Radar MicroDoppler for Security Applications: Modeling Men versus Women

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Introduction

Estimation of human motion parameters is an important issue in security applications. In particular, determining whether a heavily clothed person is a woman or a man in disguise is of particular interest. In security applications one would like to observe humans unobtrusively and without privacy issues, and radar provides one method to accomplish this. In this paper we focus on modeling and measuring the characteristics of human walking parameters in order to determine signature differences that would distinguish men from women.

For observing humans, radar has advantages over other sensors. The transmitted radar signal is insensitive to day and night, while smoke, dust, and fog only slightly reduce the signal. This is why radar can be used in situations where other sensors give low performance or cannot be used at all. Radar signals also penetrate most clothing, preventing disguise from being effective. Using radar to determine gender, and thus to identify individuals trying to disguise their gender, is of great interest for security applications.

Radar can be used to measure the direction, distance, and radial velocity of a walking person as a function of time. Detailed radar processing can reveal more characteristics of the walking human. The parts of the human body do not move with constant radial velocity; the small micro-Doppler signatures are time-varying and therefore analysis techniques can be used to obtain more characteristics [1, 2]. Looking for modulations of the radar return from arms, legs, and even body sway are being assessed by researchers. [3, 4, 5] We analyze these techniques and focus on modeling human body motion to determine the radar techniques that are needed to measure the variations. We perform simulations of the human gait and verify them with radar measurements. We break down the radar spectrogram into its components based upon simulated and measured human signatures. We then model the variation to be expected when measuring men and women.

Method and Data

Simulation of the human gait has been performed by many researchers, often with the goal of improving animated movies [6, 7, 8, 9, 10, 11, 12]. Here we are taking the extensive research on human gait and animation and using it to model the expected Doppler velocities measured over time by a radar system. We started with the measurements made in [15]. Twenty men and twenty women whose ages ranged from 20 to 38 years with an average age of 26 years had their motions captured on video and extracted, then their characteristics analyzed. The resulting motion information was extracted, and then animated. We took the animated gait and extracted the micro-Doppler signature that would be created by differentiating the motions. The simulated micro-Doppler motions for different body parts are shown in Figure 1. These are
calculated from the actual motions of the model and are calculated at 17GHz. The resulting spectrogram is shown in Figure 2.

Figure 1. Simulated Doppler motions for a man walking, broken into component parts. This simulation is noiseless.

Figure 2. Simulated spectrogram for a man walking at 1.5 m/s, compared with a measured spectrogram at 17 GHz.

Figure 3. The foot and knee motions as predicted by the model, and the measured spectrogram for a walking man’s legs, measured with the same system as Figure 2.
The comparison of measured and simulated spectrograms of an entire walking man shows reasonably good qualitative agreement. The radar measurements were taken at an outdoor radar test range with realistic but low levels of clutter at 17 and 34 GHz. However, we needed to verify that the simulation method is accurate in the assignment of Doppler velocities to the component parts of the human body. Measurements were taken of only the legs of the target, shown in Figure 3, and found qualitatively to fit well with the pattern described for the legs. Now that we have confidence that we can simulate a reasonable spectrogram, we next simulate a spectrogram for people with different gait characteristics and compare them in a noiseless environment to determine whether we can potentially distinguish between the two gait types.

![Simulated spectrograms for (a) walking man and (b) walking woman.](image)

Figure 4. Simulated spectrograms for (a) walking man and (b) walking woman. Note the difference in the footfall, the difference in the torso line, and the hands, but also how small the differences will be.

An interesting gait type to distinguish for security applications is the difference between male and female gaits, and in particular men pretending to be women. The simulated spectrograms for men and women are shown in Figure 4. The differences are shown to be small, but not outside of the ability of modern methods to measure. Visually, the simulated spectrograms are similar but different. Because we control the parameters like the stride length, hop, bounce, sway, and velocity in the simulation, the comparison is much cleaner than it is in measured data. This is important because the stride length and velocity will vary from person to person and can be changed, but the underlying musculature and bones that produce the motion are much more difficult to change.

The gait simulations require modeling motion at a high frame-rate in order to capture the entire Doppler signature, which precluded using a full radar cross section (RCS) and ray tracing in these simulations. Thus the spectrograms are indicative of the expected signature at RF frequencies where the size of the body is large compared to the wavelength of the radar. At larger wavelengths, the relative positions of different body parts combine to form corners (especially at the elbows) where a full RCS simulation is necessary in order to make reasonable agreement with measurements.

**Future Work**

The simulation work has been relatively successful in providing a qualitative guide to improving our analysis, and has produced a reasonable model for studying men’s and women’s signatures using radar micro-Doppler, but a full-scale double-blind study to
evaluate the effectiveness has not been finished yet. These studies, as well as improving
the RCS in the simulations are part of the future work for this project. Understanding the
variability of both genders will also be important in the development of a classification
method to be used with radar micro-Doppler.

Conclusions

We created a model of human motion that was built upon extracted gait data, and
calculated the spectrogram that would result from the radar measurements. We verified
the model with several measurements. We modeled the radar Doppler signature of the
component parts of the human body that build up the spectrogram, and verified the
components. We then modeled the spectrograms of men versus women and compared
these with some early measurements. The results show that this approach could be
promising since small though measurable differences are apparent, though a larger study
is necessary in order to adequately explore the issue.

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