Tracking Moving Ground Targets from Airborne SAR via Keystoning and Multiple Phase Center Interferometry

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***Abstract*— Without some form of motion compensation, SAR images experience significant range walk and be quite blurred. In 1997, MITRE reported development of the Keystone Process [1], [2]. Keystone Formatting simultaneously compensates for multiple target motion at multiple radial velocities.**

The target motion causes the moving targets to appear at locations different from their true instantaneous locations on the ground. In a corresponding interferometric phase image, all points on the ground nominally appear as a continuum of phase differences while the moving targets appear as discontinuities. By threshold comparisons within the intensity and the phase images, we [4], [5], [6] and others [3] have shown that it is possible to detect and georegister moving targets in the SAR. .

***Index Terms*—Airborne SAR, Geolocation, Interferometry, Keystoning, Surface Moving Targets.**

I. Introduction

Conventional synthetic aperture radar (SAR) requires sufficient integration time to generate pixels that are roughly symmetric in the range and cross-range dimensions. Pixel deviations from perfect symmetry (ellipticity) are normally considered undesirable because human visual perception is optimized for images consisting of round pixels. As pixel ellipticity increases, image interpretability by human operators decreases. However, in conventional SAR, useful moving target effects noticeable over short processing intervals can be significantly suppressed unless extensive target-specific motion compensation techniques are applied. The most noticeable form of moving target degradation is caused by range walk, wherein the signal returns from moving targets successively "walk" through many adjacent range/cross-range pixels during the image data collection time interval, causing substantial target blurring.

Without some form of motion compensation, SAR images experience significant range walk and be quite blurred. In 1997, MITRE reported development of the Keystone Process [1]. Keystone Formatting simultaneously compensates for multiple target motion at multiple radial velocities. Thus no matter what radial velocity the target is moving at, it will remain in a given range cell determined by its position at the center of the coherent processing interval.

Coherent processing of the data without any compensation for target motion results in an integration loss and smearing of the target over multiple range cells. Standard motion compensation will only correct the range walk for one target at a time. The Keystone process compensates for the motion of all the targets simultaneously. (See Figure 1).

Further, the SAR data has to be acceleration-compensated to produce focused images. Since each target may have a different acceleration, the moving targets can be individually and automatically focused after detection using the procedures previously reported in [1].

The target motion causes the moving targets to appear at locations different from their true instantaneous locations on the ground. This is due to the coupling of the cross-range position to the target radial velocity and the fact that the moving target and the ground under it have different radial velocities relative to the platform. The result is the well known 'train off the track' or 'boat off the wake' phenomenon (Figure 2).

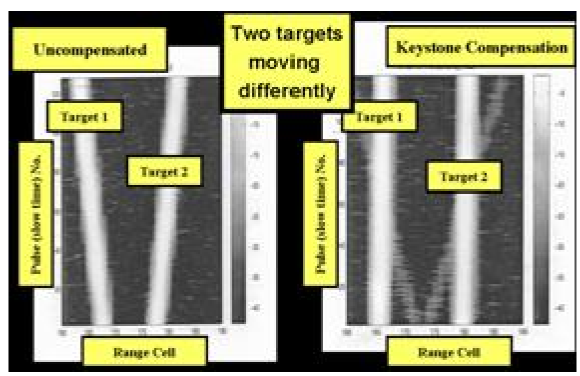

Figure 1. Keystone Formatting Performs Motion Compensation for Targets Moving at Different Velocities

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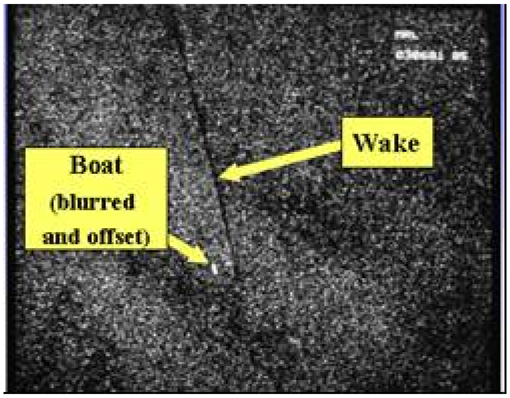


Figure 2. Moving Boat Appears Displaced From its Actual Position in a SAR Image (Source: www.sandia.gov)

