Simulation of Human Radar Signatures in the Presence of Ground

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Introduction

Both wideband and Doppler radars have been developed to monitor human activities in non-line-of-sight environments for law enforcement, security and surveillance operations [1, 2]. The non-rigid motions of the different human body parts are manifested either as time-varying range profiles for wideband radars or time-varying microDoppler returns for Doppler radars. However, the propagation environment between the human and radar can significantly distort the human radar signatures. Recently, we developed a simulation methodology and studied the effects of transmission through walls on the high range-resolution [3] and microDoppler signatures [4] of humans. Another problem of interest is the effect of ground on human signatures. It is well known that target-ground interactions can significantly alter the radar signatures of ground vehicles. To the best of our knowledge, the effect of ground on human signatures has not been addressed to date. In this paper, we develop a simulation approach to study the effect of a flat ground on the radar signatures of human motions such as walking and crawling. We use a primitive based prediction technique to simulate the time-varying radar cross-section (RCS) of a computer animated human [5]. We then model the interaction between the human and the ground using the method of images and a ground reflection coefficient. The simulated signatures are presented as functions of ground reflectivity, radar elevation and type of motions.

Methodology

Fig. 1 illustrates the methodology used to compute the radar returns of the humans in the presence of the ground. We assume a vertically polarized, monostatic radar located at a height, h_1, from a flat ground of dielectric constant ε_r. The radar cross section of the human is computed using the primitive based method described in [5], with computer animation data of the human as the input. Typically, computer animation data describe a human as a skeleton with different bones connected through joints. The motion of the human is described by specifying the motion of each joint of the human body. To carry out the RCS simulation, each bone of the human body is modeled as a simple primitive, whose RCS, σ, is a function of its dimensions and incident angle. We use ellipsoids to model all the body parts. Multiple interactions between the different body parts and shadowing are ignored in this construct. Next we incorporate the human interaction with the ground by the method of images. The propagation from the radar to each body part is described by two mechanisms: the direct path and the ground-reflected path from the radar to the phase center of the body part. To simplify the analysis, we assume the phase center of the body part is the same for both the direct path and ground-reflected path. At time instant t, the phase center of a body part is assumed to be at a height, h_2, from the ground. The direct path length and the ground-reflected path length are r and r_1+r_2 respectively and θ is the angle of incidence at the specular reflection point on the ground. Assuming a vertically polarized wave of frequency f, the radar returns from the body part at time instant t is given by

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$$y_b(t,f) = \sqrt{\sigma}\left[\frac{1}{r}e^{-j\frac{2\pi f}{c}r} + \frac{\Gamma_V(\theta)}{r_1 + r_2}e^{-j\frac{2\pi f}{c}(r_1+r_2)}\right]^2 \quad (1)$$

where Γ_V is the Fresnel reflection coefficient for the vertical polarization. Note that in the two-way path, 3 distinct mechanisms are generated: the direct-direct path, the reflected-reflected path, and the direct-reflected path (or the reflected-direct path). The radar returns of the human are computed from the complex sum of the radar returns from all the body parts.

Simulation Results

We consider a 3-second duration human walking motion obtained from the ACCAD Motion Capture Lab of Ohio State University. The radar is assumed to be located at a height of 1m above the ground. First, the radar returns are computed for each time instant over a 2GHz bandwidth (1.4 GHz to 3.4 GHz) using equation (1), assuming that the ground is absent. The wideband data is inverse Fourier transformed along the frequency dimension to obtain the time-varying range profiles of the human walking motion, which is shown in Fig. 2a. The range of the human torso decreases from 6m to 2m as the human approaches the radar. The swinging movements of the arms and legs give rise to fluctuating features in the range profile. The inset in the figure shows the range of the right foot over a 0.5s duration. Next the radar range profile of the same motion is generated while assuming that the ground is perfectly conducting (PEC). The range profile in Fig. 2b clearly shows the additional range features arising from ground reflection. In fact, three components are clearly visible in the range profile of the right foot in the inset of the Fig. 2b, corresponding to the direct-direct path, direct-reflected path and reflected-reflected path.

