SINGLE VERSUS STEREO ERS-1 SAR IMAGERY FOR PLANIMETRIC FEATURE EXTRACTION♥

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ABSTRACT

This Letter compares two conventional methods for the extraction of planimetric features: the monoscopic method, using an image and a digital elevation model to generate an ortho-image; and the stereoscopic method, using two images for the three-dimensional reconstruction of the stereoscopic model of the terrain. Feature extraction then occurs in mono or stereoscopic viewing, depending on the method used. When compared with the topographic data, accuracies of the lake shoreline extraction from ERS-1 SAR images show 22-m versus 17-m root mean square accuracies with 66% confidence for the monoscopic and stereoscopic methods, respectively. More consistency is also achieved with the stereoscopic method.

1. INTRODUCTION

Two conventional methods can be considered to extract planimetric information from remote sensing data (Figure 1):

- the monoscopic method which uses one image and a digital elevation model (DEM) to generate an ortho-image from which planimetric features with their 2-D map coordinates (XY) can be extracted; and
- the stereoscopic method which uses two images to generate a “virtual” stereo-model from which planimetric and altimetric features with their 3-D map coordinates (XY and/or Z) can be extracted.

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MONOSCOPIC METHOD	STEREOSCOPIC METHOD
Image + DEM (2D +1D)	Image + Image (2D + 2D)
⇓	⇓
Rectification Process	*Relative & Absolute Orientation Process*
⇓	⇓
Ortho - Image (2D)	"Virtual" Stereo-Model (3D)
⇓	⇓
Planimetric Feature Extraction	*Planimetric and/or Altimetric Feature Extraction*
⇓	⇓
XY Cartographic Co-ordinates (2D)	XY/Z Cartographic Co-ordinates (3D)

Figure 1. Description of the monoscopic and stereoscopic methods for planimetric feature extraction.

In the first method, the DEM has to be produced from any method (contour lines digitizing, images correlation, interferometry, etc.) with some errors. These errors will propagate through the rectification process and the planimetric features extraction. Furthermore, resampling during the rectification process degrades not only the image geometry and radiometry, but also the image interpretability.

In the second method, the use of two two-dimensional images results in an over estimation of the three-dimensional ground space. The XY cartographic coordinates of the planimetric features are computed independently of its altimetric coordinate, since the operator always plots in stereoscopy at the vertical of the point (Toutin, 1996). Consequently, the planimetric accuracy of feature positioning is not affected by any error on elevation. Furthermore, since the stereo-extraction is done directly on the raw images, no re-sampling degrades the image radiometry, geometry and interpretability.

This superiority of stereoscopic viewing is supported by biological evidence because stereoscopy is one of the main characteristics of the human vision. Indeed, research in psychology related to human vision and depth perception has shown that the qualitative interpretation of cartographic information can be facilitated by using three-dimensional or perspective representations, relative to flat two-dimensional displays (Benis et al., 1988). This statement has already been confirmed with aerial photos (Trinder, 1986). Little research has been done on this topic using remote sensing data, with the exception of airborne SLAR images by Koopmans (1974). He qualitatively interpreted drainage patterns from single and stereoscopic imagery in different topography. No quantitative results on position accuracy were given.

The objectives of this Letter are to expand on these previous results, and quantitatively compare the accuracies of planimetric features extracted from single and stereoscopic imagery from the European Remote-sensing Satellite Synthetic Aperture Radar (ERS-1 SAR).

2. STUDY SITE AND DATA SET

The study site is located north of Sudbury Basin (Ontario, Canada). This terrain is characterized by rolling topography where the elevation ranges from 300 to 500 m, and slopes generally do not exceed 15°. The land cover consists mainly of a forest mix of coniferous and deciduous trees, approximately 10-m tall. Lakes and ponds are numerous and they are connected through a series of small rivers with gentle shorelines. The relief is typical of the Canadian Shield of Quebec and Ontario.

