Potential of Road Stereo Mapping with RADARSAT Images

ABSTRACT

Two stereo pairs generated with standard mode images (S1-S7 and S4-S7) and one with fine mode images (F1-F5) are used to evaluate the potential of RADARSAT-SAR for extracting planimetric features, such as roads on a PC-based stereo workstation. First, monoscopic and stereoscopic plotting for the GCPs are performed to evaluate the impact on the accuracy. It is prerequisite, especially for smaller intersection angle stereo pairs, to acquire GCPs in stereoscopy since monoscopic collection mode degrades the relative and absolute orientations of the stereo model with a ratio of two to four depending of the stereo geometry. The roads are then interactively stereo extracted by an operator and compared with the roads of the digital topographic maps. Statistical results over a large sample (more than 900 km) show accuracy of about 15-24 m for fine mode and 25-50 m for standard mode stereo-pairs with 90% confidence levels, independently of the stereo configuration. The impact of image sampling on the road positioning accuracy is also addressed. Finally, comparisons with the ortho-rectification process show that the stereoscopic method to extract planimetric features is slightly more accurate.

1 INTRODUCTION

In the 1960's, stereoscopic methods (La Prade, 1963) were first applied to radar images to derive ground elevation leading to the development of radargrammetry. Unfortunately, research uncovered contradictions and a dichotomy between error propagation theory and practical results, particularly over high relief areas (Leberl *et al.*, 1988). These contradictions combined with the lack of stereo radar pairs led to the relative decline of radargrammetry.

The launch in 1995 of Canada's first earth observation satellite, RADARSAT with the various operating modes of the Synthetic Aperture Radar (SAR) and its specific geometric characteristic (Figure 1) (Parashar *et al.*, 1995) has turned the tide. It is the first commercial radar system from which true stereoscopic images can be generated at different resolutions and from its wide range of incidence angles (from 10º to 60º). It thus enables us to take advantage of various geometry and radiometry of stereo images for the three-dimensional (3D) representation of the terrain (Figure 2). However, the opposite-side stereo configurations can only be realized over terrain with rolling topography and slopes smaller than 5° (Toutin, 1999).

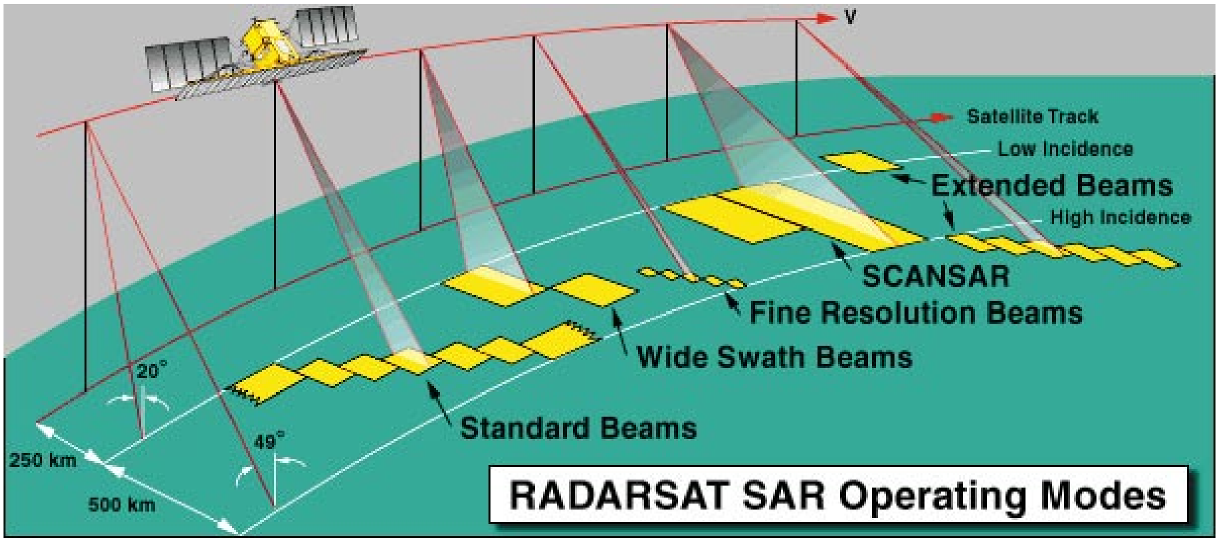

Figure 1. Operating modes of RADARSAT-SAR.