II. Moving Target Detection with Phase Interferometry

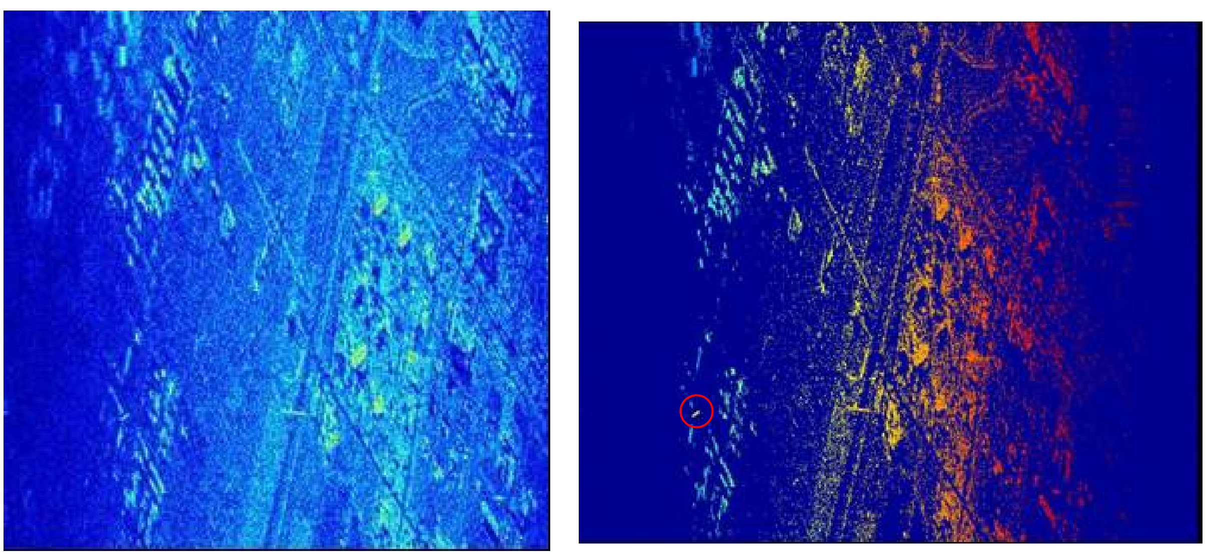
Figure 3 shows the range-Doppler-intensity (RDI) image of the urban area of Ft. Huachuca, Arizona. This image is created from a single channel from an 8-channel SAR data collected by Lincoln Laboratory on its LiMIT data collection campaign.

To make use of the above-mentioned displacement phenomenon to detect moving targets in SAR images, we also form a phase interferometry image as a complement to the SAR image (Figure 4). Parts a and b of figure 3 show the phase-difference images created from the complex images created from channels 1 and 4 and 1 and eight, respectively.

In the interferometric phase image, all points on the ground nominally appear as a continuum of phase differences while the moving targets appear as discontinuities. In this particular case, we did not have truth data from instrumented moving targets. However, by searching for color, i.e., phase, anomalies, one can identify several moving targets near the left bottom of the interferometric images. One such target is circled in red.

By threshold comparisons within the intensity and the phase images, we [4], [5], [6] and others [3] have shown that it is possible to detect and georegister moving targets in the SAR. Figure 4 shows the results of automatic moving target detection on a larger SAR image of Ft. Huachuca.

In particular, using a QuickSAR technique [4] comparing sequential short-duration, elliptically pixelleted SAR images, we have obtained excellent results detecting moving targets against background scenes and correctly georegistering them in composite images.



