Synthetic Aperture Radar for Search and Rescue: Evaluation of Advanced Capabilities in Preparation for RADARSAT-2

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ABSTRACT

Researchers at the Canada Centre for Remote Sensing of Natural Resources Canada are exploring the use of remotely sensed imagery to assist Search and Rescue in Canada. Studies have been examining the use of Synthetic Aperture Radar for the detection of crashed aircraft. Promising results have been obtained with techniques for detection of dihedrals in interferometric and polarimetric data. With further development in technologies and techniques, and improved coverage of the Canadian landmass by future spaceborne systems such as RADARSAT-2, it is expected that it will be possible to assist in Search and Rescue for land targets.

Keywords: Search and Rescue, Synthetic Aperture Radar, SAR

1. INTRODUCTION

A major fraction of the Canadian landmass is sparsely populated, and there are major areas of Canada that are in total darkness for prolonged periods each year. Airplane traffic over these areas continues to increase. The need to reach the site of an airplane crash (often of small planes carrying only a few passengers) and to assist the victims is served by Search and Rescue (SAR) in Canada. This is the responsibility of the Department of National Defence and is carried out through the Rescue Coordination Centres (Halifax, Trenton, and Victoria).[1]

Along with listening for Emergency Locator Transmitters (ELTs), the current Canadian Search and Rescue procedure involves visual searches from spotter aircraft. These are not limited to the military and include those made available through the Canadian Civil Air Search and Rescue Association (CASARA). The methodology has been well detailed in the National Search and Rescue Manual. [2]

Unfortunately, the functioning of ELTs has been problematic although recent years have seen improvements. Statistics from the U.S.A. indicate that ELTs function only about 25 percent of the time:[3] Consequently, other means of crash site detection need to be explored. Furthermore, even in those cases where ELTs do function, improved location of the crash site may be provided by use of imagery. In particular, in the case of inclement weather, this would be best performed by synthetic aperture radar systems, which see through cloud and at night. As well, there are cases where the visual search for targets can be particularly difficult (e.g. detection of white aircraft on a snow white background).

There are significant periods of the year when large regions of the Canadian North are in darkness for much or all of the day as is shown in Figure 1 taken from an Environment Canada publication.[4] For example, at Eureka (79° 59' N - 85° 57' W), the sun "disappears" for about four months.

Microwave imagery can be particularly useful for the location of crashed airplanes because of the imaging of the dihedrals forming parts of the structure. It has been found that these often survive the crash: When the orientation between the Synthetic Aperture Radar (SAR) system and the target make it possible to image such dihedral structures, these make it easier to find the crashed aircraft.[5]

In some cases, airborne systems flying above the weather would be the sensors of choice. However, advantages exist in the use of spaceborne Synthetic Aperture Radar systems. Their access and coverage of the northern regions of Canada may be more timely than those achieved by the ferrying of an observation plane from a more southerly location. Airborne missions in bad weather can be difficult and of higher risk to searchers.

The possibility of assisting in search and rescue with satellite imagery was initially considered as early as the mid-1970's (e.g. W.E. Sivertson [6]). Such a potential application provides the opportunity for scientists to assist in the development of techniques using microwave remote sensing systems.

Fortunately, in recent years, there have been active initiatives in this area. In particular, the potential of Synthetic Aperture Radar imagery has been explored by the Search and Rescue Mission at NASA Goddard Space Flight Center which launched a project in 1988 to investigate the feasibility of using space and airborne remote sensing technology to aid in such beaconless (i.e. not dependent on ELTs) searches.[7] Experiments have been carried out for a variety of test targets and locales in the United States using a number of Synthetic Aperture Radar systems.[8]

Work under a Canadian initiative at the Royal Military College examining the use in Search and Rescue of Synthetic Aperture Radar and optical imaging from spaceborne platforms and other systems was described in presentations at conferences and in reports.[9]

This paper describes some of the work in an initiative at Natural Resources Canada (NRCan) in the Canada Centre for Remote Sensing (CCRS). These studies build on these previous efforts and on CCRS experience with Synthetic Aperture Radar using airborne and spaceborne systems which dates back to the 1970's.

