Time-Integrated Range-Doppler Maps for Visualizing and Classifying Radar Data

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Abstract—A time-integrated range-Doppler map shows the micro-Doppler characteristics of targets in radar images that enable an operator to classify different target types and to classify different activities being done by the targets. A time-integrated range-Doppler map is a compilation of range-Doppler maps over time that results in a spectrogram-like characterization of Doppler while maintaining the range information as well. These are compiled from the range-Doppler maps by taking the maximum value for each pixel over a time range. The time resolution is overlapped onto the range resolution, which is in effect a rotation of the traditional spectrogram which compresses range. This type of radar imaging also allows multiple subjects to be viewed simultaneously and avoids tracking issues in spectrogram creation.

I. INTRODUCTION

Typical radar data is shown in a series of image types for an operator, starting with the range-Doppler map, then progressing to images of radar tracks that are usually a series of points, then potentially showing the spectrogram of the tracked target. A spectrogram is the square modulus of the short-time Fourier transform of a time series extracted from a radar track. This process allows the operator to delve into the details of each track in the spectrogram while maintaining a very fast update rate for the positions of targets in the range-Doppler map. For vehicular targets, there is often no need for a spectrogram at all, but for animal or dismount targets the spectral information can help in the classification and analysis of detections and tracks.

Detailed radar processing can reveal many characteristics of human motions and of the human body, including gait characteristics. Micro-Doppler signals refer to Doppler scattering returns produced by the motions of the target other than gross translation. Parts of the human body do not move with constant radial velocity; some of the small micro-Doppler signatures are periodic and therefore analysis techniques can be used to obtain more characteristics. Micro-Doppler gives rise to many detailed radar image features in addition to those associated with the bulk target motions.

Extracted micro-Doppler features are typically viewed in the joint time-frequency domain. Micro-Doppler displays of spectrograms are not standard on traditional radar displays. This paper demonstrates a method for displaying micro-

Doppler data on traditional radar displays as a method for improving the amount of information sent to the operator without significantly changing hardware. Instead of using a separate display for the micro-Doppler information, it is integrated into the space of the traditional range-Doppler map.

II. METHODOLOGY

Much of the analysis in this paper makes use of spectrograms for the display of micro-Doppler phenomenology. Because micro-Doppler varies rapidly with time, we employ short-time Fourier transforms (STFTs) [1] of the IQ radar data. The length of time used in the STFT is called the dwell time or coherent processing window, and this determines the resolution in Doppler frequency that can be measured. This can partially be overcome by super-resolving the frequency. The breakdown of the micro-Doppler signals from different body parts of a person walking is shown in Figure 1. This temporal micro-Doppler information is the data that we would like to include onto traditional radar displays. The potential to clearly distinguish between multiple humans, wheeled vehicles, tracked vehicles, clutter, and animal classes is one advantage, with the potential to use radar micro-Doppler as a biometric adding additional value.

Fig. 1. Simulated Doppler motions for a man walking, with the signatures of each part of the man displayed. This simulation is noiseless. Note that body-part interactions are eliminated from this plot, and the simulated motion is in the radial direction to the radar.

A typical range-Doppler map is sparse, with a blob for a detection and significant empty space. A time-integrated range-Doppler map is a compilation of range-Doppler maps over time that results in a spectrogram-like characterization of

Doppler while maintaining the range information as well. These are compiled from the range-Doppler maps by taking the maximum value for each pixel over a time range, usually on the order of a few seconds. Because range-Doppler maps are often very sparse, the integration of a few seconds worth of time usually does not clutter up the radar display. The additional information can come at a cost since targets are known to exhibit momentarily large returns, which means that a large amount of what could be considered noise can be held on the display. Another way to describe a time-integrated range-Doppler map is to think of a max-hold on the radar display that automatically maintains a consistent amount of time.

The time resolution of a spectrogram is replaced by the range resolution on the range-Doppler map. This can lead to a large amount of smearing for slowly moving targets on radars with poor range resolution. However, we have rotated the traditional spectrogram which compresses range and extends time into the range axis. There is significant information contained within time-integrated range-Doppler maps that can be visually extracted. An example time-integrated range-Doppler map is shown in Figure 2. Multiple targets and their micro-Doppler can be viewed simultaneously. Alternatively, the range-Doppler maps can be interleaved to incorporate more information to the operator.

Fig. 2. Time-integrated range-Doppler map of two men walking, a cyclist, and two cars. The RCS and micro-Doppler characteristics can all be used to visually classify. Using the velocity alone has the potential to confuse slow-moving vehicles with fast cyclists and runners. Note that the flashes from the vehicle are stored by the map, which presents a potential signal-to-noise issue. There is also the potential to overlap tracks.

III. MEASUREMENTS

Multiple measurements were done to try to characterize micro-Doppler in outdoor conditions with realistic but low levels of clutter. Details of the systems can be found in [2, 3]. A time-integrated range-Doppler map of a men walking, a man bicycling, and two vehicles is shown in Figure 2, demonstrating that there are significant micro-Doppler

characteristics to classify different activities. Animals move with a quadrupedal motion, which can be distinguished from the bipedal human motion. Time integrated range-Doppler images of moving horses and humans are shown in Figures 3 and 4.

Fig. 3. Time-integrated range-Doppler maps of a horse walking toward the radar with a rider, a horse trotting, and a human walking. The micro-Doppler is easily visible to the operator and can be classified.

Fig. 4. Time-integrated range-Doppler maps of a human sprinting and a vehicle slowing down. The micro-Doppler is easily visible to the operator and can be classified.

IV. DISCUSSION

The measured motions of a man versus an animal (in this case a horse) can be seen in Figure 3. Note the variation in the motion even over time periods of less than a minute. The motions of a man and a vehicle are also shown in Figure 4, where the minimal micro-Doppler of a vehicle makes it clearly recognizable. Of course, the large velocity is another

feature of vehicles that makes them simpler to classify through their motion.

The classification of various human activities such as boxing and crawling has been done [4]. The classification of human versus animal is verification that the mover is a human and performing a human activity rather than an evaluation of wildlife motion. Aided target recognition can be done using short time-integrated range-Doppler map tiles by correlating the tile with stored database tiles and performing a nearest neighbor search to find the appropriate classification. This is never perfect, though analysis on a small database has shown tolerable performance. One issue is that the time variability of the features is not displayed as accurately as with a spectrogram. A spectrogram of the runner shown in Figure 4 is shown in Figure 5 as a comparison. The range information is lost as the focus is on the temporal variations in the spectrogram.

Fig. 5. Spectrogram of a runner.

CONCLUSIONS

The display and aided classification of micro-Doppler features from radar data in a time-integrated range-Doppler map has been shown to be feasible, and a straight-forward approach to producing them has been demonstrated. The information content in the relatively sparse range-Doppler maps is significantly increased. We found that the radar micro-Doppler data did provide a significant amount of improvement for the operator, enabling effective visual classification of animals walking versus humans walking as well as vehicle activity such as slowing down or turning. We also found that animal activities such as grazing are difficult to detect, suggesting that classification of animal activity would be challenging.

Micro-Doppler has been used for the determination of whether a dismount could be armed, but this type of experiment with live operators is part of the future work. We expect that this would be much more challenging than the determination of whether a target is a walking animal or walking human. Additionally, the automatic detection of potential overlap on the time-integrated range-Doppler maps is an additional improvement that is planned. The suppression of flashes from vehicles is also an issue since they can produce additional noise that obscures other targets in the scene.

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