(a) RDI Image from channel # 1

(b) Phase-Difference Image, Channels 1 & 8

Figure 3. Moving Targets in Image of Ft. Huachuca, Arizona Image

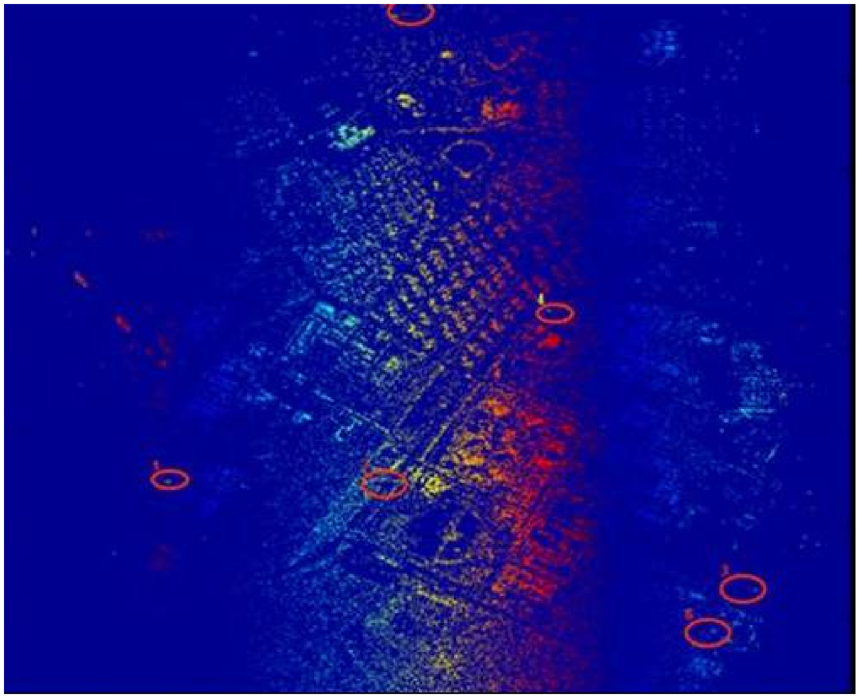


Figure 4. Automatic Phase-Interferometric Detection of Moving Targets in the SAR Image of Ft. Huachuca, Az.

III. Clutter Cancellation for improved detection and geolocation

Although we can easily detect and accurately georegister bright (targets with large radar cross-sections) moving targets using these techniques, we have found that, for smaller targets, the phase differences between the cells containing the moving target are greatly distorted by the presence of strong ground clutter in those cells. Only after the ground clutter is cancelled will the phase difference be sufficiently dominated by the target response to allow correct georegistration.

Two pairs of phase centers are used to form two new phase centers with reduced background clutter. This is accomplished using a linear least squares planar best fit to the differential phase surface for each pair to obtain the complex weights to reduce their clutter. A new reduced clutter interferometer pair is then formed and processed to detect and correctly geo-position the moving targets.

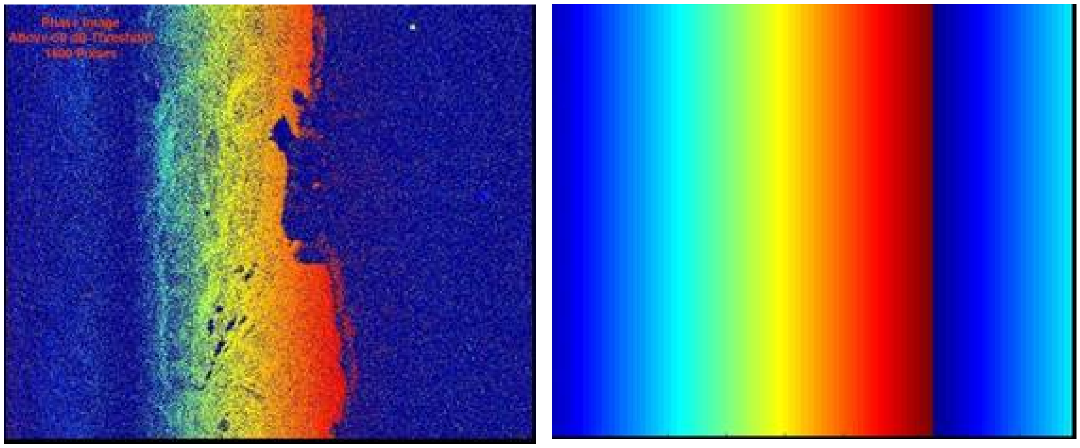
Part a of figure 5 shows the phase difference image of the north-east coastal region of the Catalina Island off the coast of California while part b shows the plane fitted through the phase difference image. This fitted plane is used to weight the channel 5 image to reduce the stationary clutter in the channel 1 image. This clutter reduction is shown in figure 6.

Thresholding this image produces the detections shown in part a of figure 7. By applying a phase threshold to the phase difference image created from two clutter-cancelled images and combining the results with the above, one gets the results shown in part b of figure 7. Clearly, this process reduced false alarms further.

In this case also, we do not have information about what targets were in motion during the data collection. However, it appears that the two targets out on the water are boats or ships in motion.