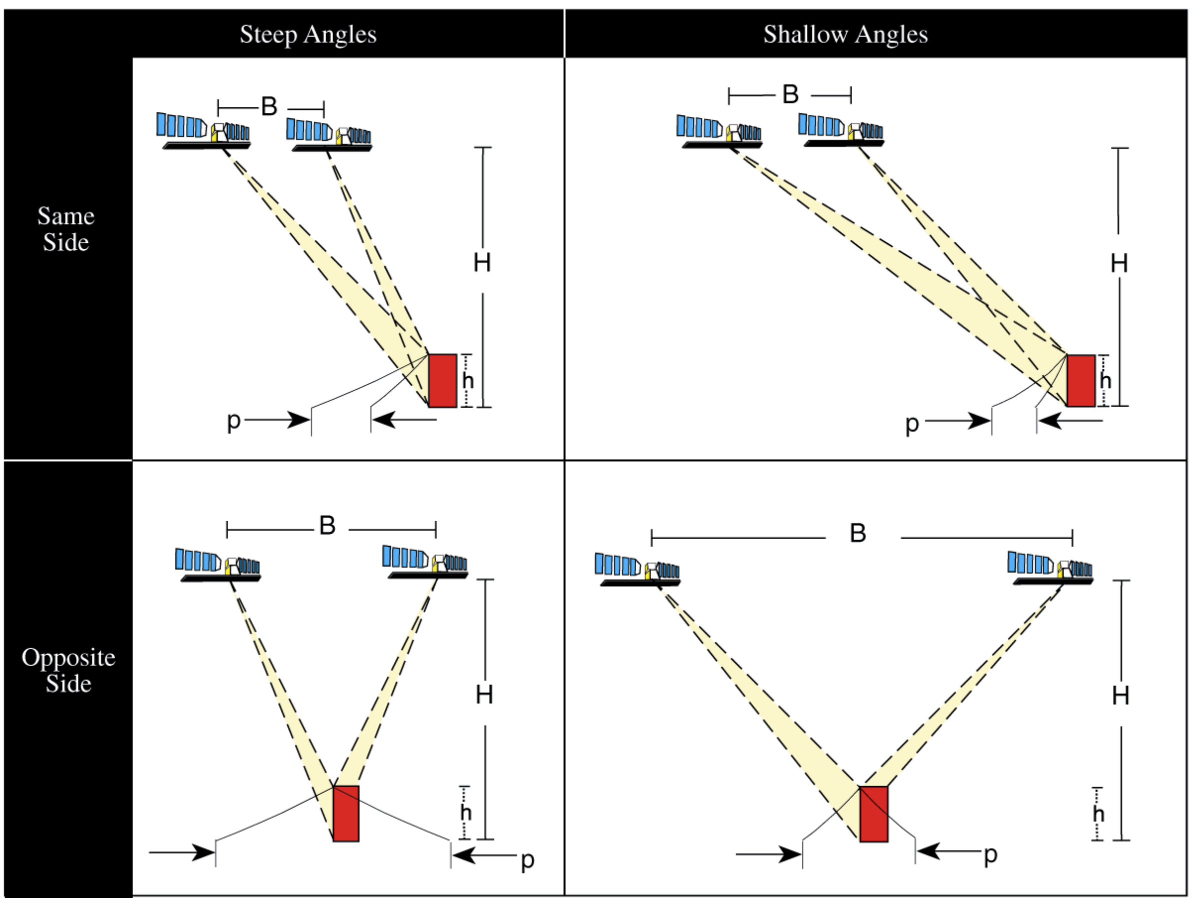

Figure 2. Various configurations of RADARSAT-SAR stereo pairs.

Because of the variety and the operational availability of stereo pairs, radargrammetry has once more become a hot R&D topic. Unfortunately, stereo-radargrammetry is only used for digital model elevation (DEM) extraction in the international research communities. By analogy with photogrammetric stereoscopic methods, it also could be used to extract planimetric features from a digital stereo workstation without *a priori* existing elevation information. In extracting of planimetric features, why is it important that the third dimension be conveyed? Humans are naturally able to see in three dimensions. The "naturalness" of a 3D representation of reality enhances our ability to interpret two-dimensional imagery. Cartographers, engineers, geologists, hydrologists, and other geo-scientists, use different three-dimensional viewing methods to perceive the ground elevation to better understand the Earth's surface. For example, representation of the third dimension of the terrain relief supplies important information about the relationship between land shape and structure, slopes and waterways, surface material and vegetative growth. Consequently, subtle features not discernible in a single SAR image are often recognized in stereo images combining the radiometry of the two images and the relief perception.

Few qualitative and quantitative results have been published on cartographic feature extraction from RADARSAT images. Sempere (1998) made a quantitative evaluation of the image content of ortho-rectified RADARSAT images in a French operational context for topographic mapping and digital data base updating. He noticed a small potential for mapping planimetric features (roads, railroads) at 1:100,000-map scale in developed countries due to the high density of communications network. Although the ortho-rectified RADARSAT images are compatible with the planimetric precision at this scale, important fieldwork should be required to resolve the omission and commission errors. Nevertheless, such mapping applications remain possible for developing countries, which are often difficult to survey with optical sensors due to perennial cloud cover. However, the SAR ortho-rectification process requires precise DEM, which are rarely available in these countries. Figure 3 shows the relationship between the DEM accuracy, the viewing angle of the SAR image, and the resulting error generated on the ortho-image (Toutin and Rivard, 1997). As an example, a 20-m elevation error due to the DEM accuracy and the interpolation into the DEM generates a positioning error of 60 m and 20 m on the standard-1 (S1) and fine-5 (F5) ortho-images, respectively.

Stereoscopy is thus an important issue in countries where precise DEM and maps are not available. Stereo-radargrammetry has been proven to be more accurate for planimetric feature extraction, because the feature positioning is not affected by any elevation error in the stereo compilation (the operator plots at the vertical of the point) (Toutin, 1997). Furthermore, since the stereo-restitution is directly done on the raw images, no resampling, such as in the ortho-rectification process, degrades the image radiometry, geometry and interpretability.

