3D Data Stereoscopic Extraction from Mixed VIR and SAR Sensors

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Abstract - **By choosing compromises to reduce geometric and radiometric disparities, the brain is able to perceive depth suitable for stereo mapping planimetric and elevation features using mixed radar and visible sensors. Planimetric and elevation accuracies of about 30 m and 20 m, respectively are obtained for opposite and same-side ERS-SAR and SPOT-P stereo images. From the stereo-fusion of these two ERS-SAR/SPOT-P pairs, the radiometry of the SPOT-P images mainly contributes to determine the planimetric features with the quality of its image content, while the geometry of the ERS-SAR image mainly contributes to determine the elevation with its high sensitivity to the terrain relief.**

I. INTRODUCTION

Combining and merging of images acquired in the visible and infrared (VIR) and in the microwave spectrum are largely used in earth resources mapping and monitoring to extract geophysical information. A method related to photogrammetric work is the stereo fusion and the stereoscopic extraction of 3D cartographic information.

At the first attempt, human stereo fusion and perception seem almost impossible. This process of stereo fusion and depth perception is not a passive but an active phenomenon in which the eye/brain is the source of the organizing power that creates and gives meaning to our visual environment (Friedhoff and Benzon, 1991. Depth perception from VIR stereo imagery reproduces the "naturalness" of our visual system. It is no longer true when combining VIR and SAR imagery. However with training and practice, the human brain can learn and acquire this "non-natural" stereo-capability because depth perception is an active system.

The paper addresses then the stereomapping of planimetric and altimetric features from two mixed sensor stereo-pairs (ERS-SAR and SPOT-P). With a PC-based digital stereo workstation, the DVP, results and accuracies are presented and analyzed.

II. STUDY SITE AND DATA SET

The study site is located in British Columbia (Canada), is characterized by a rugged topography (400 m along Lake Okanagan to more than 2000 m. The two SPOT images were acquired on 24 September 1989 and 11 July 1990 with a viewing angle of +26.2º (eastward looking direction, P26) and -10.4º (westward looking direction, P10) respectively. Both are raw level -1 images with ephemeris and attitude data recorded in panchromatic mode (10-m pixel size). The ERS-1 SAR was acquired on 3 July 1993 from a descending path, with a viewing angle of -23º (westward looking direction). The image is generated in ground range projection with 12.5-m pixel spacing

Two mixed-sensor stereo-pairs are then generated: an opposite-side with ERS-SAR and SPOT-P26, and a same-side with ERS-SAR and SPOT-P10 (Fig. 2. Since the three images were acquired from descending paths, geometric disparities related to the satellite and orientations of the azimuthal planes have been minimized. But radiometric disparities related to image content are obvious: on SPOT images, the roads and the cleared areas contrast with tree and other vegetation cover. Conversely, on ERS-SAR image, when cleared areas are visible (such as the power line clear-cut) they are dark in comparison with the surrounding tree cover, whose surface roughness increases the backscatter.

The topographic data was originally stereo-compiled by the Canada Centre for Topographic Information from 1:50 000 scale aerial photographs taken in 1981. The file contained a set of planimetric entities stored in several layers. Most layers (roads, hydrography, land-covers, etc.) have a horizontal accuracy of three (3) metres, while the layer representing hypsography had a contour interval of ten (10) metres.

III. EXPERIMENT

1) S*tereo model set-up:* The digital data are transferred to the PC-based digital stereo workstation: it includes the images, the sensor parameters, the ephemeris and attitude data and the Earth surface parameters. The geometric modelling parameters are first computed from these parameters, and further refined using the CGPs co-ordinates with an iterative least square bundle adjustment with photogrametric techniques (Toutin, 1995). The *a-priori* stereo mapping accuracy assessment is given over the 14 GCPs and 9 tie points residuals (Table I). As a consequence, the stereo model