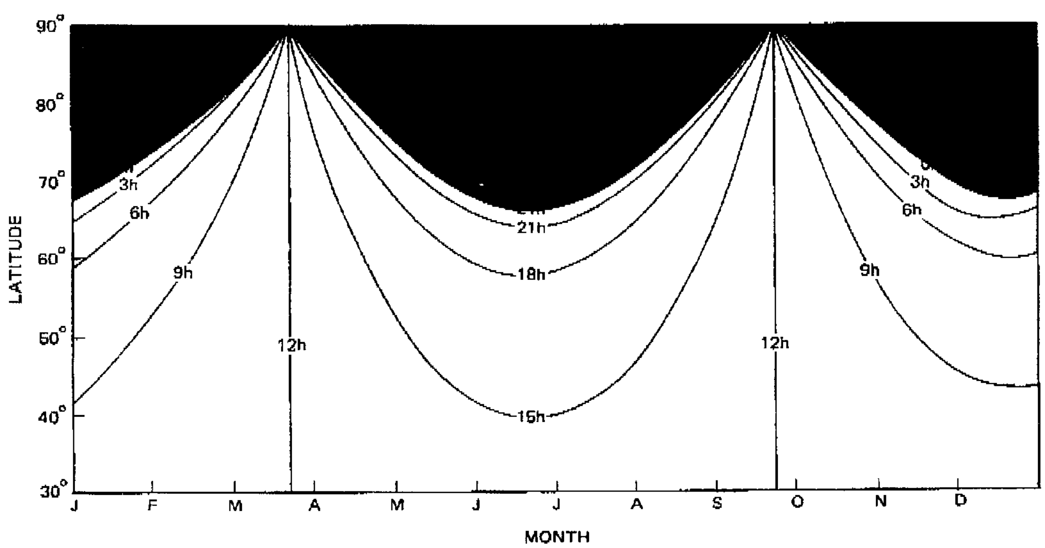

Figure 1. Duration of Daylight (Hours) as a function of the latitude and month of the year in the Northern Hemisphere.

The difficulties of penetration of C-Band radiation through heavily forested canopies are expected to prove limiting in the searches in particular in the southern reaches of Canada. However, in the thinly forested and, in many cases, treeless areas of the further Canadian North spaceborne systems including the Canadian RADARSAT-1 and -2 operating at C-Band could potentially be used for Search and Rescue. It has been proposed elsewhere that RADARSAT-2 provides capabilities that could be exploited.[10] It is also expected that the use of longer wavelengths on systems that are to be launched in the future should provide improved / increased capabilities, in particular for the southern regions.

RADARSAT-2 to be launched in November 2003 retains the capabilities of RADARSAT-1, but with a number of improvements. These includes imaging with polarizations other than the Horizontal on transmit and Horizontal on receive of RADARSAT-1, the ability to image in polarimetric modes with ground resolutions as low as approximately 11m by 9 m resolution, a high resolution mode with ground resolutions of approximately 3 m by 3 m, and the ability to image on either side of the ground track. [11]

In Search and Rescue, time is of the essence. Waiting time can be shortened significantly if a single image acquisition is required. If two images that require repeat passes (with the satellite at essentially the same location) are necessary (as for interferometry), the time to wait increases to the impractical minimum of 24 days (RADARSAT) or 35 days (ERS or ENVISAT). However, since there are large archives of data, it is possible to develop methodologies that could use these archive data with imagery acquired following the crash. Only one post-crash image would thus be required to find potential crash locations.