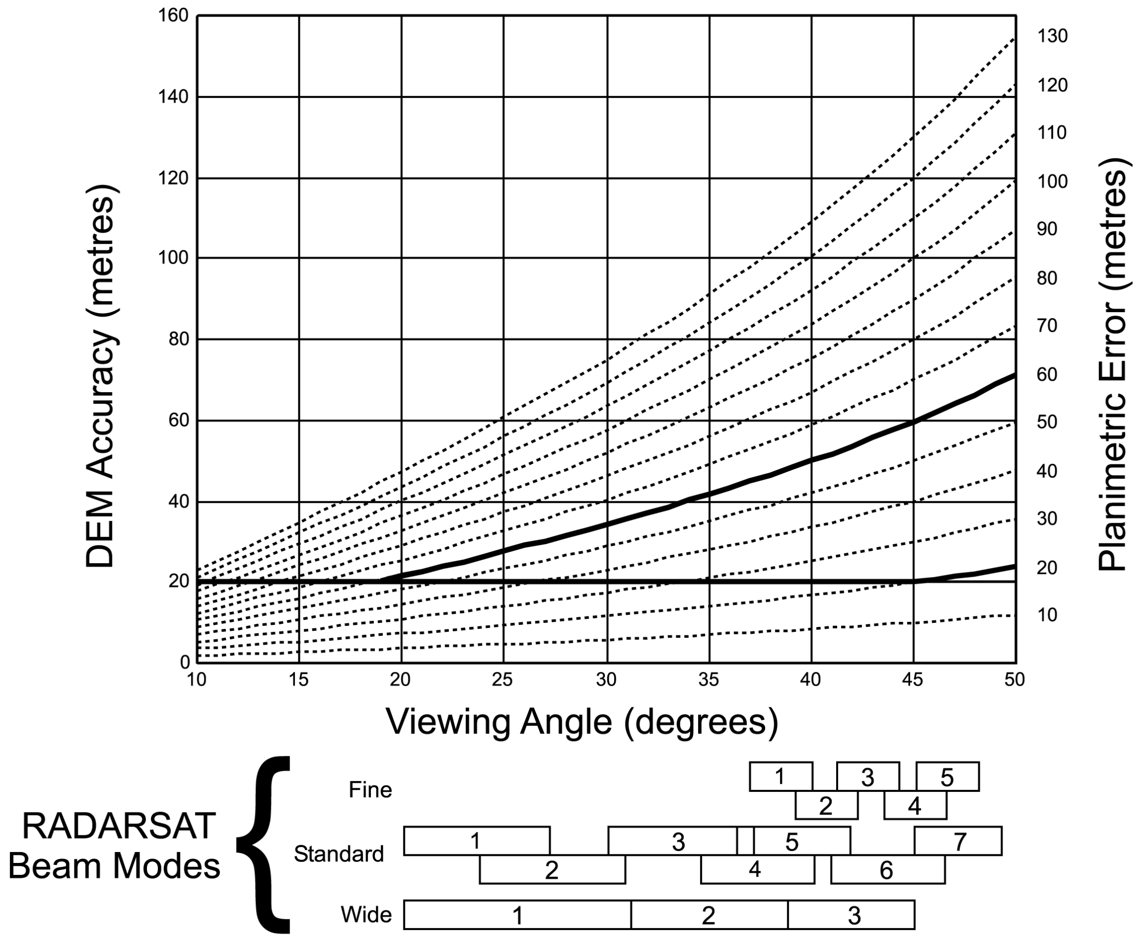

Figure 3. Relationship between the DEM accuracy, the viewing angle of the SAR image, and the resulting error generated on the ortho-image. The different boxes at the bottom represent the range of viewing angles for each RADARSAT beam mode.

As a result, researchers at CCRS have undertaken an exhaustive study under the Applications Development and Research Opportunity (ADRO) program sponsored by the Canadian Space Agency (CSA) to evaluate the parameters, which enable a general understanding of radar stereoscopic capabilities for mapping applications. First results have been presented for the geometric evaluation (Toutin, 1998) and for DEM generation (Toutin, 1999). The objectives of this paper is to present the evaluation of the RADARSAT potential for planimetric feature extraction using stereo-radargrammetry. The image content and the positioning accuracy are analyzed as a function of different geometric and radiometric parameters: the type of roads, the RADARSAT beam modes (fine, F and standard, S), the stereo configuration (small and large intersection angles), the look direction (east or west). Finally, a last comparison is done with the same features extracted from an ortho-rectified S1 image.

2 STUDY SITE and DATA SET

The study site is located in the Sherbrooke region, Quebec, Canada. This area is characterized by a rolling topography with an altitude variation of about 450 metres with up-to-40º slopes in the alpine ski resorts. Stream bank slopes and glacial formations with drumlins and ridges indicate NE-SW ice advance, and NE-SW lineaments and folds are probably related to the structural trend of the region. The land cover is a mixture of coniferous and deciduous trees with large areas of agricultural land. Different types of water body are found: lakes, ponds, rivers and creeks. The topographic data are the Sherbrooke Data Set in the province of Quebec (Canada) for the topographic applications of remote sensing (Lassere et Lemieux, 1990). The study site covers approximately a 1 : 50,000 map sheet and represents land coverage of about 40 km by 26 km (Figure 4).

