# USING A CLUSTERING TECHNIQUE FOR DETECTION OF MOVING TARGETS IN CLUTTER-CANCELLED QUICKSAR IMAGES

*Mr. D. P. McGarry, Dr. D. M. Zasada, Dr. P. K. Sanyal, Mr. R. P. Perry*

The MITRE Corporation, 26 Electronic Parkway
Rome, NY 13441, dmcgarry@mitre.org

## ABSTRACT

The ability to detect and track moving targets in Synthetic Aperture Radar (SAR) images has become a topic of much current research. The authors have been reporting on a multi-channel phase interferometry technique for detecting moving targets in SAR images for some time. They have also shown that the phase interferometry between two channels can be utilized to cancel ground clutter from one channel by subtracting a phase-weighted version of the image from the other channel. This is analogous to, but not the same as, the well known DPCA (Displaced Phase Center Antenna) technique for clutter cancellation.

This paper reports on a clustering technique we have successfully used to detect moving targets, which in almost all cases occupy many more than one or a few pixels in the clutter-cancelled SAR image. This technique greatly reduces false alarms.

*Keywords: SAR, Multi-channel, Phase Interferometry, Clutter Cancellation, Clustering*

## 1. INTRODUCTION

Traditionally, GMTI (Ground Moving Target Indication) has been the technique of choice for detecting ground targets from airborne radars. The basic GMTI technique works on the principle that, in the Doppler domain, a fast moving target stands clear of the stationary ground return or ‘ground clutter’.

Because of the finite beamwidth, the ground clutter has a spread in Doppler and slower targets do not always stand clear of this clutter spread. Often the target is embedded at least in the edges of the clutter spread. Various clutter cancellation schemes have been proposed and developed; the most widely know being the DPCA (Displaced Phase Center Antenna) technique [1]. Space time adaptive processing techniques have also been used with mixed results against a wide range of moving target sets [8].

As radars have become more capable, many airborne radars are now equipped with a SAR (Synthetic Aperture Radar) mode. The SAR mode produces SAR images, which, when properly executed, appears almost like optical image of the ground being illuminated by the radar. In such high quality images, an observer can easily identify large stationary features, both natural and manmade, such as hills or buildings of various sizes. Depending on the resolution, one might be able to detect and even identify large and small stationary vehicles.

Given that airborne SAR images have become commonly available, the question is widely asked: can one detect moving targets in a SAR image. It is well known that, for sharply focused ground SAR images, moving objects do not focus into sharp images; they tend to be smeared in the cross-range dimension. This is especially true when long integration times are used to produce high resolution in the cross-range dimension of the ground image. In these images, the moving targets tend to appear as long streaks. To a human observer, the presence of these streaks is almost sure indications of the presence of moving objects. The next question is: can a machine automatically detect moving targets in a SAR image?

We have processed data collected by General Dynamics using their 8-channel DCS system. This data was delivered in a scene-center stabilized form that eliminated the need for any extensive motion compensation. More than about 207 seconds of data is available. In the scenario, there were several targets moving in a circular loop on an airfield runway. The GPS data from the targets is also available.

## 2. PHASE INTERFEROMETRY

The authors have recently reported in references [2, 3, 4, and 5] on a technique for using phase interferometry in multi-channel SAR for detecting moving targets in sequences of short duration SAR images (QuickSAR). Similar applications for interferometry have also been reported for velocity estimation in [10]. A somewhat similar approach has also been described by Zhang et al [6]. This technique creates a ‘phase difference or ‘phase interferometry’ image by subtracting the phase of the image from one channel from the phase of the image from an adjacent channel.

Figure 1 shows such a phase-difference image of a run-way complex created from real data collected with multi-channel radar. With the phase magnitude coded in color, and in the absence of phase fold-overs, the phase difference image appears as a continuum of vertical color fringes. In the figure, the ground features are discernible because all pixels with power below a certain magnitude have been assigned a –π radian phase value. Thus the runway, whose smooth surface reflects much less signal than the surrounding terrain, appears dark and hence is differentiated from the terrain.