The remote sensing data comprise two ERS-1 SAR images acquired on August 22 and 28, 1992, from ascending and descending orbits, respectively. The stereoscopic coverage is about 50 km by 50 km. Both images are in ground range presentation with 12.5-m pixel spacing. Images have been linearly compressed from 16 to 8 bits; an antenna pattern correction has been applied, and a 5 x 5 Lee filter has been used to reduce speckle. It has been proven that opposite-side stereoscopic SAR images are feasible in some contexts, such as rolling topography (Toutin, 1996). The topographic data (hydrology and 10-m contour lines) was digitized by the University of New Brunswick, Canada from a 1:20 000 topographic map. The planimetric and altimetric accuracies are 5 m and the DEM has been generated with an accuracy of 10 m.

3. DATA PROCESSING

Since the mathematical tools and systems for the two methods (monoscopic and stereoscopic) have already been described (Toutin 1995; Toutin, 1996), only a summary is presented. The "Système de Rectification des Images de Télédétection" developed at CCRS (Toutin, 1995) and a low-cost softcopy stereoscopic workstation, the DVP, developed jointly by Laval University and CCRS (Toutin, 1996) are used for the monoscopic and stereoscopic methods, respectively. There are four main processing steps before the feature extraction step:

(1) Acquisition and preprocessing of the remote sensing data, image(s), ephemeris and general information on the ERS platform and the SAR;

(2) Acquisition of the GCPs in mono- or stereoscopy;

(3) Computation of the geometric correction model(s) with the condition of colinearity[1] (for both methods) and coplanarity[2] (only for the stereoscopic method); and

(4) Ortho-image generation using the DEM with a 12.5-m pixel spacing, or set-up of the "virtual " stereo-model of the terrain.

Once the ortho-images or the stereo-model have been created, the data extraction follows in monoscopic or stereoscopic viewing, respectively. On these ERS-1 SAR images, few features were identifiable due to low contrast and the forest cover. Thus, only lake shorelines have been digitized from the 12.5-m pixel spacing, and compared with the check topographic data.

Figure 2 is a sub-area (506 by 600 pixels) of the two SAR images (ascending on the left and descending on the right), and is also an example of the opposite-side stereo-pair.

[1] The colinearity condition states that the exposure centre, the location of a ground point and its image point are colinear.
[2] The coplanarity condition states that the projection ranges from both sensor positions for the same ground point are coplanar.