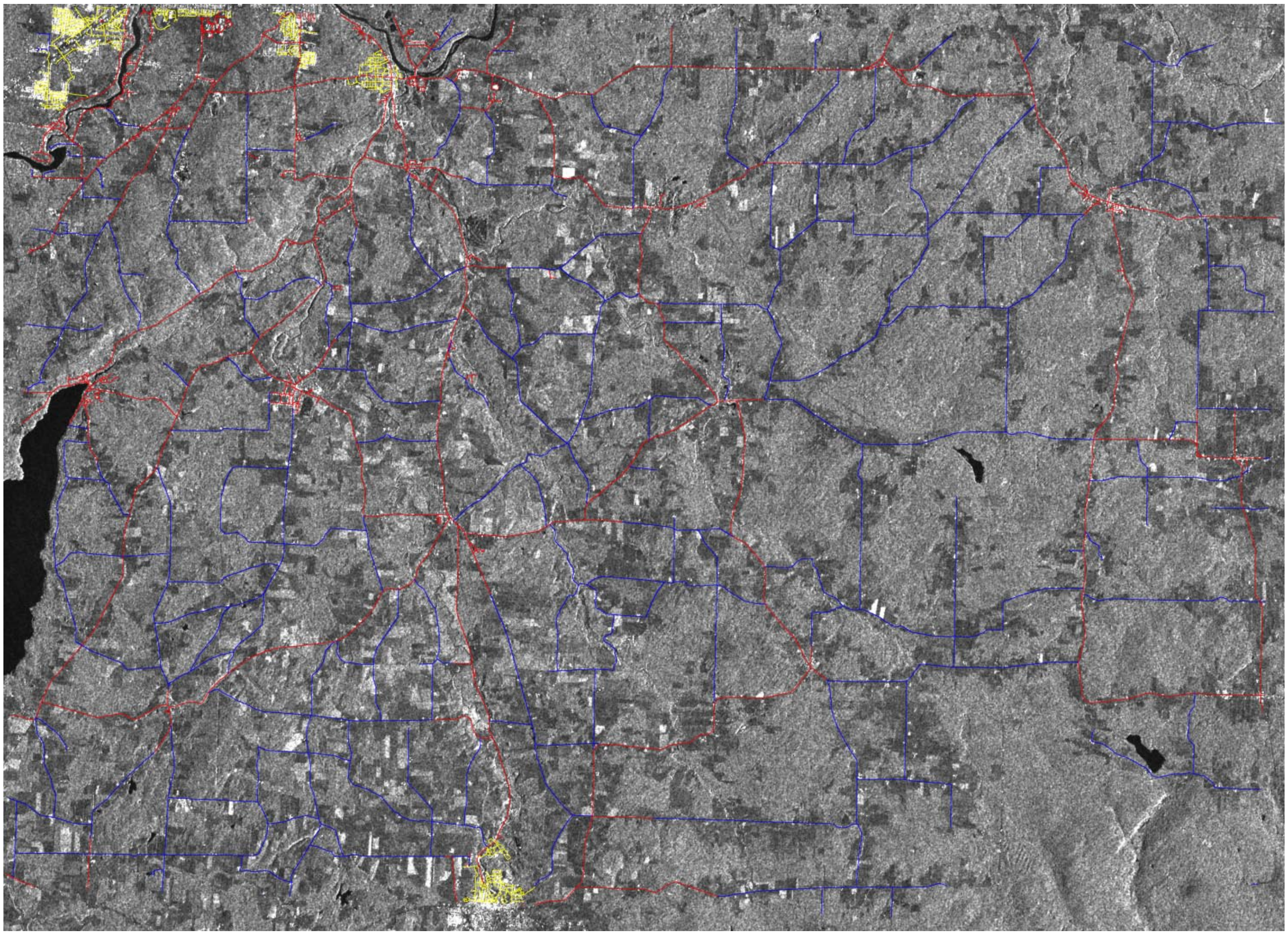

Figure 4. Ortho-rectified F5 RADARSAT-SAR fine mode image with main (in red), secondary (in blue) roads and city streets (in yellow) overlaid. RADARSAT Image: Courtesy of CSA, 1996.

The digital cartographic data used in this experiment was produced by Geomatics Canada and are:

- 235 reference points which have been obtained from photogrammetric triangulation using an STK-1 stereocomparator for the photo-measurements. The root mean square error of the cartographic coordinates are better than three metres. These points are mainly intersections of expressways, highways, roads, streets or railroads;

- the vector data of the digital topographic map. All the elements are positional data, as observed on the surface of the Earth in X, Y and Z coordinates and without movement of the element due to cartographic generalization. They have been stereo-compiled (B8-S, 2^{nd} order) in 1986-87 from aerial photographies taken in 1985. The field completion was done in 1985-86. The positioning accuracy of the data is in the order of five meters. These data are unstructured (without topology) and are not cleaned (errors of closure and of segmentation at the intersections); and
- A DEM with 50-m grid spacing generated from 10-m contour lines and geomorphologic features (thalwegs, crest lines and lakes). Its accuracy is in the order of five metres.

Figure 4 displays an ortho-rectified RADARSAT-SAR fine mode image with the main, secondary and city roads from the topographic files. The dark lines represent the main roads with hard-surface all-weather two lanes (300 km of total length); the white lines are the secondary roads with loose or stabilized surface all-weather and two lanes or less (530 km of total length). The other white lines regrouped in the northwest part are the "unclassified city streets" (90 km of total length). The digital file of roads also includes hard-surface all-weather dual highways (6 km of total length).

The image data set used in this experiment includes five RADARSAT images (C-band, HH-polarization) acquired over the Sherbrooke region, Quebec, Canada of the twelve images acquired under the ADRO program sponsored by the CSA:

- Two fine mode images, single-look processing, F1 and F5 acquired from ascending orbit the 20/10/96 and 8/6/96 with look angles of 37º-40º and 45º-48º, respectively;
- Three standard mode images, four-look processing, S1, S4 and S7 acquired from descending orbit the 24/10/96, 14/10/96 and 22/10/96 with look angles of 20º-27º, 34º-40º and 45º-49º, respectively.

