DISMOUNT MICRO-DOPPLER FOR ISAR

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Abstract— The moving parts of a target induce additional features in the Doppler frequency spectrum in ISAR imaging. These features are called micro-Doppler, are rich in information, and appear as variations to the central Doppler frequency that are often periodic and non-linear in nature. We extract a new model based on measurements and simulations of the micro-Doppler returned by both stationary and moving dismounts at SAR-relevant angles.

I. Introduction

Radar shadows are generated by objects which reflect almost all of the incident radiation in directions other than back to the radar and have enough height to obscure the view of other objects. A stationary dismount creates a radar shadow in a Synthetic Aperture Radar (SAR) image relative to the background. The projected shadow area of the person on the ground appears as a region with less radar return. However, moving dismounts will create variable shadowing effects moving throughout the SAR image.

In order to improve the SAR image by removing the dismount shadows, or to look for dismounts themselves in SAR data, it is important to characterize the types of micro-Doppler signals as well as the expected RCS of the shadows as a function of angle. This paper looks at measuring and modeling the motion and RCS of moving dismounts at SAR-relevant angles, as well as simulating the variability.

The different 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]. A breakdown of the different parts of the motion is shown in Figure 1. The modulations of the radar return from arms, legs, and even body sway are being studied [2]. We analyze these techniques and focus on measuring and modeling the

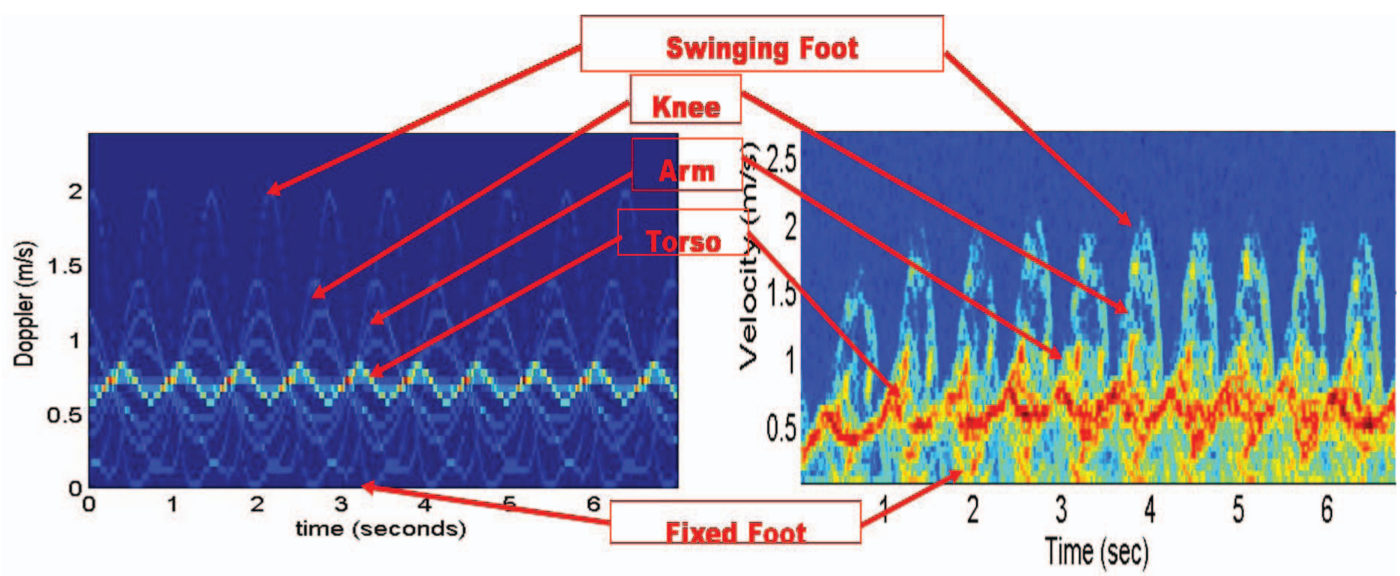


Figure 1. Simulated spectrogram compared to a measured spectrogram of a man walking toward a radar.

motion of a moving human body to help understand and remove their effects from SAR images. The micro-Doppler of rotations [3], wheels [4], and joint time-frequency analysis for SAR signals [5] has already been discussed.