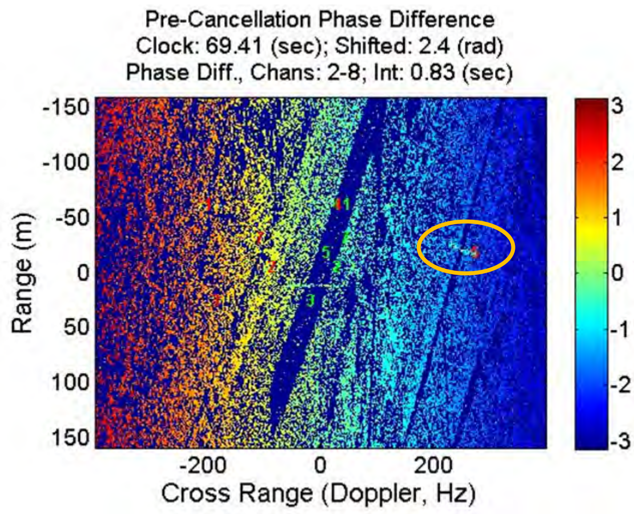


Figure 1. Phase-Difference image of a runway complex with moving targets

As is well known, moving targets in SAR images not only appear smeared but also displaced from their actual location on the ground. In this data collection scenario, there were several vehicles moving in a circular loop on the runway. The recorded true position and velocity (GPS data) of these targets are available. The green numbers in Figure 1 show the instantaneous true positions of the targets at the time of this image (69$^{th}$ second). Since the velocities of the targets and the platform are also known, we can compute the observable Dopplers of the targets. These are shown in the corresponding red numbers. Notice that the observed locations are displaced from their true positions.

One of the observed locations is highlighted with a circle. Notice that a smear also appears within this circle. This is the smeared image of the moving target. The area within the circle was zoomed in Figure 2 for easier viewing. In this color-coded phase-difference image, the smear stands out as of a different color than the background. The red area in figure two is the number 5 indicating the observable Doppler of Target 5 (it was distorted due to zooming the area of Figure 1). While the moving target appears at a displaced location, it retains the phase difference associated with its true position. A human observer is often able to observe this color anomaly in the phase difference image and thus detect the presence of a moving target. A machine can also automatically detect the phase anomaly [2, 3, 4] and thus readily detect the presence of moving targets in a QuickSAR image or sequence of images.

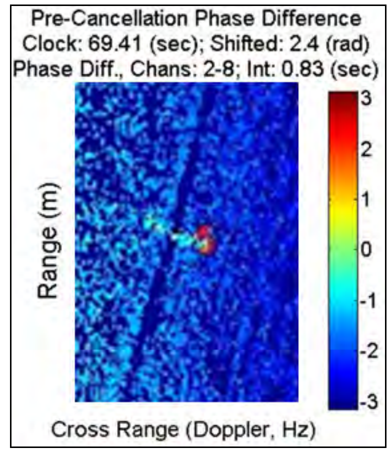


Figure 2. Zoomed-in Phase-Difference image of circled region in Figure 1

## 3. CLUTTER CANCELLATION

In the DPCA technique [1,8], cancellation of the ground clutter is achieved by a pulse-to-pulse cancellation. Similar techniques are described in [8,9]. The SAR clutter cancellation technique developed by the authors is analogous to the DPCA but is different in many ways. In this technique, two SAR images are formed from the returns received in the two phase centers or channels. The difference of the phases of the two images produces the phase-difference image shown in Figure 1. Ideally, the phase image should be a plane but because of the system noise, it is rarely so. We fit a plane, in a least square sense, to the computed phase difference image. We then subtract the phase-weighted second image from the first image, as described in equation 1, to obtain a clutter-cancelled image.

$$I^{1-2} = I^1 - I^2 \exp(j\Delta\hat{\bar{\phi}}^{1-2}) \qquad (1)$$

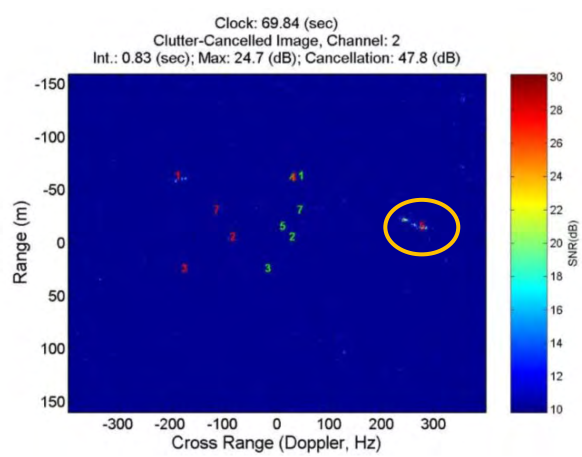


Figure 3. Clutter Cancelled SAR Image of Figure 1

As can be seen in Figure 3, most of the ground clutter has been cancelled while the moving targets are mostly intact, with targets numbered 1 and 5 apparently quite discernable even at this scale. The clutter cancellation serves as a process to "sanitize" the data of all ground clutter which allows the detection and clustering algorithms to focus on aggressively analyzing the remaining magnitude data for potential moving targets.