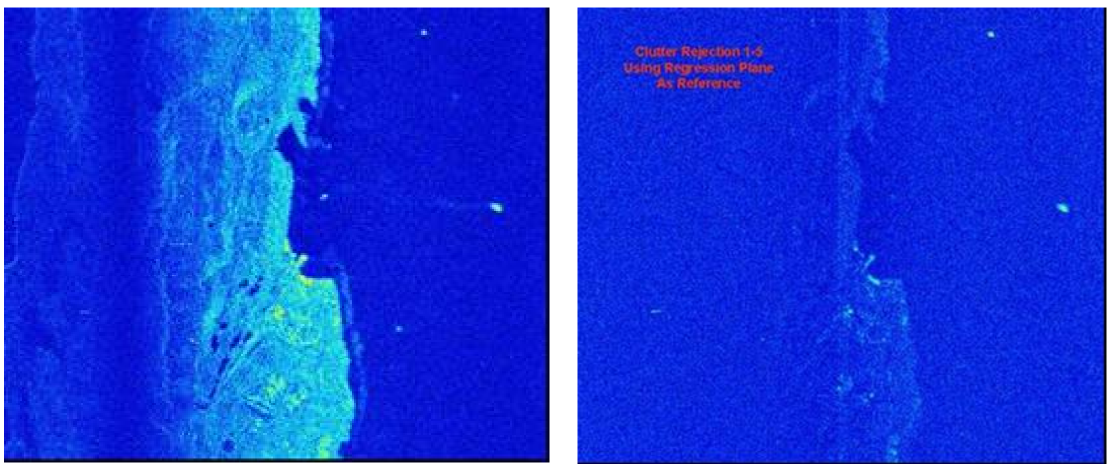
IV. Look-Ahead Constant false alarm rate (LA-FAR) detection

The interferometric moving target detection strategy requires a multi-channel radar, with the channels being ‘in-line’, i.e., the channels have to be arrayed along the platform velocity vector. This is often the case with multi-channel radars. But sometimes, the channels may not be so arrayed (or the radar might have single channel). In such cases, the one cannot avail of the interferometric technique for detecting moving surface targets buried in the SAR clutter. For these cases, we propose a look-ahead constant false alarm rate detection scheme that is applied to the range-Doppler image.



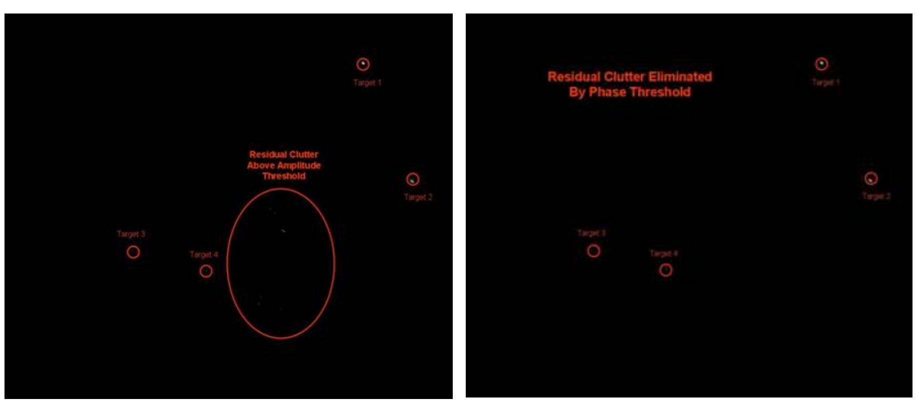
(a) Phase Difference Image, Channels 1 & 5 (b) The fitted phase plane

Figure 5. The Phase Difference Image of the north-east Coast of Catalina Island, showing land-water interface



(a) Channel 1 RDI Image before cancellation (b) Channel 1 RDI Image after cancellation

Figure 6. Clutter cancellation of image from channel 1 using phase plane between channels 1 and 5



(a) With amplitude threshold only (b) Amplitude and phase threshold

Figure 7. Detection of moving targets clutter-cancelled images

This process consists of: (1) generating a predicted position of the target in range-Doppler space (predicted cell set), (2) generating an adaptive threshold based on the current clutter and noise background statistics of the predicted cell set, and (3) testing the cell set on the next revisit for threshold crossings indicative of the presence of a target. It is necessary to test a set of cells rather than individual cells because, after QuickSAR processing, each target occupies multiple range and Doppler cells. Once the presence of a target is detected, the track filter is updated.

We propose the use of kinematic multiple-hypothesis tracking in range-Doppler space, but are considering additional filter constraints such as road-aided tracking parameters. To date, we have not implemented such trackers to work with the real single-channel radar data set available to us.