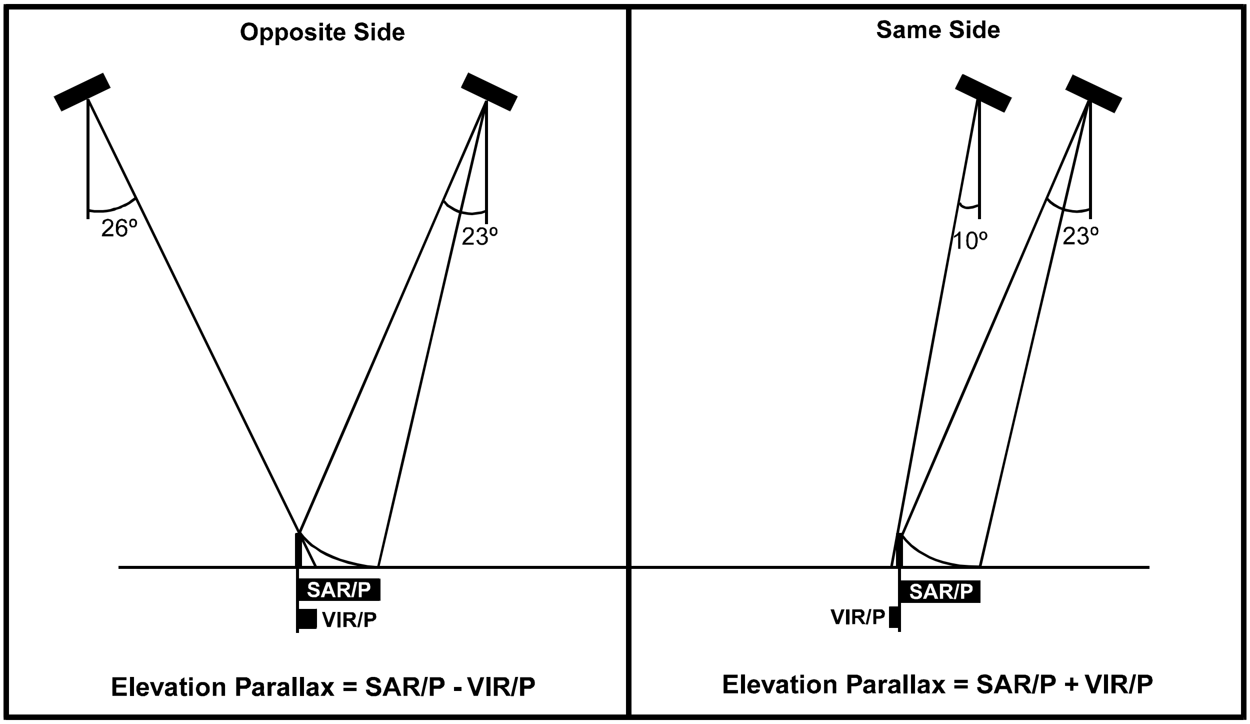

Fig. 1. Configuration of mixed sensor VIR-SAR stereo-pairs with their elevation parallaxes: an opposite-side with ERS-SAR and SPOT-P26 generates a subtractive parallax, and a same-side with ERS-SAR and SPOT-P10 generates an additive parallax.