Next, the microDoppler signature of the human walking motion is generated by applying the reassigned joint time-frequency transform [6] on the time-varying radar returns of the human computed for a carrier frequency of 2.4GHz. The spectrogram in Fig. 2c, is generated while assuming that the ground is absent. The figure shows the time-varying microDoppler features due to the movement of the human torso, arms and legs. The inset of the figure examines more closely the highest Doppler arising from the motion of the right foot over a 0.8s duration. The spectrogram in Fig. 2d, is generated under the assumption that the ground is PEC. The microDopplers of the body parts do not show significant changes from those in Fig. 2c. The effect of the ground on the human microDopplers for low radar elevation of 1m appears minimal.

Next, the radar is raised to an elevation of 19m above the PEC ground. The radar range profile is generated for the right foot and shown in Fig. 3a. Again, three distinct range features are observed in the figure arising from respectively the direct-direct, direct-reflected and reflected-reflected paths. Fig. 3b is the microDoppler signature of the right foot. In comparison with the no-ground case (not shown), the microDoppler track shows noticeable blurring. This is caused by the different incident and observation angles of the three propagation paths between the radar and the foot.

Finally we generate the radar range profile and the microDoppler signature for a human crawling motion on a ground with a dielectric constant of 5. The radar elevation is 1m above the ground. The results are shown in Figs. 4a and 4b. Both figures show very little difference from the no-ground case (not shown here). For the range data, since the human is very close to the ground, the length difference between the direct path and the reflected path falls within the radar range resolution of 7.5cm. Also, the reflection coefficient for the vertical polarization is low due to Brewster's phenomenon. For the

Doppler spectrogram in Fig. 4b, the angles of the direct and reflected paths are very close to each other due to the low elevation of the body parts and the radar.

Conclusion

A technique for simulating the high range-resolution and microDoppler signatures of a human moving on the ground has been presented. The direct path and the ground reflected path from the radar to the human give rise to three distinct two-way propagation paths between the radar and the human. The simulated signatures are studied as functions of ground reflectivity, radar elevation and type of motions.

Acknowledgments

This work is supported by the National Science Foundation under grant CBET-0730924.

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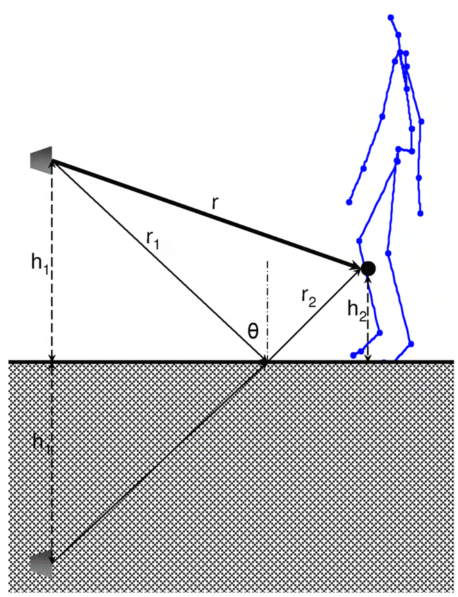

Fig. 1. Simulation methodology.

