## Detecting Moving Targets in SAR Via Keystoning and Phase Interferometry

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

The MITRE Corp., 26 Electronic Parkway, Rome, NY 13224 Ph: 315-336-4966, Fax: 315-336-4753

Approved for Public Release; Distribution Unlimited Case #05-1019

Email: psanyal@mitre.org

### Abstract

We require continuous and unambiguous radar tracking of surface moving targets for several minutes to target and engage moving targets. Conventional radar surface moving target trackers typically drop or confuse tracks after only a short time. If we can couple state of the art motion-compensated Synthetic Aperture Radar (SAR) techniques with advanced Surface Moving Target Information (SMTI) techniques, we may be far better able to automatically and continuously track individual targets through zero radial velocity in difficult environments.

Without motion compensation, moving targets within SAR images are generally blurred and difficult to detect. MITRE has developed a technique called the Keystone Formatting for motion compensation of targets, the advantage of which is that it can compensate for several targets moving at different velocities simultaneously. Along with acceleration correction, this produces sharp images.

Complimentary to the Keystone'd Range-Doppler-Intensity image, one can form a phase- interferometry image. In the phase image, where all points on the non-moving surface nominally appear as a continuum of phase differences while the moving targets appear as discontinuities. By judicious comparison of both the intensity image and the phase image, it is possible to detect and locate moving targets in the SAR.

Key words: SAR, Keystone Formatting, Phase Interferometry

### Introduction

For tactical purposes, we require continuous and unambiguous radar tracking of surface moving targets for several minutes to target and engage moving targets. Conventional radar surface moving target trackers typically drop or confuse tracks after only a short time. This is caused by target detection drop-outs due to target stops, starts, quick turns, low target radial velocity, terrain screening, etc. Hence continuous attention by a human operator is currently required to stitch these short track segments back together.

Without motion compensation, moving targets within SAR images are generally blurred. These effects are shown by the SAR images in Figures 1 and 2. MITRE has developed some novel techniques for producing sharp, focused SAR images and then to detect the moving targets therein.

In this paper, we present results of moving target detection in multi-channel SAR data collected by Lincoln Laboratories of Lexington, MA, USA.



Figure 1. SAR With and Without Motion Compensation (Source: <u>www.sandia.gov</u>)



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

### **MITRE-developed Keystone Formatting**

MITRE has developed a technique called Keystone Formatting for motion compensation of targets, the advantage of which is that it can compensate for several targets moving at different radial velocities simultaneously.

Keystone formatting can be derived by noting that the spectrum of a single received pulse is given by,

$$S_r(f) = P(f) \exp[-i\frac{4\pi}{c}(f+f_0)R(t)]$$
 (1)

where

$$P(f) =$$
 spectrum of transmitted pulse

 $f = \text{baseband frequency}\left(\frac{-B}{2} \le f < \frac{B}{2}\right),$ 

 $f_0 =$ carrier frequency.

Expanding R(t) in a Taylor series, we get:

$$R(t) = R(t_0) + \dot{R}(t_0)t + \frac{1}{2}\ddot{R}(t_0)t^2 + \cdots$$
 (2)

Substituting (2) into (1) and dropping cubic and higher order terms,

$$S_{r}(f) = P(f) \exp[-i\frac{4\pi}{c}(f+f_{0})R - i\frac{4\pi}{c}(f+f_{0})\dot{R}t - i\frac{2\pi}{c}(f+f_{0})\ddot{R}t^{2}].$$
(3)

The second term in the brackets containing the product  $f\dot{R}t$  gives rise to range walk. This term

becomes zero when we use the temporal transformation

$$t = \left(\frac{f_0}{f + f_0}\right)t' \ .$$

With the above substitution, (3) can be written as,

$$S_{r}(f) = P(f) \exp[-i\frac{4\pi}{c}(f+f_{0})R - i\frac{4\pi}{c}f_{0}\dot{R}t' - i\frac{2\pi}{c}(f+f_{0})\ddot{R}(\frac{f_{0}t'}{f+f_{0}})^{2}].$$
(4)