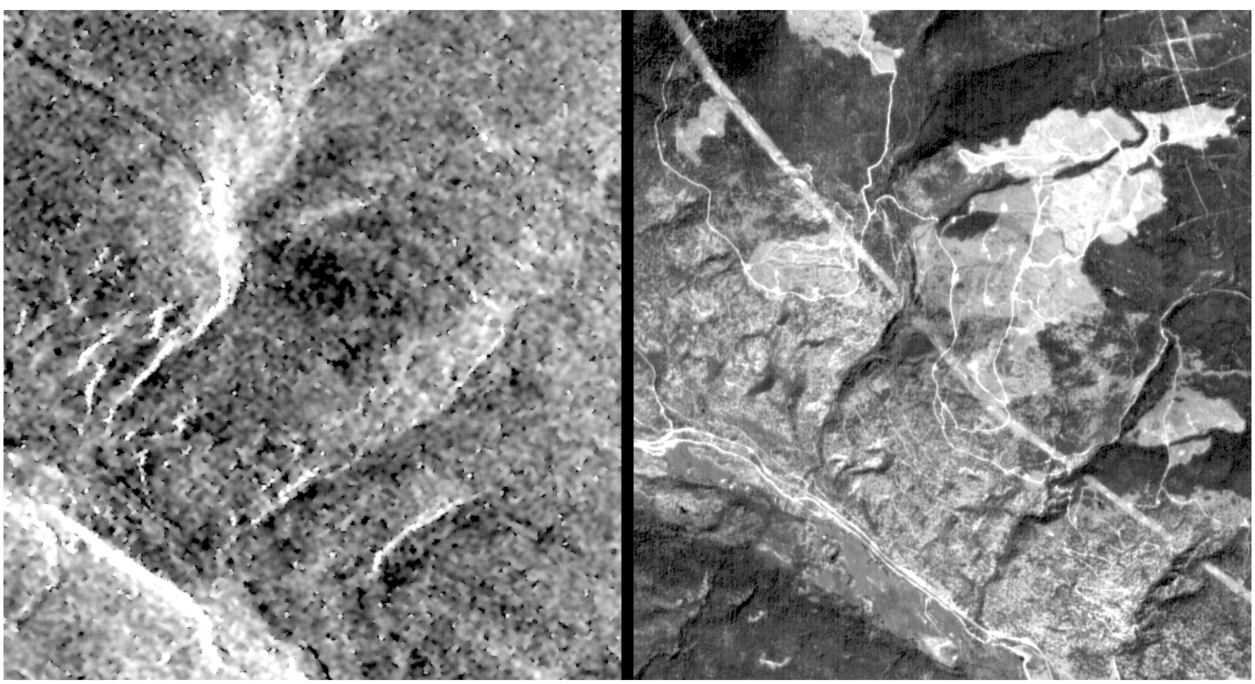

Fig. 2. Example of the same-side stereo pair ERS-SAR and SPOT-P10 over the Rocky Mountains, Canada (6 km x 7 km). The look direction is westward oriented for the ERS-SAR ground range image from a descending path and it is westward for the SPOT-P10 raw level 1 image.

is generated directly from the raw images (without any resampling) with a y-parallax of around one pixel. Although the same-side stereo pair displays a larger elevation parallax (Fig. 1), there is no significant difference in the result for the two stereo pair configurations. Errors in the plotting should have generated more errors in the opposite-side stereo pair due to the weaker geometry intersection.

Table I
RESULTS (IN METRES) FOR EACH STEREO PAIR WITH THE ROOT MEAN SQUARE (RMS), MINIMUM AND MAXIMUM RESIDUALS ON THE 14 GCPS AND 9 TIE POINTS

Stereo-pair	Opposite-side SAR - P26			Same-side SAR - P10		
Residuals	X	Y	Z	X	Y	Z
RMS	13.3	15.0	11.0	14.8	14.9	13.4
Minimum	-27.6	-30.2	-20.2	-27.4	-33.5	-20.1
Maximum	+16.5	+37.5	+16.8	+18.8	+28.8	+30.8

2) *Stereomapping:* Stereomapping does not imply only DEM generation, but also planimetric feature extraction, which so far has been one of the most neglected issues (Grün, 1997). Automatic procedures may cause problems due to the radiometric differences of the images and may generate errors larger than the stereoscopic process by itself, and then hinder accuracy evaluation. The data (roads, railroads, power lines, lakes and DEM) are then stereo-extracted visually in the stereo-model by an operator, transferred, cleaned and edited in a GIS.

IV. RESULTS AND ANALYSIS

1) *Planimetric features accuracy assessment:* Table II gives the results summary for all planimetric features.

These general results show that accuracy as a function of the stereo-pairs has no special trend. The accuracy of the planimetric features is not correlated to the stereo configuration, opposite or same-side. It is also consistent with the results of the a-priori stereomapping (Table 1). A stronger stereo geometry such as the same-side SAR-P10 stereo-pair (Fig. 1) does not provide better results for the planimetric feature extraction.

This confirms previous studies (Toutin, 1997), that show that planimetric accuracy is independent of the intersection angle, but mainly dependent on the radiometry. This dependency on radiometry explains the variations in the results for the different stereo-pairs and planimetric features:

- the image content which is related to the specificity of the sensor (SAR versus VIR; active versus passive, resolution);
- the general dynamic range of each sensor and the contrast in each image;
- the definition and the physical characteristics of each feature; and
- the contrast of each feature within its surrounding such as road in bare soil or in forest, lake very separable from forest power line outside of the forest.

In general, the image contents of the SPOT-P image "provides" the information on the feature, while the ERS-SAR combined with SPOT-P provides the third dimension with the stereo viewing. Indeed, when the feature is also visible on the SAR image (power line clear-cut, lake), it does not necessarily imply a better result

2) *Elevation accuracy assessment:* About 3900 and 4200 points (irregular DEM) are acquired on the SAR-P26 and SAR-P10 stereo pairs, respectively and directly compared to a fine grid spacing DEM generated from the 10 m contour lines with the GIS functions. This avoids errors generated by any processing to transform this irregular DEM into a regular grid, since the objective was to assess the accuracy of the extracted data and not to generate a regular DEM

We can note that Table III does not strongly support the expectation that larger intersection angles or parallaxes translate into higher elevation accuracy since the difference between the two RMS errors is only one metre and the histograms are quite similar (bias, minimum and maximum).