We perform simulations of the human motion 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 in RCS and Doppler to be expected when making SAR images with dismounts.

II. Modeling Method and Results

Simulation of the human gait has been performed by many researchers, often with the goal of improving animated movies. Here we are taking the extensive research on human gait and animation and using it to model the expected Doppler shifts measured over time by a radar system. We took motion-captured gait data [6] and extracted the micro-Doppler velocities that would be created by differentiating the motions using a point-scatterer model for each separate part. The equation for computing the non-relativistic Doppler frequency shift, F_d, of a simple point scatterer moving with speed υ with respect to a stationary transmitter is

$$F_d = F_t \frac{2v}{c} \cos\theta \cos\phi \qquad (1)$$

where F_t is the frequency of the transmitted signal, θ is the angle between the subject motion and the beam of the radar in the ground plane, ϕ is the elevation angle between the subject and the radar beam, and c is the speed of light. For complex objects, such as walking humans, the velocity of each body part varies over time as the person walks. The radar cross-section of various body parts is also a function of aspect angle and frequency. The Doppler of a moving vehicle is similar to a point scatterer, but humans and animals have a larger spread of velocities due to their bipedal or quadrupedal motion. We neglected obscuration for these simulations, and we used a metallic skin approximation to simplify the calculations. The simulated micro-Doppler motions for different body parts are calculated from the motions of the model at 17 GHz. The resulting spectrogram and a comparison with measured radar data is shown in Figure 1. We do not simulate noise in the models because most modern systems are clutter limited and not noise limited. Highly accurate mesh-modeled simulations of the human micro-Doppler signature have also been done [7] but not yet over all angles that are relevant to SAR. We validated the entire motion as is shown in Figure 1, but also measured the parts of the human motion [8]. We also use the variability in motion-capture data to try to estimate the variability in the dismount micro-Doppler signals without making exhaustive measurements.

III. Characterizing Measurements

Multiple measurements were done to try to characterize the RCS and micro-Doppler of human motion over angles that are relevant to SAR. Measurements of humans were taken at the outdoor SAR test range with realistic but low levels of clutter. Measurements were done across a range of azimuth and elevation angles in order to characterize the RCS and micro-Doppler signature response of humans with respect to angle. The measurement of the micro-Doppler is significantly more difficult as the motion approaches an angle that is perpendicular to the path of the radar illumination. This is because the relative Doppler is reduced by the angle of the motion relative to the path of the radar illumination as shown in Equation 1. However, the side-to-side motion of human walking, or body sway, is apparent [9]. This is why the effect of elevation is not as severe as the effect of azimuth because humans do move up and down due to their bipedal motion. The degradation of the micro-Doppler signature with azimuth at higher elevations is not as severe, as can be seen in Figure 2. This is due to the coordinated rise and fall of the body. Measurements at sixty degrees of elevation show measurable Doppler even at ninety degrees of azimuth, and it is clear that the majority of the RCS of the body is in the central torso line as shown in Figure 2.

A simplified model extracted from the measurements and simulations for the mean torso velocity and for the torso micro-Doppler is the principal component of the walking dismount. The primary characteristics are the mean Doppler velocity and the size of the torso variation in the micro-Doppler. The mean torso velocity at higher elevations is found to vary along the lines of a simple scatterer, with a cos(θ)cos(ϕ) dependence. However, the micro-Doppler is relatively consistent, with approximately 0.25 m/s peak to peak motion on average that is very roughly sinusoidal, though interaction with the legs sharpens the point before the peak. The micro-Doppler also is roughly invariant to changes in elevation and azimuth at elevations at or above 45^o. The simplified closed form for the motion is then:

$$Doppler = v\cos(\theta)\cos(\varphi) + \ .25\sin(\omega t + \tau) \qquad (2)$$

where τ is the phase of the micro-Doppler motion, ω is the period or stride rate of the motion, v is the velocity of the motion, and t is the time. At lower elevation angles the variations due to changes in azimuth are much higher since the motion of the arms and legs becomes more visible.