The times for revisit during a 24 day cycle are very important to the exploitation of the spaceborne systems. These have been approximately modelled using the current Swath Planner for RADARSAT-1.[12] Results (Table 1) show that for the Standard Beam Modes,[13] the expected revisit times for RADARSAT-2 and future systems will be significantly improved over those for RADARSAT-1, in particular if it is routinely possible to access both right and left-looking operational modes.[14] On Cornwallis Island, this gives more than 120 imaging opportunities in the Standard Beams during a single cycle, hence, making possible (on average) five possible "hits" during a single day. However, in the more northerly regions, which are inaccessible to left-looking imaging, the number is significantly lower. Significant numbers of imaging opportunities are made possible in the other examples shown here including approximate calculations for the Standard Quadrature-Polarization (Quad-Pol) and Ultra Fine Modes.[13] It is noted, that, on average, the Standard Quad-Pol Mode shows more than one possible "hit" every day and a half for significant parts of the Canadian landmass. These numbers increase towards the North and then, decrease as only imaging on the right side of the satellite provides coverage over the most northerly parts of the globe.

Table 1. Maximum Number of Revisits of RADARSAT-1 and -2 during a 24-day cycle at various locations in Canada.

Location	Latitude / Longitude	RADARSAT-1	RADARSAT-2 – type system with access on both sides of nadir		
		S1-S7	S1-S7	Standard QP	Ultra-Fine Wide
Chibougamau, QC	49° 55' N / 74° 22' W	14	30	16	8
Iqaluit, NT	63° 45' N / 68° 31' W	20	44	22	14
Resolute, NT	74° 42' N / 94° 50' W	36	124	45	29
Eureka, NT	79° 59' N / 85° 57' W	58	58	28	16

In the studies at CCRS, various techniques, including use of interferometric coherence and polarimetric signatures, are being examined for detection and, where possible, classification of targets as crashed aircraft. Of the capabilities of RADARSAT-2, it is expected that these will prove more useful than the improved resolution: Since the targets are not large relative to the resolution of RADARSAT-2, even at the smallest resolutions, it is expected that use of Synthetic Aperture Radar imagery for detection of a crashed aircraft will be difficult

Interferometric coherence can be used to locate non-changing, man-made targets within regions of natural targets. The location of crashed aircraft using this technique has been described elsewhere.[15] Significant potential is seen in the use of coherence but this is limited by the long time required to obtain two images.

2. DETECTION OF CRASHED AIRCRAFT IN POLARIMETRIC IMAGERY

Studies at CCRS using polarimetric imagery began by examining methodologies used at NASA[8] which can be employed to detect dihedral scatterers. In particular, the use of the Polarimetric Whitening Filter, Even Basis Decomposition and the use of the Cameron Decomposition all used in the previous work [5 16] have been further explored.

This development and testing has been performed using data acquired by the C-SAR on board the Environment Canada Convair-580 operating in polarimetric mode.[17 18] The test site is shown in Figure 2 and 3. Although these are intact aircraft, it is believed that in many cases, crashed aircraft will be easier to detect.

Figure 2. Parked aircraft at Carp Airport, March 19, 1999

3. POLARIMETRIC WHITENING FILTER AND EVEN BASIS

The Polarimetric Whitening Filter (PWF) has been used to optimally combine the individual radar images from a polarimetric radar (HH,VV,HV,VH) into a single image that shows significant improvement in quality and does not suffer any degradation in resolution.[19 5] This filter has been found to reduce speckle without affecting the resolution and improving detectability of pixels that are unlike the surrounding ones. For detecting candidate targets in an image following application of the PWF, a search for the bright returns can be performed by testing relative to the mean clutter in the area.