Table II
RESULTS SUMMARY (66% CONFIDENCE ERRORS IN METRES) OF THE COMPARISON FOR ALL FEATURES EXTRACTED FROM SAR-P26 AND SAR-P10 STEREO PAIRS AND THE CHECKED TROPOGRAPHIC DATA

Stereo-pair	Opposite-side SAR-P26			Same-side SAR-P10		
Planimetric Feature	Cumulative Distance	66% Confidence RMS Error	90% Confidence Error	Cumulative Distant	66% Confidence RMS Error	90% Confidence Error
Roads	93098	32	48	112761	29	42
Rail-roads	6171	41	52	6181	27	38
Power Lines	10983	35	49	20720	29	48
Lakes	12623	25	46	13791	30	46

Table III
STATISTICAL RESULTS (IN METRES) GENERATED FROM THE COMPARISON OF THE STEREO EXTRACTED DEMS AND THE FINE GRID SPACING DEM GENERATED FROM THE 10-M CONTOUR LINES OF THE 1:50 000 TOPOGRAPHIC DATA

Stereo-Pair	Opposite-side	Same-side
Errors	SAR-P26	SAR-P10
Bias	+0.5 m	-3 M
RMS	19 m	20 M
Minimum	-84 m	-84 M
Maximum	+141 M	+94 M

The only parameter studies evaluated for accuracy addressed theoretical error propagation (Leberl, 1990). The major limitation of error propagation modeling is the fact that it is purely geometrical and neglects the thematic image quality of the stereo-pairs, but also some other non-quantitative and psychological cues related to human depth perception. When only SAR images are involved in the stereo-pair, it is understandable that as the viewing angles differ more, the quality of the stereo fusion, deteriorates thereby setting off any gain achieved by a better stereo geometry.

But in our experiment, since the same SAR image and "almost two radiometrically similar" SPOT-P images (except for the contrast) are used in the two stereo-pairs, the radiometric aspects should not be the reason to set off the stronger geometry of the SAR-P10 stereo-pair. But, the SPOT-P contribution to the elevation parallax is very small when compared to the ERS-SAR contribution for both stereo configurations (about 10-20%) (Fig. 1.). Consequently, the difference between the two elevation parallaxes is not as large as it would be with two SAR stereo-pairs.

V. CONCLUSIONS

Geometric and radiometric disparities between SAR and VIR images can hinder stereoscopic viewing. Since depth perception is an active and process, a human operator can learn and acquire this "non-natural" stereo capability with time and practice. But compromises have to be made to minimize the geometric and/or radiometric disparities, such as acquiring images from descending path to give quasi-parallel satellite tracks and azimuthal planes, reducing the elevation parallax, processing the radiometry (dynamic range, contrast, speckle

Results of data extraction in planimetry and altimetry on a PC-based stereo workstation using photogrammetric techniques were presented with a stereo-pair, SAR-P26, (opposite-side viewing, destructive elevation parallax), and the other SAR-P10, (same-side viewing, a constructive elevation parallax).
In planimetry, the accuracies for the opposite-side stereo-pairs are 32 m, 41 m, 35 m and 25 m for the roads, railroads, power lines and lakes, respectively. For the same-side stereo-pair, they are 29 m, 27 m, 29 m and 30 m for the roads, railroads, power lines and lakes, respectively. The difference in the results between the stereo-pairs is due to the definition of each planimetric feature and the radiometric quality of each SPOT image. The geometry does not affect the accuracies, since the operator extracts along the vertical axis. In altimetry, 19 m and 20 m accuracies for the DEM have been computed with the opposite-side and same-side stereo-pairs, respectively. There was no significant bias. Larger errors occurred mainly in the strongest slopes where foreshortening and layover arise in ERS-SAR images

In summary with a mixed-sensor stereo-pair: (i) the radiometry of the SPOT-P images mainly contributes to the determination of the planimetric feature with the quality of its image content, and (ii) the geometry of the ERS-SAR image mainly contributes to the determination of the elevation with its high sensitivity to the terrain relief.

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