The SAR ground range resolution cell is 7.8 to 9.1 m in range by 8.4 m in azimuth for the fine mode and it is 20 to 26 m in range by 27 m in azimuth for the standard mode. The images are generated in the Path Image format: ground range presentation (ellipsoid projection without relief correction), aligned to the satellite's orbit path, with a 6.25-m and 12.5-m pixel spacing for the fine and standard modes respectively, and coded in 16 bits. We can notice that the fine mode images are undersampled and the standard mode images oversampled relatively to their SAR resolution cell according to the Nyquist law. Table 1 summarizes the RADARSAT data set. They are then used to create three different stereo pairs in fine (F1-F5) and coarse (S4-S7 and S1-S7) resolution with small and large intersection angles, about 8º, 10º and 23º at the centre of the stereo models, respectively.

Table 1. General characteristics of the RADARSAT images data set over the Canadian study site

Mode and Beam	**Acquisition Date**	**Orbit**	**Look Angles**	**Ground Coverage**	**Ground Resolution**	**Pixel Spacing**
Fin F1	20/10/96	Asc.	37° - 40°	50 x 50 km	9.1 x 8.4 m	6.25 x 6.25 m
Fin F5	08/06/96	Asc.	45° - 48°	50 x 50 km	7.8 x 8.4 m	6.25 x 6.25 m
Standard S1	24/10/96	Desc	20° - 27°	100 x 100 km	26 x 27 m	12.5 x 12.5 m
Standard S4	14/10/96	Desc	34° - 40°	100 x 100 km	25.7 x 27 m	12.5 x 12.5 m
Standard S7	22/10/96	Desc	45° - 49°	100 x 100 km	20.1 x 27 m	12.5 x 12.5 m

3 EXPERIMENT

The experiment is realized in four main processing steps: the transfer of the digital data to the stereo workstation, the stereo model set-up, the road extraction and the transfer to the vector-based system.

3.1 Transfer of the Digital Data to the Stereo Workstation

The RADARSAT data were read from magnetic tapes, linearly stretched from 16 bits to 8 bits and transferred to the stereo workstation, the DVP. The DVP (Digital Video Plotter) was developed by Laval University, Quebec, Canada for air photos (Gagnon *et al.*, 1990) and in collaboration with CCRS for SPOT images and further adapted at CCRS for SAR images (Toutin, 1995, 1999). Ephemeris data are also read and preprocessed to initialize the geometric modelling. No speckle filtering were applied since previous research demonstrated that although the speckle creates some confusion in stereo-plotting, it does not degrade the feature extraction since the human stereo-viewing "behaves like a filter" (Banner and Ahern, 1996; Dowman *et al.*, 1997).

3.2 Stereo Model Set Up

The stereo model set-up, based on a geometric modelling, is the mathematical reconstruction of the 3D-terrain model. The geometric modelling used in this experiment is a CCRS developed parametric model already tested on different stereoscopic data sets (Toutin, 1995). The stereo model set-up is computed with an iterative least squares bundle adjustment (relative and absolute orientations together), that enables the parameters of the geometric model to be refined with ground control points (GCPs) and tie points (Toutin, 1995). The GCPs have to be collected with stereoscopic plotting (Toutin, 1999). The main advantage of the stereo viewing is the improvement of both ground points location and information extraction by integrating simultaneous plotting, general relief perception and backscatter of both images, This permits to combine both geometric and radiometric aspects. However, since most of radar commercial workstations, if not all, does not have full stereoscopic capabilities, the GCPs are also acquired in monoscopy to evaluate the impact of the GCP image positioning errors generated by the monoscopic collection method.

3.3 Road Extraction

The road extraction follows the stereo model set-up. Since the geometric modelling formulation (exterior orientation) and its inversion are straightforward one does not need to resample the images in a "common quasi-epipolar geometry", and the real time loop does not need a powerful real time processor, which has facilitated the implementation method on a low-cost PC. Different types of roads (highways, main roads, secondary roads, and city streets) are then interactively stereo extracted by an operator from 6.25-m and 12.5-m pixel spacing raw images for the fine and standard mode stereo pairs, respectively. The digitizing accuracy is in the order of 1-2 pixels.

The control of image positioning then follows the dynamic change to cancel the Y-parallax from the raw imagery, and retains real time performance in the stereo viewing and plotting. When the operator eliminates the X-parallax to fuse the two floating marks of the measured point, a 3-D stereo-intersection is performed. Cartographic co-ordinates (planimetry and height) in the user defined map projection system are determined in real time for the measured point using a least squares intersection process (four equations with three unknowns) based on the equations and parameters of the geometric modelling. The results of this road extraction step are files with XYZ ground coordinates in the user map reference system. A descriptive code is also attached for each road.

3.4 Transfer to the Vector-Based System

The XYZ files are transferred to the ESRI ArcInfo geographic information system (GIS) using a bi-directional translator. The vector data, both topographic and DVP files, are cleaned and edited using different GIS functions. The extracted roads are quantitatively compared with the digital topographic maps (accuracy of 5 m). For each extracted feature, a first comparison is done between the topographic file and the DVP file to compute the omission errors. The omission error comes from the under-estimation due to the image content. In a second step, buffered zones of 3, 6, 9, 12, 15, 20 and 30 metres centred on the topographic file were generated. These buffered zones act as corridors "parallel" to the topographic feature at different distances; they are used to quantify the cumulative distance of stereo-extracted features within each zone. The percentage for each zone and the cumulative percentage of linear distance can then be computed, and then the accuracy with 68% and 90% level of confidence.