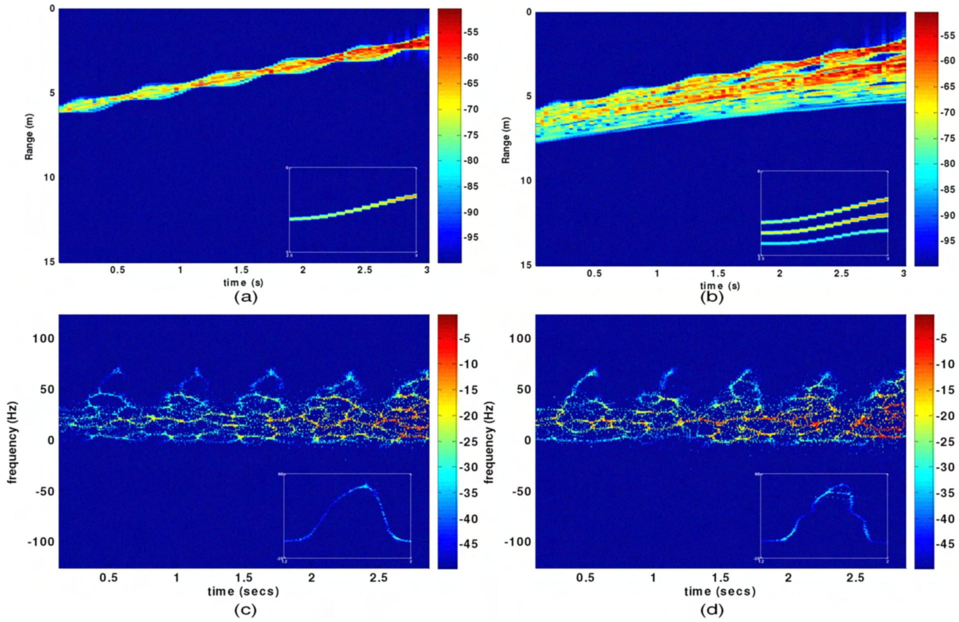

Fig.2. High range-resolution profiles of human walking towards a radar 1m above the ground, (a) without floor and (b) PEC floor. (Inset figures are of the right foot.) Doppler spectrograms of human at 2.4GHz, (c) without floor and (d) PEC floor.

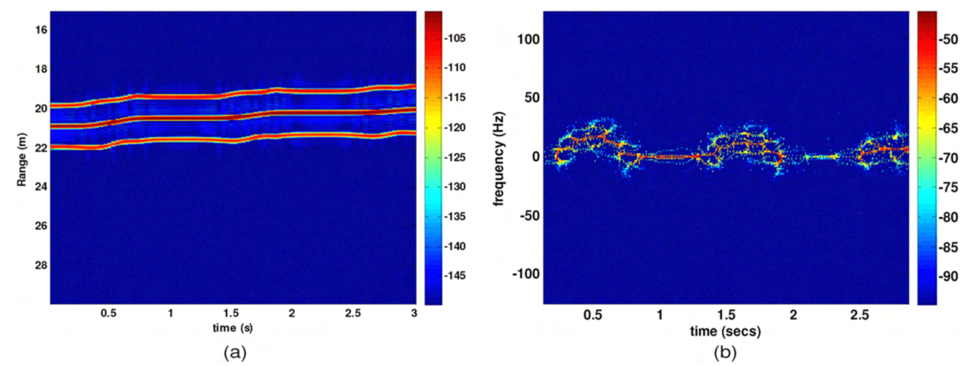

Fig.3. Radar signatures of the right human foot when radar is 19m above a PEC floor. (a) High range-resolution profile. (b) Doppler spectrogram.

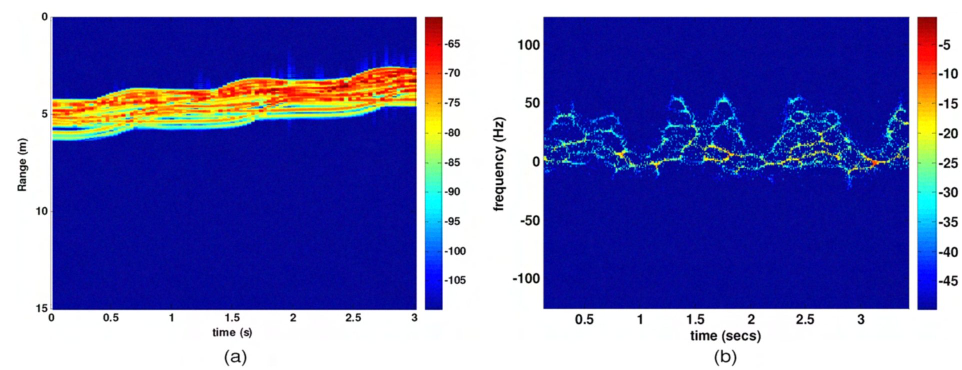

Fig.4. Radar signatures of human crawling towards a radar 1m above a floor with ε_r=5. (a) High range-resolution profile. (b) Doppler spectrogram.