (120 Hz) are obtained.

Step 2: The models of pedestrian arms are set up via using FEKO.

Step 3: The positions and postures of arms are extracted, and the radar cross sections (RCSs) values are computed via a combination of FEKO and MATLAB.

Step 4: The radar echoes of the pedestrian are simulated, and TF representations of HH and HV are obtained via STFT.

The RCSs of HH and HV of the pedestrian main body are −9.59 and −38.36 dBsm, respectively. Fig. 3a shows the RCSs of HH and HV of the right arm, from which we can see that the relatively large values of

Fig. 1 Model of pedestrian from CMU motion graphic laboratory
Fig. 2 Pedestrian’s lower arm models and main body
a Lower arm
b Main body

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HH and HV RCSs of right arm appear at different times. Fig. 3b shows the HH and HV RCSs of the left arm, and the same phenomenon is exhibited. Figs. 4a and b show the TF representation of HH and HV scatterings, respectively, from which we can see the HH m-D of arms rises as time increases while the HV m-D of arms falls at the same time. Obviously, the motion of a pedestrian can be identified better via combining MDS of HH and HV polarisations.

Figs. 5a and b show the TF representations of HH and HV polarisations, respectively. As one can clearly see from Fig. 5, the HH m-D of arms rises when the HV m-D of arms falls, which has the same m-D features as that of simulations as shown in Fig. 4. By comparing Fig. 4 with Fig. 5, we can also see that besides the mDs of arms, the mDs of the torso are also very similar between simulation and real radar measurement.

Conclusion: Both simulation and experimental investigations of polarimetric MDS of a pedestrian are conducted. Simulation results and real radar experimental results agree with each other very well, which show that the HH m-D and HV m-D have different variation trends with instant times. It has been shown that cross-polarisation detection of m-D can be an effective supplement to co-polarisation detection. Currently, studies on extracting the MDS of the different pedestrian are underway.

References

7. Available at http://mocap.cs.cmu.edu/, accessed October 2017

Fig. 3 RCSs of pedestrian’s arms

a Right arm
b Left arm

Fig. 4 TF representation of pedestrian by simulation

a HH
b HV

Fig. 5 TF representation of pedestrian by experiment

a HH
b HV

Experiments: The radar echo signals from a pedestrian are collected by real Ka-band dual-polarisation radar at outdoor. The transmitting antenna is a parabolic antenna, which has 39.9 dBi gain and 1.6° beamwidth in both azimuth and elevation angles. The receiving antenna is an orthogonal mode horn antenna. During the experiment, horizontally polarised signals are transmitted and both horizontally and vertically polarised echoes are received. So we can obtain HH and HV polarimetric informations simultaneously. The transmitting and receiving antennas are separated about 0.5 m and positioned about 1.2 m above the ground. The target person walks from a dozen of metres to several metres away from the radar.

Stepped-frequency chirp signal is adopted in the experiment [8]. The total bandwidth is 2 GHz with 20 sub-chirps and each of which has a bandwidth of 110 MHz. The carrier frequencies increase from 33 to 35 GHz at a step of 110 MHz. The interval between adjoining sub-chirps is 60 µs and the burst repetition frequency is 700 Hz. In this configuration, the maximum unambiguous Doppler velocity at 700 Hz pulse repetition frequency (PRF) is about 3.18 m/s for 33 GHz carrier frequency [9], so this velocity range is enough for measuring the arms and torso velocities.

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