4 RESULTS and DISCUSSION

4.1 Stereo Model Set-Up Results

The first interesting result is related to the GCP collection method, which has an impact on the full processing. The number of GCPs of the 235 reference points acquired on each stereo pair vary according to the SAR image backscatter, which can affect the feature visibility and the shape and appearance of the targets. The image co-ordinate accuracy is one to two pixels for each image in the monoscopic collection method and one pixel in the stereoscopic collection method. Although the minimum number of GCPs is 4-6, 180 GCPs for the fine mode and 130-135 GCPs for the standard mode were acquired and used for the stereo model set-up. Since the general results on the geometric accuracy of RADARSAT data have been presented in details, such as number, density and spatial distribution of GCPs, etc. (Toutin, 1998), only the tests related to the GCP collection method are presented. Table 2 provides the root mean square residuals from the least squares adjustment of the stereo model set-up computed with the GCPs extracted with the monoscopic or stereoscopic collection method.

Table 2. Root mean square residuals (RMSR in metres) from the stereo model set-up with the monoscopic and stereoscopic GCP collection method

Stereo-pair	GCP Collection Method					
	Monoscopic			Stereoscopic		
RMSR (metres)	R_X	R_Y	R_Z	R_X	R_Y	R_Z
F1-F5 (180 GCPs)	34	7	32	9	5	7
S4-S7 (130 GCPs)	82	18	85	20	12	16
S1-S7 (135 GCPs)	38	17	31	18	11	11
S1 (132 GCPs)	27	21		19	13	

As we can notice on Table 2, the residuals for the stereoscopic collection method are in the same order of magnitude of the GCP accuracy (1-2 pixels). They represent an *a-priori* stereo mapping error and are then a good indication of road extraction errors. As a consequence, these RADARSAT-SAR stereo-models are generated without Y-parallax (less than one pixel). Furthermore, collecting the GCPs in monoscopy generates X- and Z-residuals in the stereo model set-up two to four times larger than collecting them in stereoscopy. The main reason is purely geometric since the GCPs are relatively well-defined targets in the SAR images (road and railway intersections). When they are independently collected with 1-2 pixel accuracy, it generates artificial parallaxes (in column and line) between the two images, which propagate through the exterior orientation of the stereo model, mainly in the X and Z directions. It does explain why the X-residuals are much larger than the Y-residuals. Due to same-side stereo geometry, the error increases with smallest intersection angles and shallowest viewing angles such as with F1-F5 or S4-S7. In fact, for these equivalent stereo-pairs (same viewing and intersection angles), the degradation in X- and Z-directions is approximately the same and proportional to the SAR resolution: one resolution in stereoscopy versus four resolutions in monoscopy.

In the case of stereoscopic collection method, it enables a better relative correspondence of the same GCP between the two images and better orientations of the stereo model, so that explains the smaller residuals. However, the X-residuals are also larger than the Y-residuals, due mainly to foreshortening in some images (S1, S4). For S1 image, the two tests were also realized, and the stereoscopic collection was made with S1-S7. One can notice that the results of the S1 image was improved using the GCPs collected in stereo. It confirms with SAR images previous results obtained with optical images than stereoscopic viewing improves the identification of points (Welch *et al.*, 1990; Heipke, 1995).

Consequently, the stereoscopic collection of GCPs with SAR stereo pair is a prerequisite before any feature extraction to avoid large error propagation in the stereo model and the extracted features. Consequently, the stereo pairs computed with the GCP stereo collection method were only used to extract the roads. These results are consistent with the theoretical analysis of error propagation, which demonstrates that the accuracy in range and elevation increases with the intersection angle (La Prade, 1963). This error analysis is only true when the geometric aspects are more important than the radiometric aspects, such as the case of GCPs definition and collection (Toutin, 1998).

4.2 Road Extraction Results

As mentioned previously the roads were separated into four categories according to 1 : 50,000 Canadian map standards: highways (four or more hard-surface all-weather lanes), main roads (two and more hard-surface all-weather lanes), secondary roads (two and more loose or stabilized lanes), and unclassified "city streets". The entire data set (more than 900 km of roads) is used in the statistical accuracy evaluation. From the comparison of the topographic roads and the extracted roads, the omission error and the circular errors with 68% and 90% confidence levels (CE68 and CE90) are computed for each stereo-pair F1-F5, S4-S7 and S1-S7 and are presented in Table 3.

Table 3. Omission errors, circular errors with 68% and 90% confidence levels, CE68 and CE90 of the road extraction for the stereo pairs F1-F5, S4-S7 and S1-S7

Stereo-pair	Road category	Omission	CE68	CE90
F1-F5	Highways	0 %	6 m	12 m
	Main	7.5 %	10 m	20 m
	Secondary	31 %	11 m	24 m
	City	7 %	9 m	17 m
S4-S7	Highways	24 %	18 m	29 m
	Main	34 %	17 m	37 m
	Secondary	48 %	17 m	40 m
	City	73 %	13 m	21 m
S1-S7	Highways	4 %	18 m	37 m
	Main	47 %	18 m	40 m
	Secondary	55 %	22 m	48 m
	City	73 %	10 m	18 m

Obviously, the omission errors are larger for the standard mode stereo pair for each category of roads due to the coarsest resolution cell (20 to 26 m in range by 27 m in azimuth, average 23 by 26 m). A comparison of two stereo pairs is given in Figure 5.