Similar to Figure 2, Figure 4 represented a zoomed image of the area circled in Figure 3. In this view a human can easily see the color difference between the observable Doppler location of the target versus the background, indicating a difference in magnitude of about 8-12dB. The combination of these human and machine observable differences allow for the authors' dual threshold detection algorithm to have favorable results on clutter cancelled SAR data.

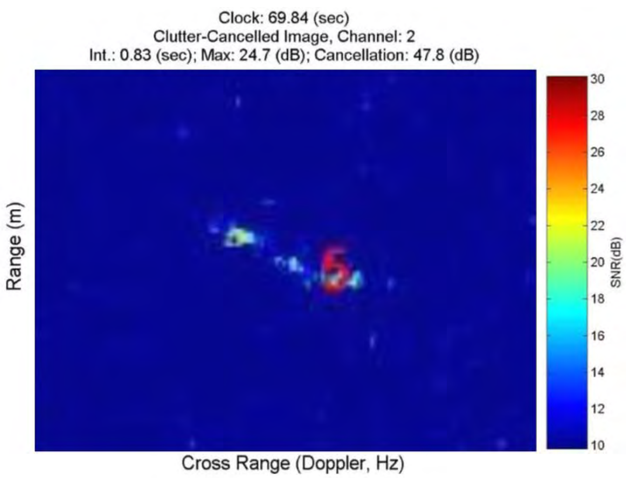


Figure 4. Zoomed-in Clutter Cancelled image of circled region in Figure 3

## 4. DETECTION & CLUSTERING ALGORITHM DESIGN

After clutter cancellation, the moving targets can be detected in the image by applying a magnitude threshold. By performing a double thresholding, namely, one in magnitude and one in phase, false alarms can be greatly reduced [5]. MATLAB code was used to generate the phase difference images and clutter cancellation; the rest of the detection and clustering algorithm is a custom library written by the first author (and, hence, informally referred to as the "McGarry" algorithm) in C++ using standard object oriented design techniques.

Once the clutter cancellation was performed, two channels of magnitude data and one channel of phase data were saved for each QuickSAR image. QuickSAR from the General Dynamics data were 0.83 seconds apart, and consisted of just over 207 seconds of continuous data. The detection/clustering algorithm organizes a set of SAR data into three classes: the individual SAR images (detection frames), the potential moving targets in those frames (target groups), and the pixels that make up the potential moving targets (target points). Each of these three classes is related to one another using the composition relationship; a detection frame is composed of many target groups and a target group is composed of many target points. In our implementation of the algorithm two clutter-cancelled images were used for each timeframe; one from channel pairs 1, 2 and one from 2, 3.

During the detection process these two images are processed individually until the end of the algorithm when they are compared to reduce false alarms. Further pairs of channels could be added in future implementations to decrease false alarms even further. A single set of phase data was also processed and used in the detection algorithms for both clutter-cancelled images. The primary threshold values include a magnitude threshold (dB) and a variable phase threshold (radians).

Each SAR image is loaded as an array of floating point values representing the magnitude values, as well as the phase data which is copied as an array of floating point to both detection frames. Both the magnitude and phase arrays had a dimension of 661 (Doppler) by 383 (range), which represents each pixel in the actual image.

After loading the magnitude and phase data for each detection frame, the algorithm iterates left to right, top to bottom through the entire magnitude array and determines whether each pixel will pass both the magnitude and variable phase threshold conditions. Magnitude thresholding is accomplished through a simple greater-than or equal to comparison with the actual magnitude value of the individual pixel. If this condition is satisfied, then the variable phase threshold for that pixel is calculated as described in the equations below.