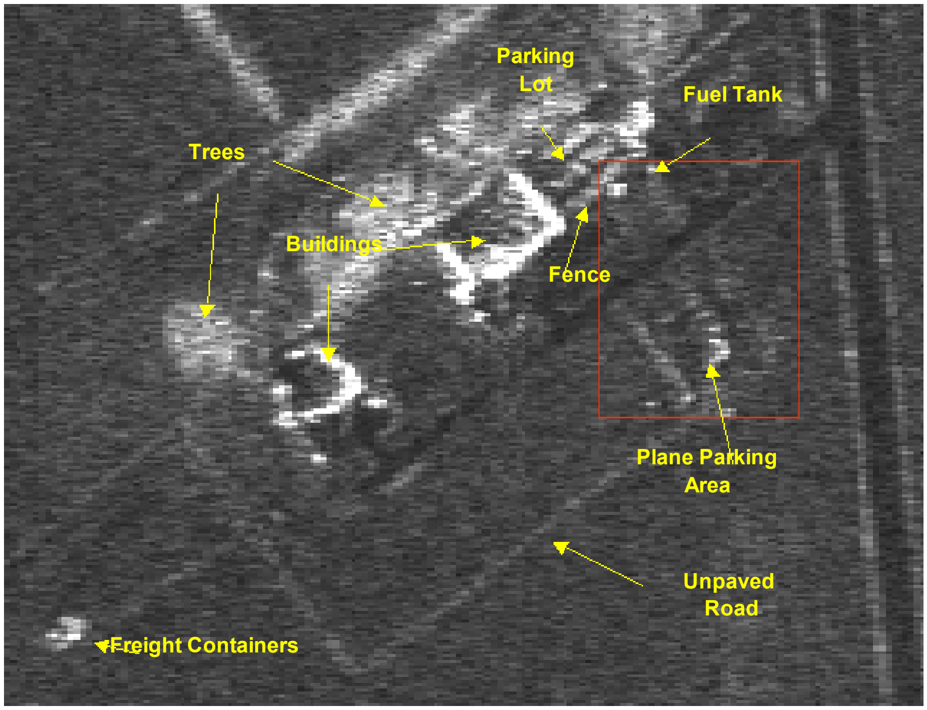

Figure 3. Synthetic Aperture Radar imagery of parked aircraft at Carp Airport, March 18, 1999

The Even and Odd Bounce basis can be used to transform the measured individual HH, HV (and VH), and VV radar returns into the parameters as shown below:[20 5]

$$E_{even} = \frac{|HH - VV|^2}{2} + 2|HV|^2 \quad (1)$$

$$E_{odd} = \frac{|HH + VV|^2}{2} \quad (2)$$

The underlying assumption for use in detection is that natural clutter is more likely to have more odd bounce while man made objects should exhibit more even bounce returns. Use of this detector alone is difficult since it is not easy to determine and validate the optimal threshold value to be used to extract objects with the highest even bounce which could be declared as possible targets.

4. CAMERON DECOMPOSITION

The Cameron Decomposition can be used to classify each pixel by the dominant type of scattering based on the physical scattering mechanism.[21 5] A metric has been developed by Cameron:

$$d(z_1, z_2) = \cos^{-1}\left[\frac{\max\left(\left|1 + z_1 z_1^*\right|, \left|z_1 + z_2^*\right|\right)}{\sqrt{\left(1 + |z_1|^2\right)\left(1 + |z_2|^2\right)}}\right]$$

This can be used to measure the similarity between a model and the data where z_1 and z_2 represent respectively contributions from the model and the scattering data (as presented in the scattering matrix values.

5. COMBINED APPROACH

These three methods of processing were examined at CCRS and applied to the test data obtained by the C-SAR polarimetric system. It was found that the optimal method uses all three, but, in a modified approach to select the potential target locations (Figure 4).