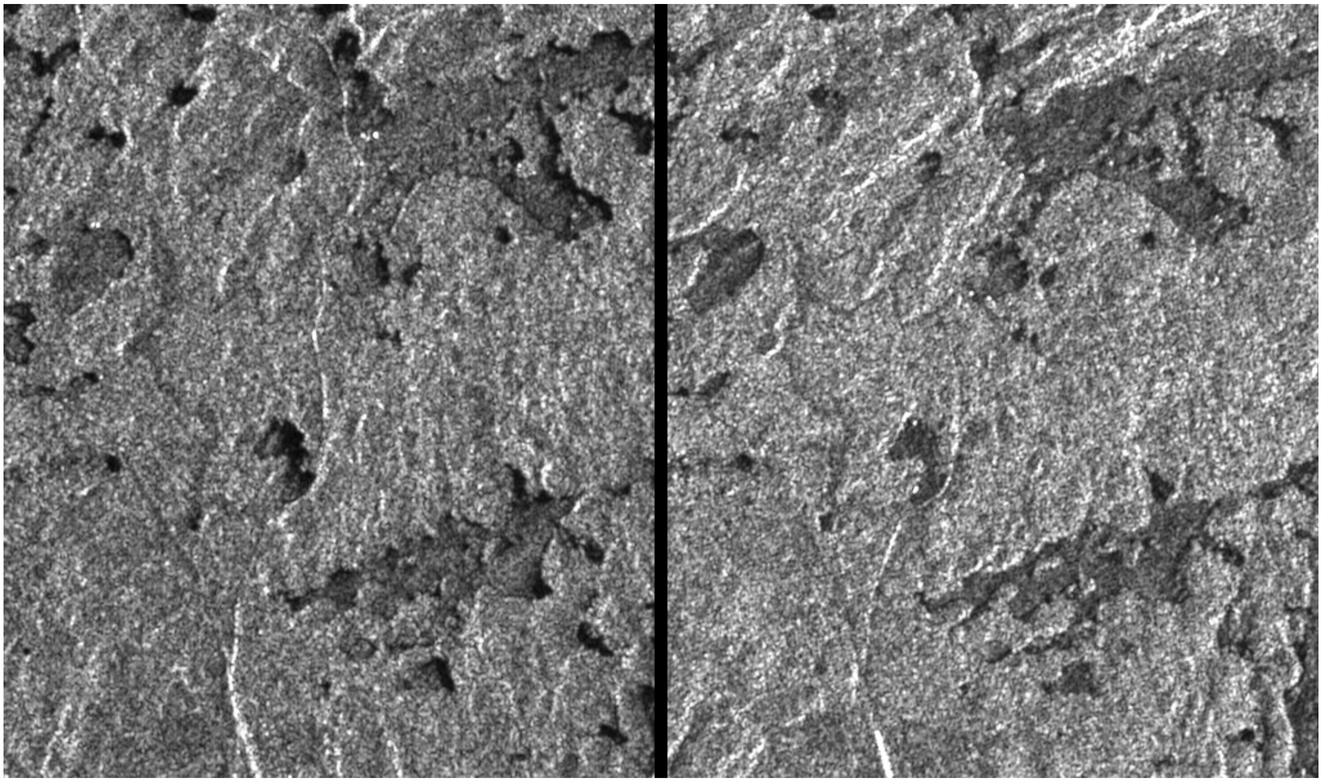

Figure 2. Example of ascending (left) and descending (right) ERS-1 SAR IMAGES (506 by 600 pixels; 12.5-m pixel spacing). © ESA, 1992. They also generate an opposite-side stereo-pair.

4. RESULTS AND DISCUSSION

The first results are with the computation of the geometric correction model(s). Table 1 gives the root mean square and maxima residuals on the 12 ground control points (GCPs), and the root mean square, maxima and bias errors on the 32 independent check points (ICPs) in metres. The stereoscopic results are a little better for the GCPs residuals. These residuals are in the same order of magnitude as the plotting error (1-2-pixel spacing) which contributes largely to the final error. They reflect the accuracy of the geometric modeling. For the ortho-images, only the condition of colinearity is used for the geometric modeling computation. However, for the stereoscopic method, the coplanarity condition and equations are one more of the components in the geometric modeling computation, which tie the two images together and thus, generate more robustness. For the same reason, the ICP errors, which reflect the restitution accuracy, are generally better for the stereoscopic configuration.

Table 1. RMS, maxima residuals (in metres) on the 12 GCPs, and RMS, maxima and bias errors (in metres) on the 32 ICPs for the different ERS-1 SAR image(s) configurations (monoscopic and stereoscopic)

Image(s) Configuration		Monoscopic Ascending Image		Monoscopic Descending Image		Stereoscopic Images (asc. + desc.)		
		X	Y	X	Y	X	Y	Z
GCPs	RMS	26.0	16.0	18.9	19.3	18.3	15.6	6.5
Residuals	Max	-46.6	-29.0	-29.5	-24.4	-29.0	-24.9	8.8
ICPs	RMS	27.1	21.0	32.3	28.5	24.9	17.9	9.2
Errors	Max	-70.0	-43.5	63.4	61.8	66.8	-41.3	18.8
	Bias	-2.7	-8.2	-0.6	5.4	-1.8	-1.8	-0.9

The second result is the comparison of the 200 lakes with a total perimeter of 322 km visually and interactively extracted from the ortho-images or the stereo-model, and compared with the topographic data. Table 2 gives the accuracy with a percentage of confidence for the three-image(s) configurations: ascending and descending ortho-SAR and stereo-model. It shows a 22-m versus a 17-m RMS accuracy with 66% confidence for the two ortho-SAR and stereo-SAR images respectively. But it also shows a 41 to 42-m versus a 31-m with 90% confidence. One can thus note that there is almost no variation between the two ortho-SAR results, but the stereo-SAR results are always better. Further, the percentages are higher in the larger "accuracy zones" (over 30-m) for the stereo-SAR configuration resulting in fewer large errors, and better and more consistent results.

