Pipeline Encroachment Monitoring Using Polarimetric SAR Imagery

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***Abstract*—Mechanical damage incurred from unauthorized third party activities remains a leading cause of onshore oil and gas pipeline failure, indicating the need for effective strategies to monitor encroachment over extensive sections of pipeline right-of-way (ROW). In this paper, the use of polarimetric SAR imagery (as will be available from RADARSAT-2) for pipeline monitoring of encroachment activities is explored. Experimental data were acquired of a test area near the shores of Lake Simcoe (north of Toronto, Ontario) in September, 2001 by the C-SAR on board the Convair-580. The vehicle deployments and ground truthing were conducted by C-CORE with processing from signal data (including calibration) and analysis performed at the Canada Centre for Remote Sensing.**

Keywords - Synthetic Aperture Radar (SAR); Polarimetry; Target Detection

I. INTRODUCTION

Mechanical damage incurred from unauthorized third party activities remains a leading cause of onshore oil and gas pipeline failure. This indicates the need for effective strategies to monitor encroachment over extensive sections of pipeline right-of-way (ROW). Research over the last 5 years has identified important trends that imply the need for a proactive, preventative capability to avoid mechanical damage caused by third-party encroachment upon ROWs. Conventional surveillance practices currently in use include field observations and air patrols. These are costly and limited in both spatial coverage and revisit frequency. The repeated coverage of large areas in short time intervals and all weather capability is highly desirable in order to achieve effective monitoring. Responding to this requirement, C-CORE and the pipeline service company *via+* (commercializers of the service) have been pursuing the development of automated target detection using spaceborne radar and high-resolution optical satellite imagery [1][2].

This paper describes preliminary results on the use of polarimetric SAR imagery for monitoring of encroachment activities along a pipeline ROW. The Canada Centre for Remote Sensing (CCRS) acquired experimental data with the C-SAR on board the Environment Canada Convair-580 of a test area near the shores of Lake Simcoe (north of Toronto, Ontario) in the fall of 2001. Analysis of polarimetric imagery and generation of results was performed using the methodologies that have been applied for man-made target detection at CCRS [3].

The following sections include descriptions of the various facets of this experiment and details of the results obtained.

II. EXPERIMENT DATA

Signal data were acquired on one pass in the polarimetric mode of the C-SAR on September 29, 2001. These were processed to calibrated imagery at approximately 5.6 metres resolution in slant range and approximately .6 metre in azimuth [4] [5] [6].

A portion of this image showing the area where the encroaching vehicles were located is shown as Figure 1. In this figure, the images in the three polarizations are displayed as Red: HH, Green: VV, Blue: HV. Blue arrows indicate the range (R) and azimuth (A) directions. The orange rectangles

Figure 1. Ground-processed C-SAR colour imagery of pipeline right-of-way area on September 29, 2001 (Red:HH, Green:VV, Blue:HV). Arrows indicate range (R) and azimuth (A) directions. Orange rectangles indicate the vehicle locations.

show three of the areas where target vehicles were deployed.

Deployment of calibration targets at another site accessed during this flight was carried out as part of another experiment by CCRS. These were used in the calibration of this imagery.

The vehicle deployments and ground truthing were conducted by C-CORE. The targets in this part of the imaged areas were located in the pipeline ROW and were ground truthed: Photographs of the test targets are shown in Figures 2 to 4.

Four vehicles located at Site #1 are shown in Figure 2.

Figure 2. Targets located at Site #1. Targets 1 and 2 are adjacent to one another. The blue truck container is located next to a white tank and both are considered to be "false targets".

Figure 3. Targets located at Site #2

Figure 4. Targets located at Site #3

Target 1 and Target 2 are close to each other, about 2 metres apart. Target 3 and Target 4 are also close to one another, about 3 metres apart. Site #2 shown in Figure 3 included a dump truck and trailer. At Site #3, two vehicles were parked quite close to one another as shown in Figure 4.

These target vehicles include target types that have been found to be very useful in other studies at CCRS (e.g. [3]). These include symmetrical radar reflectors such as, dihedrals and narrow diplanes formed by the surfaces of these objects. It was expected that such reflectors could be distinguished and detected in analysis of the polarimetric imagery.