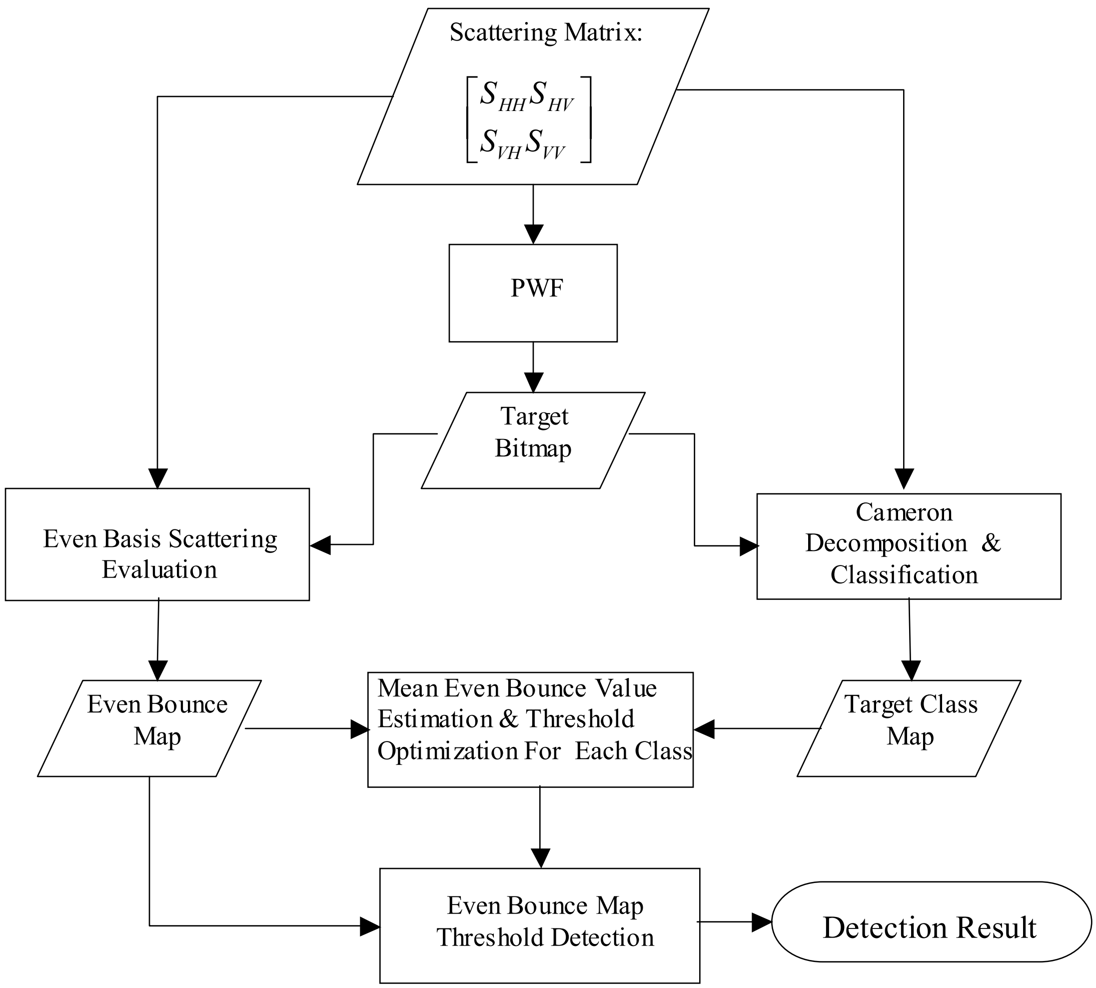

Figure 4. Test algorithm used for detection of aircraft in SAR imagery.

The algorithm begins with the formation of a PWF image and thresholding of the result. Then, the Cameron Decomposition and classification is applied to components selected by this thresholding. This is used to select those targets that are symmetric and have dihedral or narrow dihedral signatures. The next step is to determine the Even Bounce parameter value again for only those pixels selected by thresholding of the PWF image. The fourth step is to compute the average Even Bounce value for all pixels which are classified as corresponding to dihedral and narrow dihedral targets by application of the Cameron Decomposition. This average value is then used to determine a threshold to select candidate pixels in the Even Bounce "scene". An iterative method is implemented which determines the optimal threshold value to apply to the Even Bounce scene that will highlight pixels classified as dihedral and narrow dihedral targets and having high "even bounce" values.