The errors are related to the physical characteristics (size, width), the definition (hard surface, loose or stabilized surfaces) and the visibility of each feature in the SAR images, but also are dependent of their surroundings. As examples, the highways are easier to perceive in the fine mode stereo pair because they are long strait lines with more than three-to-four image pixels wide (Figure 5; letter a). The strong backscatter due to light standards in the middle of the highways is also very helpful for their identification. On the other hand, they were not easily identifiable on S4 and S7, but better on S1 (Figure 5; letter c), that explain the better omission result for S1-S7. For the city streets, the houses in the city act as dihedral corner reflectors with also a strong backscatter from sloped roofs (Figure 5; letter b); the higher contrast better defines the city streets in the fine mode stereo-pair. In the other hand, the coarse resolution of standard mode stereo-pairs induces difficulties in identifying this feature (less than 20-m width) (Figure 5; letter d).

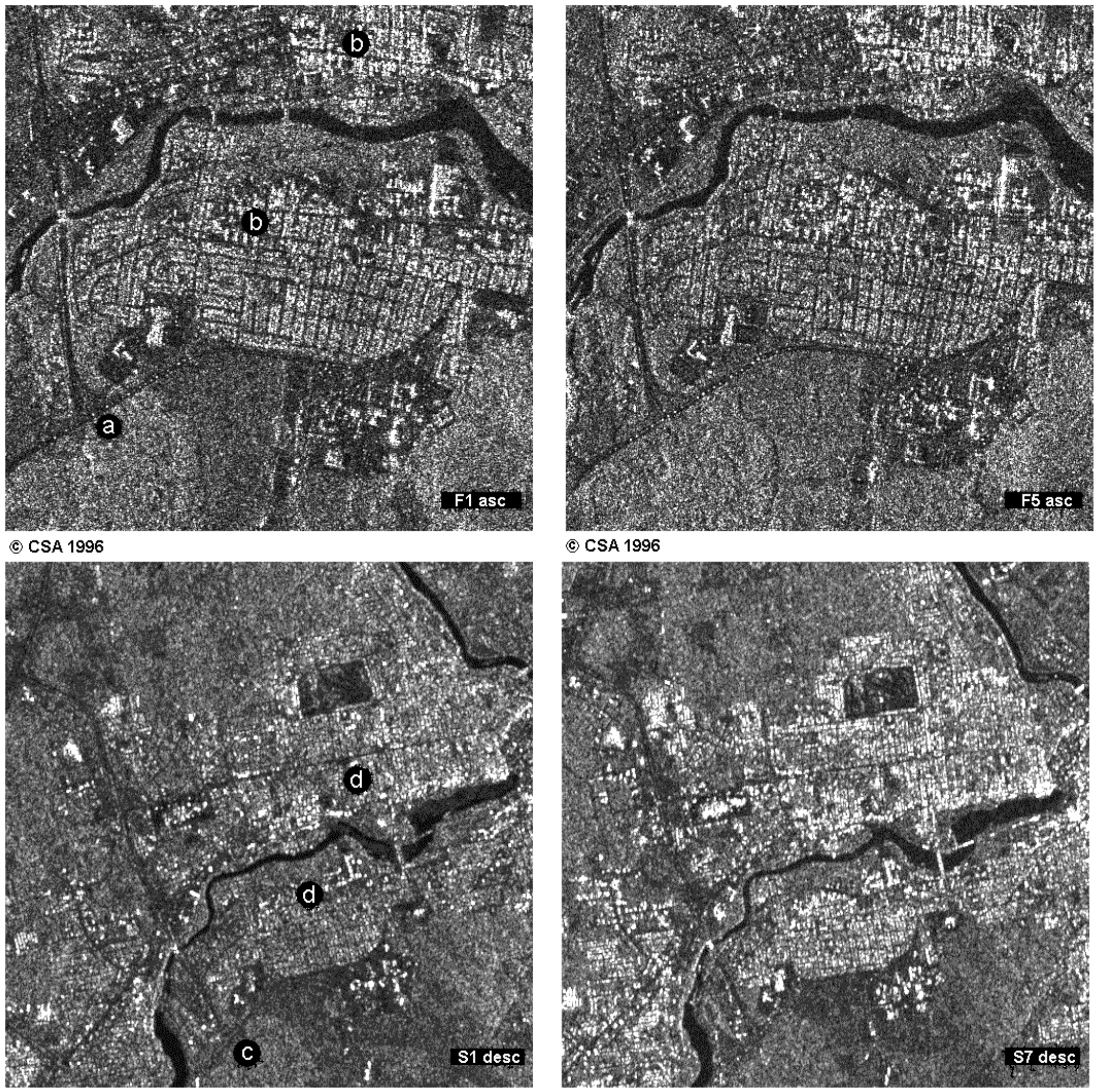

Figure 5. Comparison of two stereo pairs: F1-F5 (top) and S1-S7 (bottom). Letters “a” and “c” show locations of a highway with the strong backscatter due to light standards in the middle of the highways, only on F1-F5. Letters “b” and “d” show locations of city streets with the “double-bounce” due to the houses and the strong backscatter of the sloped roofs. RADARSAT Images © Canadian Space Agency, 1996.