Since the Keystone formatting does not solve the quadratic (or higher order) motion problem, let us also drop the quadratic term in (4) and simplify it as:

$$S_{r}(f) = P(f) * \exp[-i\frac{4\pi}{c}(f+f_{0})R - i\frac{4\pi}{c}f_{0}\dot{R}t'].$$
<sup>(5)</sup>

Notice that the substitution of t' for t has removed the phase term that varied with both time and frequency and this removes the range-walk. Thus no matter what velocity the target is moving at, it will remain in a given range cell determined by its position at the center (t=0) of the coherent processing interval. Figure 3 shows the 'keystone' nature of the transformation.



### Figure 3. Keystone Formatting Performs Motion Compensation for Targets Moving at Different Velocities

Figure 4 shows the effect of Keystoning on the range walk The left inset in Figure 4 shows the RTI with two targets moving at different speeds. The two targets go through different amounts of range walk. 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 correct the range walk for one target at a time.



Figure 4. Keystone Formatting Performs Motion Compensation for Targets Moving at Different Velocities



# Figure 5. With Keystone Formatting, Targets Moving at Different Velocities will Focus Simultaneously

The Keystone process is seen to compensate for the motion of both the targets simultaneously. Figure 5 shows that they can now be coherently integrated without any significant loss due to range walk.

## Acceleration Correction

The Keystoning corrects only for the range walk due to the velocity. However, by itself, it cannot correct for the image defocusing that results from the acceleration that introduces quadratic phase error (QPE). Figure 6 shows the typical SAR geometry and the resulting acceleration. Given the look angle, one can pre-compute the acceleration and apply an appropriate correction to the data.

Figure 7 presents SAR images created from data collected by Lincoln Laboratory. The left inset is the range-Doppler image without any acceleration correction while the right inset is the image that results after an optimum acceleration correction has been applied.

Without the appropriate acceleration correction, the image is practically unrecognizable. With the optimum acceleration correction, the image is clearly recognizable as an area with several buildings, roads, a ball park, etc.

To find the optimum acceleration correction, we applied pre-selected trial few values around the expected value of  $1.97 \text{ m/s}^2$  until the image intensity peaked. This value was found to be  $2.225 \text{ m/s}^2$ .

Moving targets tend to appear removed from their actual locations in SAR. For example, moving trains appear to be floating a considerable distance away from the stationary tracks.



Figure 6. The Typical SAR Geometry and the Resulting Acceleration



Figure 7. SAR Images of Ft. Huachuca created from LiMIT Data Collected by Lincoln Laboratory



(b) 0.9 Second Dwell Time Image, Dwell 1 second Later



The Doppler,  $f_D$ , of a point at  $\theta$  radians from the normal to the velocity vector for a small angle  $\theta$  reduces

to 
$$f_D = \frac{2V\theta}{\lambda}$$
.

If a moving target has the Doppler  $f_{targ}$ , then it will appear shifted in cross-range by an angle  $\theta$  such that  $f_{targ} = \frac{2V\theta}{\lambda}$  or  $\frac{2v_{targ}}{\lambda} = \frac{2V\theta}{\lambda}$  or  $\theta = \frac{v_{targ}}{V}$ At a range R, this amounts to a linear shift of  $cross - range - shift = R\theta = \frac{Rv_{targ}}{V}$  Figure 8 shows two images from the LiMIT data about 0.9 seconds apart.

A careful inspection of the two images reveals a moving target at the tip of the red arrow. Though the comparison of a sequence of SAR images can reveal the presence of moving target (i.e., coherent change detection), we have applied an in-line phase interferometry technique for detecting and locating moving targets in a multi-channel SAR data.