Results presented in Figure 5 corresponding to the image of Figure 3 show that man-made targets have been detected and classified as dihedral or narrow dihedral targets (which thus could be aircraft) based on their polarimetric

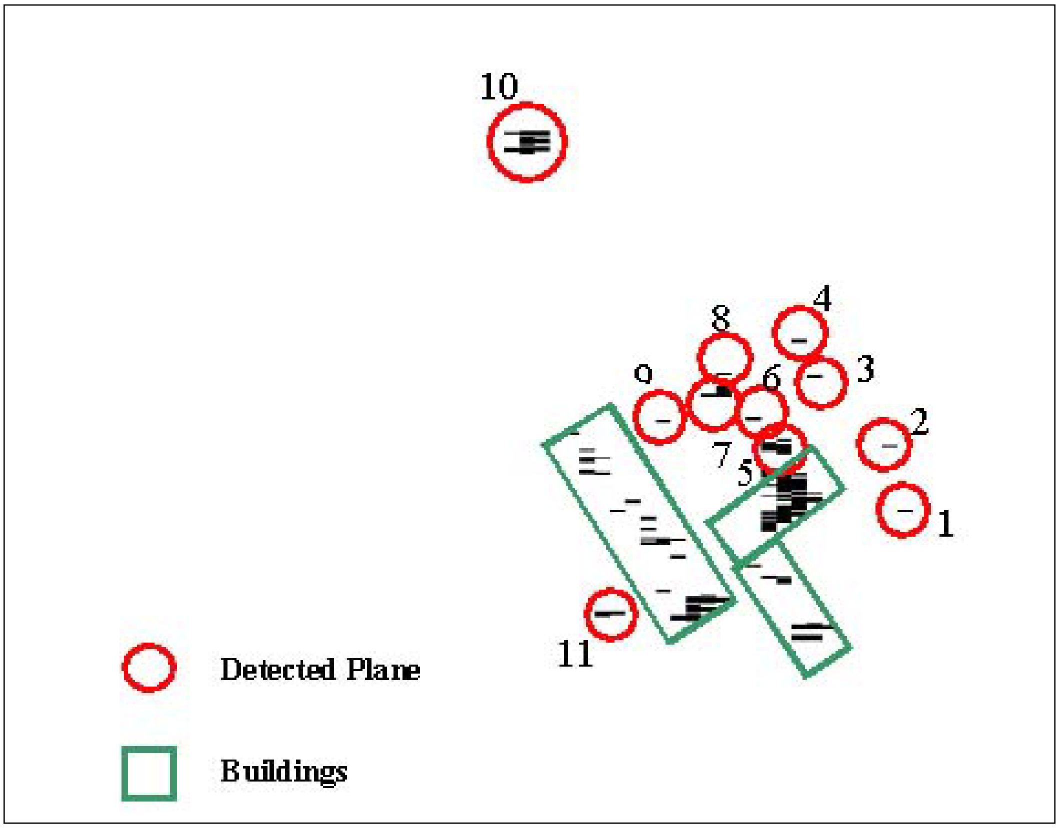

Figure 5. Detection of parked aircraft at North-East side of Carp Airport, March 18, 1999 corresponding to Figures 2 and 3.

signatures: Results for another part of the airport are presented as well in Figure 6. This study was complicated by the proximity of a number of other man-made targets (buildings) which are not expected to cause such difficulty in an actual search. Further study and development using this methodology are ongoing.

CONCLUSIONS

These examples show potential uses of Synthetic Aperture Radar systems for detection of man-made targets, in particular, aircraft, to assist Search and Rescue in Canada. It is believed that the number of dihedrals in a crashed aircraft would in fact increase compared to these test cases. Further studies including acquisition and testing of imagery of crashed aircraft are in progress. Algorithm development is continuing.

Considerable development is required to move from these results to an operational capability for detection of crashed aircraft. There will soon be an increase in available spaceborne Synthetic Aperture Radars (including RADARSAT-2) with more complex operating modes. It is hoped that they can be of assistance so that the possibility of saving lives and mitigating the effects of aircraft crashes will thus improve.