By displaying the errors that are greater than 30-m it may be seen that these errors originate in the interpretation of the limit between lakes and swamps, combined with the positioning errors resulting from the 10-m accuracy of the DEM during the rectification process of ortho-SAR images. The lakes, rivers, and other bodies of water are quite distinct from the wetlands and forest, unless wind reduced surface roughness increases the backscatter due to small waves. Wetlands (marshes, swamps, etc.) with significant open water also exhibit this phenomenon which causes them to be confused with forest. Furthermore, vegetated wetlands generally appear similar to forest. In the stereoscopic SAR configuration, the images from ascending and descending orbits are complementary in terms of geometry and radiometry.

Table 2. Statistical results (accuracy in metres with percentage of confidence) of the extracted lake shorelines for the three image configuration.

Image(s) Configuration	**Ascending Ortho-Image**	**Descending Ortho-Image**	**Stereo-Model**
Accuracy (metres)	Percentage (%)	Percentage (%)	Percentage (%)
5	18.9	20.5	22.8
10	37.3	38.2	43.4
15	52.3	52.8	60.3
20	64.2	64.2	73.5
25	73.6	73.1	82.9
30	80.8	79.5	88.9
35	85.9	84.8	92.9
40	89.5	88.9	95.6
45	92.2	91.8	97.3
50	94.2	94.0	98.3
50+	100.0	100.7	100.0

The stronger geometry of an opposite-side stereo-pair enables larger parallaxes to be produced, and consequently a more robust stereoscopic configuration. Furthermore, since no DEM is used, there is no elevation error propagation through the planimetric feature extraction. In terms of radiometry, the opposite viewing (east and west lookings) enables the different orientations of the shoreline to be extracted and the "best information" of each image is used by the operator during the stereo-extraction process. Secondly, as there is generally less wind during the night (ascending image), it gives different radiometric contrasts for lakes, wetland and forest features between the two images. These complementarities allow for a better determination and interpretability of these different features, and thus explain why the stereo-SAR configuration achieves better results.

5. CONCLUSIONS

The accuracy of extracted feature is method and data dependent. This study has looked at two methods for planimetric feature extraction and its accuracy:

(1) The monoscopic method which uses an image and a DEM to generate an ortho-image; and

(2) The stereoscopic method which uses two images to generate a “virtual” stereo-model.

With two ERS-1 SAR images from ascending and descending orbits, the ortho-SAR images and the stereo-SAR model have been created with a geometric modeling based on the co-linearity and coplanarity conditions and developed at CCRS. Only lake shorelines have been visually extracted since no other feature was clearly identifiable on these SAR images over the Sudbury Basin (Ontario, Canada) which is mainly covered by coniferous and deciduous trees.

The first results on the geometric modeling computation(s) show that residuals on GCPs and errors on ICPs are better for the stereoscopic method. The second results on the 322-km lake shoreline extraction, when compared with the topographic data, confirm this statement. A 17-m versus a 22-m RMS accuracy with 66% confidence and a 31-m versus a 42-m accuracy with 90% confidence are achieved for the stereoscopic and the monoscopic methods, respectively.

With this data set, the larger errors for the monoscopic method, when compared to the stereoscopic method can be explained thus:

- The errors on the DEM generate errors in the ortho-SAR images and consequently on the planimetric feature extraction;
- The stereoscopic method using two images allows for an over estimation for the planimetric coordinates computation which are also computed independently of the altimetric coordinate;
- the stronger geometry with ascending and descending orbit images gives a more robust stereo-model; and
- The radiometric complementarities of opposite viewing and day and night images enable better discrimination between lakes, wetland and forest features due to a different backscatter.

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