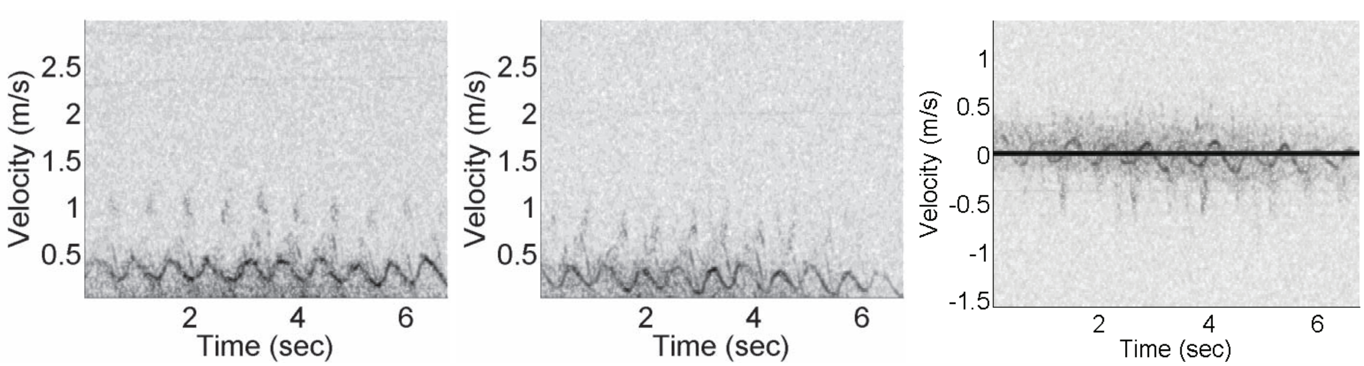
IV. RCS Estimation

There are three different parameters that we used to model the RCS of the dismount with angle. The first two are the angle θ, which is the angle between the subject motion and the beam of the radar in the ground plane, and the angle ϕ, which is the elevation angle between the subject and the radar beam. The third parameter in our RCS model is the number of dismounts in the same range gate. This is useful for estimating when you can see a large group moving together. The system, the data collection, and the data that this model is built upon are detailed in [10].

The most inconsistent part of the model is the comparison of the RCS of a group of men. This falls roughly on the expected 10 Log_{10}(number of dismounts) but can be inconsistent due to shadowing and other effects. Incorporating the number of dismounts term, the remaining data can be combined together. The data on the dismounts at an elevation of 60 degrees then shows very little variation with azimuth, primarily because the arm and leg motion is not as visible. This suggests a transition from multi-scatterer model to a single-scatterer model around an elevation of 45 degrees. The variation in RCS then will roughly linearize as a function of θ for angles of 45 degrees or higher to be:

$$RCS = -1.8\left(\frac{\theta}{15}\right) - 8 + 10Log_{10}N \qquad (3)$$

Note, however, that the RCS measurements are made at 35GHz and may not scale well to low frequencies. There is also some question as to how well the RCS can be measured at an azimuth of 90 degrees, where most of the signal is in



El=60°, Az=0° El=60°, Az=45° El=60°, Az=90°

Figure 2. Spectrogram of the Doppler signature with azimuth angles of 0, 45, and 90 degrees but an elevation of 60 degrees. Note the Doppler can still be seen even though the azimuth angle is 90 degrees

the clutter line and the clutter cancellation is an issue. This simple equation encapsulates the drop in RCS with elevation. The reduction of the dismount RCS at higher elevations implies that the shadows will be more pronounced at higher elevations. However, this is balanced by the smaller size of shadows at higher elevations.

V. Conclusions and Future Work

A simplified model for the RCS, the mean torso velocity, and for the micro-Doppler of moving dismounts has been created out of both simulations and measurements. We focus on modeling and measuring the characteristics of human walking parameters to determine effect of dismounts on SAR signals. We found that the mean torso velocity acts like a single moving scatterer with a $\cos(\theta)\cos(\phi)$ dependence on azimuth and elevation at SAR angles. We also found that the micro-Doppler of the torso line stays consistent at about 0.25 m/s peak to peak. We do note that at lower elevations the model must be made more complex in order to account for the motion of arms and legs. For RCS, we determined that the change is 1.8 dB per 15 degrees of elevation. Low-elevation SAR imaging will have a reduced shadowing due to a larger RCS, but the size of the shadow is reduced at higher elevations.

Simulation of the variability of human micro-Doppler motion has given us new insight into the possible measurements that can distinguish gait patterns. Future work is to compare these measurements to work using correlation techniques.

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