ACKNOWLEDGEMENTS

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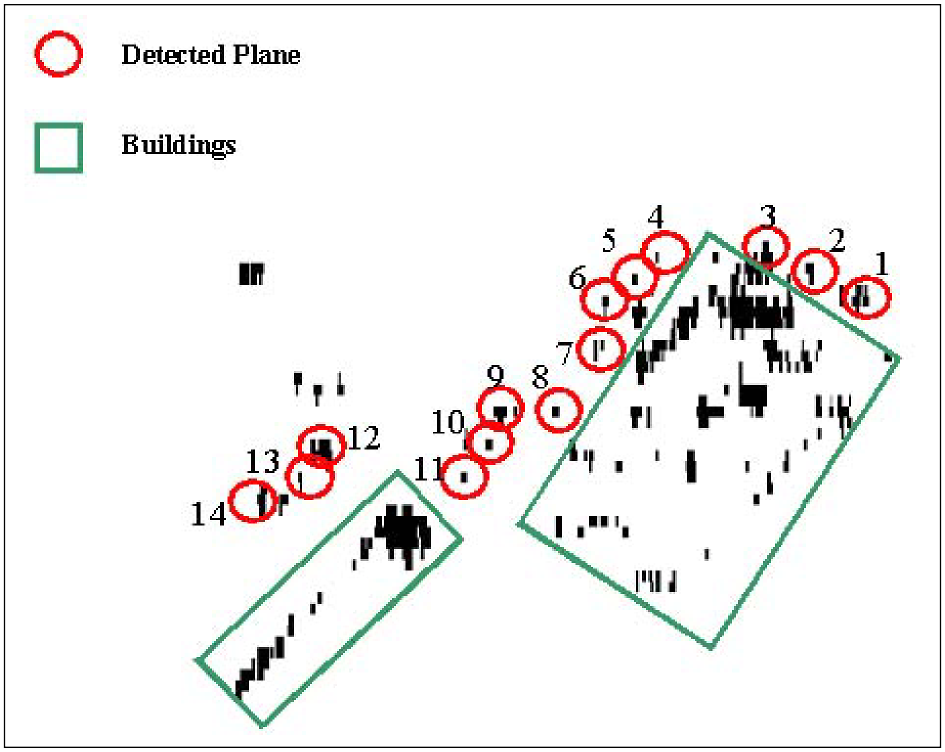

Figure 6. Detection of parked aircraft at North-West side of Carp Airport, March 18, 1999

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REFERENCES

1. A good introduction to Search and Rescue in Canada is given in:
http://www.dnd.ca/menu/SAR/eng/index.htm

2. National Search and Rescue Manual (B-GA-209-001/FP-001, DFO 5449) Issued on Authority of the Chief of the Defence Staff and the Minister of Fisheries and Oceans, May 1998.

3. R. Dreibelbis, D.W. Affens, H. Rais, and A.W. Mansfield, "The Montana Project," *Proceedings of SPIE Conference on Automatic Target Recognition IX*, *SPIE Vol. 3718*, F.A. Sadjadi, Ed., Orlando, Florida, pp. 2221-2229, 1999.

4. B.M. Burns, *The Climate of the Mackenzie Valley - Beaufort Sea Volume I,* Climatological Studies, Number 24, Environment Canada, Atmospheric Environment Service, Toronto, Canada, p. 22, 1973.

5. C.R. Jackson, H. Rais, and A.W. Mansfield, "Polarimetric target detection techniques and results from the Goddard Space Flight Center Search and Rescue Synthetic Aperture Radar (SAR^2) program*," Proceedings of Automatic Target Recognition VIII*, *SPIE Vol. 3371*, F.A. Sadjadi, Ed., Orlando, Florida, pp. 185-193, 1998.

6. W.E. Sivertson Jr., *A Global Search and Rescue Concept Using Synthetic Aperture Radar and Passive User Targets NASA Technical Report NASA -TN- D-8172*, NASA Langley Research Center, Hampton, Va., U.S.A., 31p., 1976.

7. R.G. Wallace, D.W. Affens, H. Rais, " Beaconless Search and Rescue Overview - History, Development, and Achievements," *Proceedings of Automatic Target Recognition VII, SPIE Vol. 3069,* F.A. Sadjadi, Ed., pp.162-166, 1997.