III. Data Processing and Results

The methodology used to locate the man-made targets exploits the full polarimetric information available for the imaged scene. For detection purposes, three methods of polarimetric data analysis can be applied when looking for man-made targets: Polarimetric Whitening Filter (PWF)[7], Cameron Decomposition [8] and Even Bounce analysis [9]. Each of them can be used to select possible targets based on one aspect of the target backscattering characteristics. The PWF method can be used to select bright targets whose magnitude is higher than a pre-defined threshold. The results of Cameron Decomposition are examined here to distinguish the symmetric dihedral or narrow diplane reflector from other symmetric scatterers (disregarding the magnitude of this backscatter). Other possible "primitives" such as trihedrals and quarter-waves were noted, but it appears that the use of dihedral or narrow diplanes provides a good target signature for this case. This can be seen from examining the vehicles in Figure 2. Even Bounce analysis is used to detect targets having structures that cause the radar signal to "bounce" twice on the target.

Each method can lead to a number of "false targets". To decrease the number of "false targets", the logical AND ("$\cap$") operator is applied to each image sample. Thus a target sample is defined as "PWF target $\cap$ Cameron target $\cap$ Even Bounce target". A sample is considered to be a potential target only when it is selected by each method [3].

Some results of the preliminary analysis are shown in Figure 5 from Sites #1 and #2. The orange rectangles indicate the true location of the vehicles. In this figure, the highlighted samples correspond to the locations of brighter targets which behave as dihedrals or narrow diplanes and show a significant amount of Even Bounce backscatter. These are expected to correspond to the deployed targets as well as to other man-made objects. It is difficult to uniquely identify the location of each vehicle in these images due to the small separation between them (about 1or 2 metres) which is on the order of the resolution of the imagery.

In this imagery, it is seen that there are a number of possible targets identified as being man-made. This is particularly noticeable in Figures 5(a) and (b) in which the southern portion of the image chip shows several other detections that are not due to vehicle targets. These targets correspond to a subdivision development, which is just across the road as shown in Figure 6. In the photo, just beyond the

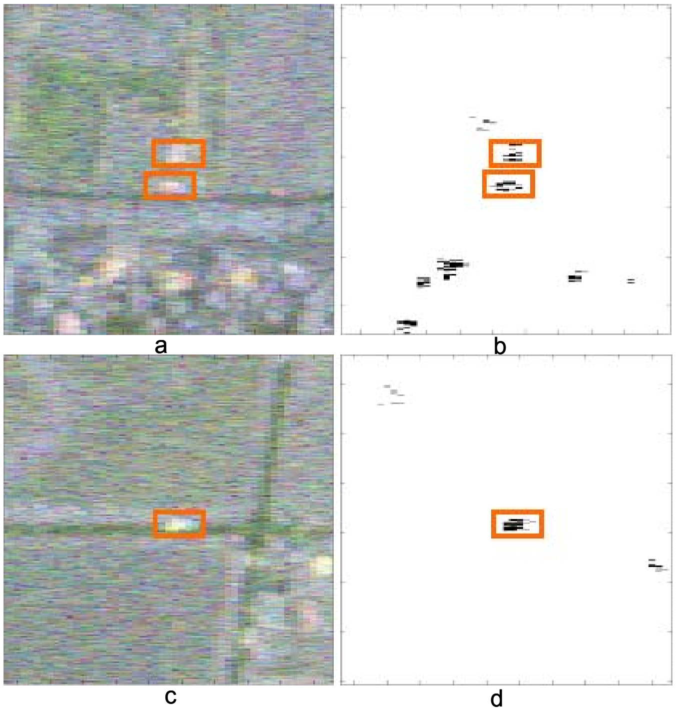

Figure 5. Detection results of Sites #1 and #2. Orange rectangles indicate the vehicle locations. (a) Colour image of Site #1. (b) Target map of Site #1. (c) Colour image of Site #2. (d) Target map of Site #2.

Ingersall-Rand roller, a tree line that borders the road is shown next to one of the dwellings in the subdivision that produced a detection using the algorithm of this study. These detections, due to permanent scatterers, can be easily removed using an accurate GIS database of the infrastructure.

Figure 6. This picture shows an examples of a "false target" due to a permanent scatterer. In the photo, just beyond the Ingersall-Rand roller, a tree line that borders the road is shown next to one of the dwellings in the subdivision that produced a detection using the algorithm of this study.

IV. Conclusions

Preliminary results using these data show the detection of vehicles that have encroached onto the ROW as well as other man-made targets. More study is needed examining the possible man-made target signatures and determining the optimal characteristic backscatter combinations that could be used to give potential locations of targets.

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