Figure 9a shows the same image shown in Figure 8 but with the range axis stretched; hence, the image is not recognizable as such. However, one can now see





(b) Phase Image (Ch. #1 – Ch. # 8)

Figure 9. A Moving Target in the Ft. Huachuca Image (Channel # 1)

that there are certain streaks, specifically the one identified with the arrow that seem to have a cant to their stretch. This is an indication of a moving object.

Figure 9b plots the pixel-by-pixel phase differences between the images from channel #1 and channel # 8. The channels or sub-arrays are located at the two ends of the antenna array and each point on the ground (and objects at the same spot on the ground) has slightly different path lengths to the arrays and thus there is a path-length difference or a phase difference. The path length difference varies very little as one moves out in range but there is a significant change as one moves in cross-range across the image. This produces the vertical striped nature of the phase image.

#### Phase Interferometry for Moving Target Detection

At the same location in the phase image where there was a feature with a different cant in the amplitude image, we notice a feature that appears to have different coloration and have a different phase difference value from its surrounding. Specifically, we see a light bluish feature in a red background. This signifies that the object that generated the feature belongs in the image where the other bluish stripes are, but because of the Doppler processing, it appears at a location consistent with the rate of change of the phase to any channel. The presence of discontinuities in the phase image indicates the presence of moving targets and the value of the phase difference at the discontinuity indicates where they actually belong.

Having located a moving target, we 'chipped' out the moving target and focused it further to produce the image shown in Figure 10. From an estimation of the length of the object and it's slightly curved appearance, it appears highly likely that it is a tractor-trailer. Unfortunately, we did not have ground truth information available to verify this.

#### Summary

For tactical purposes, we would require continuous and unambiguous radar tracking of surface moving targets for several minutes to target and engage moving targets.

By coupling state-of-the-art motion-compensated Synthetic Aperture Radar (SAR) techniques with advanced Surface Moving Target Indication (SMTI)





# Figure 10. Acceleration Focused SAR Image of a probable Moving Tractor-trailer

techniques, one may be far better able to automatically and continuously track individual high value targets through zero radial velocity in difficult environments. In this paper we have described the Keystone Formatting for removing range walk in SAR data and have shown, using real multi-channel SAR data collected by Lincoln Laboratories of Lexington, MA, USA, how the Keystone formatting and acceleration correction produces sharp SAR images.

We have shown that moving targets appear in the SAR at positions displaced from their actual location in the scene. This displacement is directly related to their radial velocities.

Further, we have shown that phase interferometry using two channels of the multi-channel data reveals the presence of moving targets in the SAR image.

## **References**

- 1. Richard P. Perry, Robert C. DiPietro and Ronald L. Fante, The MITRE Corporation, 1999. SAR Imaging of Moving Targets. IEEE Transactions on Aerospace and Electronic Systems, Vol. 35, No. 1, pp. 118-199
- 2. Stockburger, E. F., Held, D. N., Interferometric Moving Target Imaging, IEEE International Radar Conference, 1995

## Author Info

|          | Probal Sanyal got his B.Tech. (EE) and M. Tech. (Control Systems) from IIT, Kharagpur, India in 1967 and 1969 Respectively. He received his Ph. D. in Systems Eng. From RPI, Troy, NY in 1973. He has been with the MITRE Corp. for over 15 years and is currently a lead engineer. He has worked on various radar signal processing projects.                       |
|----------|--|
|          | David M. Zasada is a senior Principal Engineer at the MITRE Corporation. He received a BS in Physics from Georgetown University (1971), an MS in astrophysics from RPI (1973) and a Ph.D. in Electrical Engineering from Syracuse University (1995). He joined MITRE in 1979.  |
| <b>B</b> | Richard P. Perry is a Senior Principal Engineer at The MITRE Corporation and has a BSEE degree<br>from Lehigh University (1953) and a MSEE degree from the University of Pennsylvania (1966). He<br>is currently working on advanced Synthetic Aperture Radar processing algorithms. He has been<br>with MITRE for 15 years and has previously worked at RCA and GE. |