The other results (CE68 and CE90) are related to the positioning accuracy of the extracted features. The errors are more and less the same for the main and secondary roads relatively to the SAR resolution cell: around one resolution cell for the CE68 and two to three for the CE90. Some exceptions are for the highways and the city streets. It is also about the same than the digitizing error (1-2 pixels). However, the standard mode stereo pair gives slightly better results relatively to the image resolution because the standard mode images are oversampled (12.5-m pixel spacing versus 20 to 26-m resolution cell) while the fine mode images are undersampled (6.25 m pixel spacing versus 8 m resolution cell). This confirms the first results of this ADRO research on the geometric and DEM accuracy of RADARSAT images (Toutin, 1998, 1999). It is also important to notice that the road positioning accuracy is independent of the intersection angles since the results with the two standard mode stereo pairs (10° and 23° intersection angles) are equivalent.

The same reasons given previously for the omission errors applied for the statistical results, such as the light standards in the middle of the highways. It is also obvious that the "double-bounce" due to the houses and the strong backscatter of the sloped roofs (Figure 5; letter b) have helped the positioning accuracy of the city streets with F1-F5, but also with the standard mode stereo pairs when they were identifiable (Figure 5; letter d).

The main differences in the results between the categories of roads, but also between the stereo pairs can be accounted for:

- the SAR resolution cell and the image pixel spacing;
- the different physical characteristics of roads related to the SAR and surface interaction; and
- the contrast within their surroundings (forest, bare soil, agricultural fields, houses, etc.), which determines the road limits.

Finally, the last results come from the traditional monoscopic method based on the ortho-rectification process: the S1 image was ortho-rectified using the existing DEM, and the roads were extracted with monoscopic plotting. The same method in the ESRI environment was used for the comparison with the topographic data and to compute the statistics. Table 4 gives a summary of the results from the road extraction for the ortho-image S1.

Table 4. Omission, CE68 and CE90 of the road extraction for the ortho-image S1

Ortho-image	Road category	Omission	CE68	CE90
S1	Highways	10 %	13 m	33 m
	Main	68 %	18 m	42 m
	Secondary	76 %	23 m	60 m
	City	85 %	15 m	27 m

The omission results and the positioning accuracy (mainly the CE90) are generally worse than with S1-S7, except for the accuracy of the well-identifiable highways (Figure 5; letter c). Since the CE90 differences between the two extraction methods are worse than the CE68 differences, it is also an indication of larger errors with the monoscopic extraction method. The degradation is also more important with smallest roads (secondary and city). It should be noticed that a precise DEM, which does not induce any significant positioning error, was used in the rectification. These general results confirm that stereoscopy improves the location and the extraction of targets or ground features by integrating the simultaneous compilation and superimposition, the general relief perception and the backscatter of both images. Combining both geometric and radiometric aspects of the images and the stereo pair, 3D representations then facilitate the interpretation of cartographic information compared to flat 2D representation.

5 CONCLUSION

Three RADARSAT stereo pairs with fine (F1-F5) and standard (S1-S7 and S4-S7) mode images have been evaluated for planimetric feature extraction in regard to cartographic applications. The digital topographic map (accuracy of 5 m) of the Sherbrooke region (Canada) has been used to validate the roads interactively extracted on a PC-based stereo workstation (DVP) adapted at CCRS for processing SAR stereo images.

First, tests were done to evaluate the impact of GCP collection method. Due to the 1-2 pixel plotting error on each image, artificial parallaxes in the stereo model are generated with the monoscopic collection method and degrade the relative and absolute orientations of the stereo pair with a ratio of two to four depending of the stereo geometry. It is more important for smaller intersection angle stereo pairs with shallow viewing angles. Since stereoscopy increases the location and collection accuracy of GCPs and then of the stereo model set-up, it is a prerequisite to use stereoscopic collection method before any feature extraction. The roads were then stereo-compiled only from stereo pairs computed with the stereoscopic GCPs. Comparison with the topographic data enables to compute the omission errors and the circular errors, CE68 and CE90.

The omission errors and positioning accuracy depend mainly on the definition, the visibility of each road category by itself and with its surrounding element (forest, bare soil, agricultural fields, houses, etc.) and the backscatter related to SAR and surface interaction. It varies from 0% for the highways extracted from F1-F5 stereo pair to 73% for the city streets extracted from S1-S7 or S4-S7 stereo pairs. Some completeness has then to be realized depending of the density of the communication network and the map scale. Positioning accuracies with 68% and 90% confidence level of about one resolution cell and two to three resolution cells respectively, were obtained. The stereo configurations (e.g., the intersection angles) do not have an impact on this accuracy.

Nevertheless, these road accuracy results obtained from the stereo compilation of fine and standard mode RADARSAT images are quite encouraging since they correspond to the positional accuracy standard of 1 : 50,000 and 1 : 100,000 paper maps, respectively. Due to an image oversampling, the results are better with the standard mode stereo pair relatively to its SAR resolution cell. Fine mode stereo pairs with oversampled pixel spacing, such as the Path Image Plus format with 3.125-m pixel spacing should be preferred to consistently ensure 10-m positioning accuracy for digital stereo mapping at 1 : 50,000 map scale.

Finally, the omission and the positioning error results of roads extracted from an ortho-rectified S1 image are a little worst: it confirms the superiority of the stereoscopic method when compared to the ortho-rectification method to extract planimetric features.

Acknowledgements

The RADARSAT images have been acquired under the ADRO program sponsored by the Canadian Space Agency. The author thanks Dr. Ridha Touzi of the Canada Centre for Remote Sensing and Dr. Costas Armenakis of the Canada Centre for Topographic Information for their review and Mr. René Chénier of Consultants TGIS inc. for the data processing.

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