Modeling and Analysis of Millimeter-Wave Doppler Signature of Walking Human

M. Vahidpour and K. Sarabandi
Radiation Laboratory, Department of Electrical Engineering and Computer Science
The University of Michigan, Ann Arbor, MI

Millimeter-wave radars are envisioned for a number of safety and security applications such as collision warning for vehicles, autonomous vehicle control, perimeter securing, and detection of concealed weapons and explosives carried by individuals. Detection of and identification of pedestrian in highly scattering radar scenes such as urban and highway environments is also of great importance. The literature concerning radar signature of human at millimeter-wave region is rather scarce. This is especially true for human in motion such as a human subject in walking, jogging, or running conditions. In this study we present polarimetric radar signature of a human subject at different aspect angles with and without clothes and small metallic objects. The scattered field from a human subject undergoes Doppler modulation of a particular signature if the human subject begins to move. Apart from a constant Doppler shift which is resulted from the average relative motion of human target and the radar platform, there exist a unique Doppler spectrum resulted from the periodic motion of hands, legs, and torso. The bandwidth of the Doppler spectrum and the spread of the scattered energy in this band are functions of motion periods, and maximum velocity of moving parts. Measuring the radar backscatter of a moving human subject over an extended period of time (2 seconds or less) a complete Doppler spectrum can be extracted. It is shown that this spectrum is unique enough to distinguish a human subject from other objects in the radar scene. A signal processing method is also presented to decompose that radar backscatter of a human subject into its components (torso, hands, and legs).

To simulate the radar response of a human in motion, first a detailed human model is developed whose movement animation was replicated from the captured video frames of a real person. The dielectric constant of human skin was obtained from the Debye equation

$$\varepsilon^*(\omega)=\varepsilon_\infty+\frac{\varepsilon_s-\varepsilon_\infty}{1+j\omega\tau}+\frac{\sigma}{j\omega\varepsilon_\infty} \qquad \varepsilon_\infty=4.0, \varepsilon_s=42.0, \tau=6.9\times10^{-12}\,\text{s}, \varepsilon_0=8.85\times10^{-12}\,\text{F/m}, \text{ and } \sigma=1.4\ \text{S/m}.$$

whose parameters are obtained experimentally and has been shown to provide an adequate representation of the complex dielectric constant of human skin at millimeter-wave frequencies [H.F. Cook, *J. Applied Physics,* pp. 295- 230, 1951]. Since the skin depth is less than 1mm, the human body is modeled as a homogeneous dielectric material. Considering the fact that the radii of curvature on human body are much larger than a wavelength at W-band and the skin dielectric is very lossy, the scattered field is computed using Physical Optics (PO). Geometric Optics (GO) approach is first used to determine the shadowed areas for a given orientation of human body with respect to the direction of the incident wave. The scattered filed is computed from the equivalent electric and magnetic surface currents using the free-space dyadic Green's function. The human motion was discretized into sufficiently small increments and for each position the complex scattered filed was computed. This sequence of the scattered filed is used to derive the Doppler spectrum.

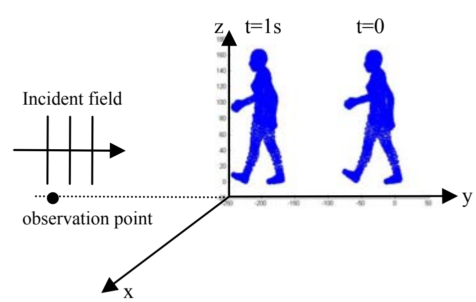

Figure 1: Human walking is modeled by a number of frames and scattering is computed using a GO-PO approach.