8. The work of the SAR^2 Project in the Search and Rescue Mission Office of NASA GSFC can be found on the website at http://poes.gsfc.nasa.gov/sar/becnless.htm . A number of publications from this group and related work have appeared in *Automatic Target Recognition VII, SPIE Vol. 3069*, F.A. Sadjadi, Ed., 1997, *Automatic Target Recognition VIII, SPIE Vol. 3371*, F.A. Sadjadi, Ed., 1998, *Automatic Target Recognition IX, SPIE Vol. 3718*, F.A. Sadjadi, Ed., 1999, and *Automatic Target Recognition X, SPIE Vol. 4050*, F.A. Sadjadi, Ed., 2000.

9. The work of the project at RMC can be found in a number of publications including C.J. Cunningham, W. Millett, and P.W. Somers, "Multispectral Satellite Imagery for Search and Rescue," *Proceedings of the 8th CASI Conference on Astronautics*, pp. 97-99, 1994, K.A. M. Creber, A.R. Green, E.A. Ough, and V. Singh, "A Comparison Study of Data from RADARSAT, Landsat, A Multispectral Camera, A Field Portable Spectrometer and A High Resolution UV-Vis-NIR Spectrometer," *Proceedings of the International Symposium on Geomatics in the Era of RADARSAT*, 5p., 1997, and, V. Singh, J.R. Buckley, and P. Somers, "Evaluation and Validation of RADARSAT Imagery for National Defence Air and Land Operations, Centre for Space Research, RMC, Technical Report CSR96-01, 12p., 1996.

10. B.Gilliam, S.W. McCandless, Jr., L. Reeves, and B.D. Huxtable, "RADARSAT-2 for Search and Rescue," *Proceedings of Automatic Target Recognition IX, SPIE Vol. 3718,* F.A. Sadjadi, Ed., Orlando, Florida, pp. 189-194, 1999.

11. "Earth and Environment, RADARSAT 2 Information: Data Products," http://www.space.gc.ca/csa_sectors/earth_environment/radarsat2/rad_inf/dat_pro/default.asp

12. Canadian Space Agency, RADARSAT Swath Planner Ver 3.1.

13. http://radarsat.mda.ca/products/

14. It is not expected that the capability to image on either side of the ground track will be used routinely for a single satellite (e.g. RADARSAT-2), but, when more than a single satellite is available, this is one method to provide the capability for an increased number of imaging opportunities.

15. T.I. Lukowski and F.J. Charbonneau, "Synthetic Aperture Radar and Search and Rescue: Detection of Crashed Aircraft Using Imagery and Interferometric Methods," submitted to *Canadian Journal of Remote Sensing*, 22p., December 2001.

16. C.R. Jackson and H. Rais, "Detection of aircraft crash sites from space using fully polarimetric SIR-C SAR imagery for Search and Rescue applications," *Proceedings of Automatic Target Recognition IX*, *SPIE Vol. 3718*, F.A. Sadjadi, Ed., Orlando, Florida, pp. 213-220, 1999.

17. C.E. Livingstone, A.L. Gray, R.K. Hawkins, P.W. Vachon, T.I. Lukowski, and M. Lalonde, "The CCRS Airborne SAR Systems: Radar for Remote Sensing Research," *Canadian Journal of Remote Sensing*, Vol. 21, No. 4, pp. 468-490, 1995.

18. C.E. Brown, M.F. Fingas, and W.C. Bayer, "The Future of the Convair 580 SAR Facility," *Proceedings of the 21st Canadian Symposium on Remote Sensing*, Ottawa, Ontario, pp. I-463 - I-467, 1999.

19 L.M. Novak, M.C. Burl, and W.W. Irving, "Optimal Polarimetric Processing for Enhanced Target Detection," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 29, No. 1, pp. 234-243, 1993.

20. D.E. Kreithen, S.D. Halversen, and G.J. Owirka, "Discriminating Targets from Clutter," *The Lincoln Laboratory Journal*, Vol. 6, No. 1, pp. 25-51, 1993.

21. W.L. Cameron, N.N. Youssef, and L.K. Leung,"Simulated Polarimetric Signatures of Primitive Geometrical Shapes," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 34, No.3, pp. 793-803, 1996.