$$\Phi_{Const} = \Phi_{Thr} * \sqrt{10^{(\frac{dB}{}}} \quad (2)$$

$$SNR_{Real} = \sqrt{10^{(\frac{dB_l}{.}}} \quad (3)$$

$$\Phi_{VarThr} = \frac{\Phi_c}{SNI} \quad (4)$$

Equation 2 calculates $\Phi_c$ which represents the square root of the real value of the magnitude threshold ( $dB$ weighted by the phase threshold value ( $\Phi$. Equation 3 converts the magnitude value of the pixel ( $dB_l$ from dB into a real value. The square root is then taken of the real magnitude value to exploit the property that the square root of an SNR is inversely proportional to the system noise, in this case the phase noise. In equation 4 we take the divide the calculated phase constant ( $\Phi_{Co}$ by the square root of the real SNR value ( $SNR_l$ to calculate the variable phase threshold for that individual pixel ( $\Phi_{Va}$). If the absolute value of the actual phase value is greater than or equal to the computed variable phase threshold, the pixel is considered to have passed both threshold conditions, and it's information is stored inside a target point object. The detection frame object maintains a temporary list of all target points to satisfy the threshold conditions so they can be grouped and further analyzed. In the SAR images of reasonable resolution, most targets of interest appear to occupy a large number of contiguous pixels, so the pixels that were above the primary threshold values must now be grouped into potential moving targets.

Grouping is done by examining each target point and the area surrounding it. The SAR images that we generated from the General Dynamics data were 661 (Doppler cells) by 383 (range cells). Since the images are rectangular, a small rectangular area around the target point is examined to see if another target point is "nearby". The rectangular area used for the General Dynamics data was a 10(Doppler cells)x5(range cells) area, which is illustrated in Figure 5.

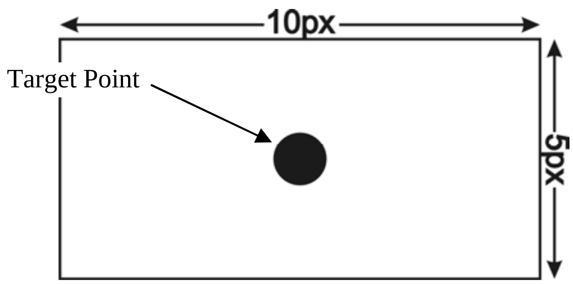


Figure 5. The 10x5 area examined around individual Target Points

If three or more target points exist in this small rectangular area, these target points are grouped into a target group. The size of the rectangle and the number of target points needed to create a target group are two of the "secondary threshold" values. Each target group object contains a list of the target points that are in the group as well as an un-weighted average center point of the group. This is illustrated in Figure 6 which shows the same Target Point and area shown in Figure 5 with 3 additional Target Points within the area.

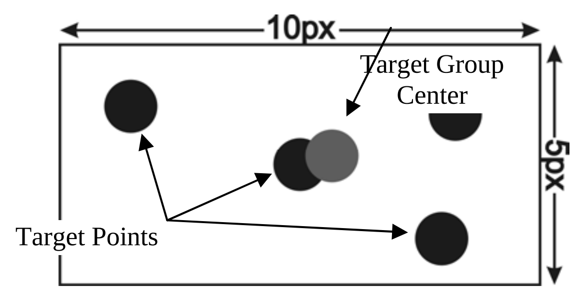


Figure 6. Target Points eligible to be grouped into a Target Group with the grey circle indicating the center

The grey shaded circle represents the average x-y position of all the Target Points within that Target Group.

Once the individual or small clusters of false alarm points have been removed by the initial grouping, we can combine nearby target groups using a similar technique with more liberal secondary threshold values. Target groups are combined by examining a 45(Doppler)x25(range) rectangular area around each target group. If one or more target group exists in the area, they are combined and their center is recalculated.

After combining target groups together, we are left with an accurate representation of all the potential moving targets for each image. In order to further reduce false alarms, a two-channel comparison is preformed. The two images that contain different magnitude data for the two channels are overlaid on one another and their detections are compared. The algorithm iterates through each target group in the first channel's image. For each target group we look to see if there was a corresponding detection in a 30(Doppler)x15(range) rectangular area in the second channel's image.

The use of an overlay rectangle was used to account for target location difference across different channels of the radar. Target groups that don't have a corresponding detection on the other channel are removed. We are left with a set of images that contain a list of target groups representing the potential moving target on that image.

Figure 7 shows a clutter-cancelled SAR image with dots indicating the target group centers. There are three callouts from the image illustrating a possible false alarm, a large moving target (Target #5) and a likely moving target (Target #2).