Instead, for initial trials, we have employed the GPS target truth data to predict the position of the targets in the next SAR image frame and search for the target in a search box around this predicted target position. (If a target is detected, the detected position is not used to predict the next potion; we still use the known GPS data for the prediction).

Figure 8 shows the result of the application of the LA-CFAR detection scheme to one frame of a SAR image of a runway complex. There were nine instrumented targets, which start off near the upper left corner of the triangular runway complex and move around the runway in a counter-clockwise fashion. The targets are of different size, e.g., sedans, SUVs, heavy trucks, etc., and they move at different speeds.

The actual position of the targets, as given by the GPS data, is shown in green numbers. At about the 58th second, they are all well spread out over one leg of the runway. Since these are moving, they appear at locations displaced from their actual locations on the ground. Given the target GPS data and the platform motion data, we computed the apparent locations and show them in red numbers. Targets moving at higher radial speeds appear farther removed in cross range from their actual positions but remain in the same range cell as the actual location.

In this particular frame, the LA-CFAR scheme detected all nine targets and the detected positions were right on top of the apparent positions. The detected positions are denoted by the yellow x's and they practically overwrite the numbers in red, indicating that the detections were almost dead-on.

This data set was about 450 seconds long and thus there are more than 250 frames of 1.6 second integration time. The LA-CFAR was applied to all the frames and the detection rate is very high, albeit it is dependent on a GPS-based prediction. We are currently trying to implement a realistic tracker to replace the highly optimistic predictor.

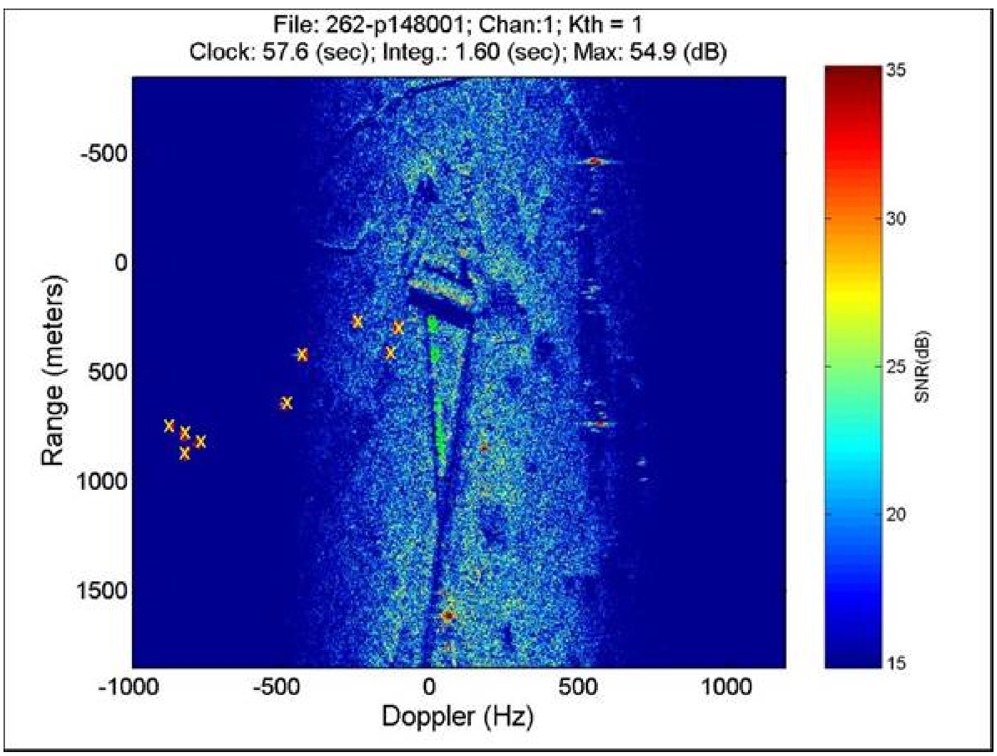


Figure 8. Application of LA-CFAR to one frame of a single-channel SAR.

V. Conclusion

In this paper, we have described an interferometric detection scheme for detecting surface moving targets in multi-channel SAR. We have included results from real multi-channel radar data.

We have also introduced the concept of a look-ahead constant false alarm rate (LA-CFAR) detection scheme that might be employed to detect moving targets in a sequence of single-channel QuickSARs and have shown a result with real data.

Acknowledgment

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