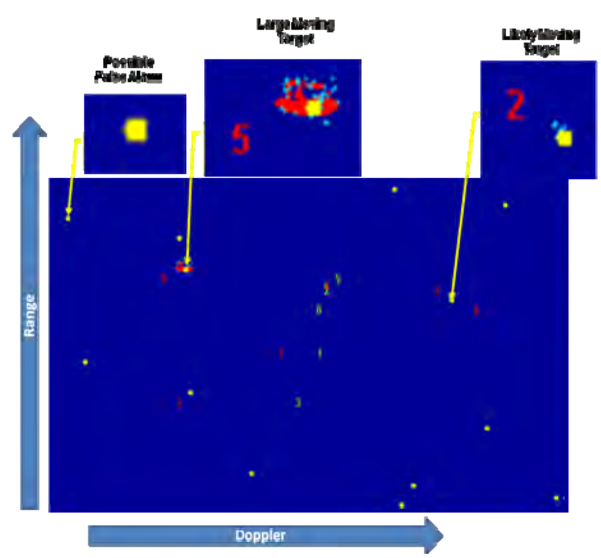


Figure 7. End-Product image of two-channel compared, clutter-cancelled SAR Image

## 5. RESULTS

In addition to reading the two channels of magnitude data and single channel phase data into the detection and grouping software, GPS truth data was also input to use as a tool to analyze our detection results. Using the truth data included with the SAR data, we could compare our detections against the actual locations of the vehicles, thereby determining our Probability of Detection (PD) and our False Alarm Density (FA/km$^2$). This data is plotted in the Receiver Operator Characteristics (ROC) curve in Figure 8, which had a sliding magnitude threshold from 24 dB to 7.5 dB and a variable phase threshold (as illustrated in Equations 2,3,4).

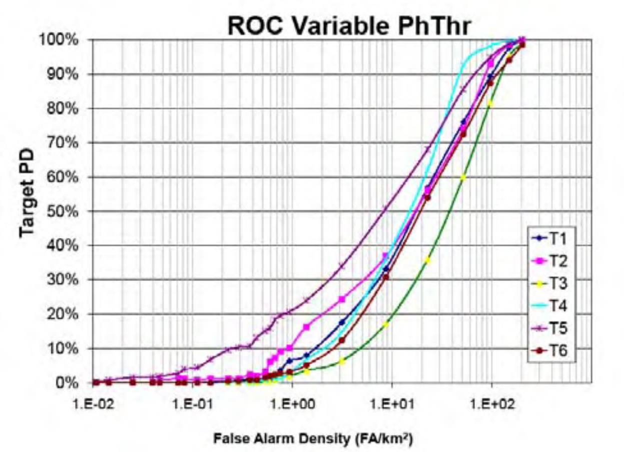


Figure 8. Receiver Operating Characteristic (ROC) Curves for the Cluster-based detection technique

In addition to determining the probability of detection, once a Target Group is matched up with a specific target in the truth data, the Target Groups calculated centers can be plotted against time to show the target's travel. Figure 9 shows a target's travel over 250 seconds in blue with the truth data also plotted in green to show the accuracy of the detection. Small images of the target are displayed along the target's path.

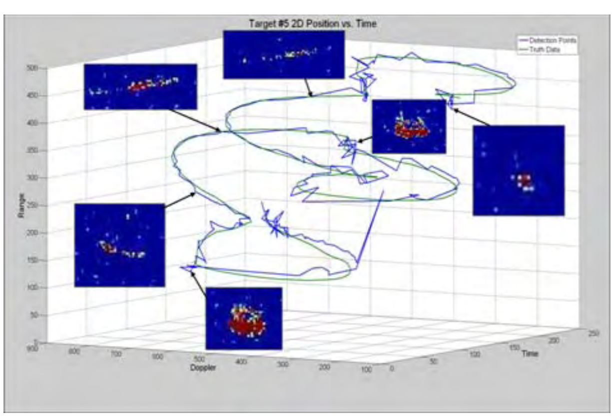


Figure 9. The detection of target # 5 over 207 seconds

## 6. CONCLUSIONS

In this paper, we have discussed a clustering technique that, in conjunction with a multi-channel SAR interferometry technique, appears to produce excellent detection of moving targets. Based on the receiver operator characteristics of this new algorithm, we were able to produce 90$^+$% PD with false alarm densities of 100FA/km$^2$. The authors feel, that with further development and optimization to the techniques used in the this algorithm, false alarm densities can be reduced even further, while still maintaining a high PD. Future research and development may include further area optimization for the secondary thresholding values, automatic and variable magnitude threshold calculation, and adding more than two channels of magnitude data.

## 7. REFERENCES

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