REAL - TIME EXTRACTION OF PLANIMETRIC AND ALTIMETRIC FEATURES FROM DIGITAL STEREO SPOT DATA USING A DIGITAL VIDEO PLOTTER

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ABSTRACT

Precise ground coordinates in the feature extraction from raster data is a key point for their integration in geographic information systems.

This paper presents a method and results of the extraction of planimetric and altimetric features from digital stereo SPOT-PLA data in stereoscopic mode.

The method uses a photogrammetric approach. The stereorestitution is done with a digital video plotter using a low-cost hardware (PC), and comparisons of the results with the digital topographic features (precision of three metres in planimetry and five metres in altimetry) are done in the ARC/INFO environment.

Results from a SPOT stereopair (B/H = 0.74) in the Rocky Mountains (Canada) show a planimetric accuracy of 12 metres with 90% confidence for well identifiable features and an altimetric accuracy for a DEM of 30 metres with 90% confidence.

Future improvements on the system should increase the accuracy to 10 metres and 15-20 metres with 90% confidence for planimetry and altimetry, respectively.

INTRODUCTION

Since the launch of SPOT-1 in February 1986, considerable interest has been expressed by the remote sensing and photogrammetric communities in the possibility of using SPOT data for cartographic purposes (topographic and thematic).

Various researchers have investigated different aspects and experiments of mapping using SPOT data: geometric accuracy in planimetry and altimetry, DEM extraction, image content, extraction of planimetric features (roads, rivers, forest, etc..), integration of raster and vector data. Basically, there are two main approaches to the extraction of planimetric features: the remote sensing approach and the photogrammetric approach.

The remote sensing approach uses one SPOT-HRV image at a time and a digital elevation model (DEM) to create a geocoded ortho-image. As this ortho-image is corrected (sensor, platform, geoid), each pixel gives the XY ground coordinates in the map system used of the identified feature. Considerable efforts have been done around the world to develop this approach using a robust and rigorous mathematical models which describes the SPOT acquisition geometry, e.g. by Masson d'Autume (1980), Guichard (1983), Toutin (1983), Konecny (1988), Priebbenow and Clerici (1988), Sharpe (1988).

The photogrammetric approach uses two SPOT-HRV images at a time for the reconstruction of a three-dimensional stereo model, in which the cartographic features can be extracted with the XYZ cartographic coordinates. Different mathematical models describing the SPOT acquisition geometry have been adapted to this photogrammetric approach and have been implemented on on-line analytical photogrammetric instruments (Masson d'Autume, 1980; Vigneron and Denis, 1984; Dowman and Gugan, 1985; Kratky, 1987; Konecny et al., 1987; Paderes et al., 1989) or on a digital stereoplotter (Lohmann et al., 1988; Toutin et al., 1991; Ahac et al., 1992).

The first concept of this approach was given by Sarjakoski (1981) and Gugan and Dowman (1986) described the main requirements for such a system. In the systems developed by Lohmann et al. (1988) and by Ahac et al. (1992), the SPOT-HRV data have to be resampled to a "common epipolar geometry" on which the stereo viewing and measurements can apply. However, resampling degrades the image geometric and radiometric quality (Gugan and Dowman, 1986) and is also computationally intensive.

On the other hand, Toutin et al. (1991) described an on-line digital stereo plotter operating on low cost hardware using raw SPOT imagery (level 1A). Real-time extraction of planimetric and altimetric features can then be made from a SPOT stereo model that is created directly from raw images, in a near-continuous computer-controlled real time positioning of the images. Feature extraction is improved since there is no resampling which degrades image quality.

As the methodology and the system have been already presented in detail (Toutin et al., 1991), operational use of the Digital Video Plotter (DVP-SPOT) must first be preceded by a quantitative study of the type and quality of data which can be extracted using this new system and SPOT imagery. In particular, this article will outline two aspects of the extraction: the planimetric accuracy of features which can be obtained on the stereo model through the geometric correction process and the accuracy of the digital elevation model and of the contour lines derived from the stereo model.

Using the photogrammetric approach, the system used for the extraction is the DVP-SPOT operating on a low-cost hardware (PC); and for the accuracy evaluation of the extracted features, an ARC/INFO system is used. The data set are two digital raw SPOT panchromatic images, and topographic digital data. After the stereo model set up and the feature extraction on DVP-SPOT, the features are transferred to the ARC/INFO system to be quantitatively compared to the topographic digital data.

DVP-SPOT SYSTEM

The DVP-SPOT has been developed through a joint project between the Canada Centre for Remote Sensing (CCRS), the Département des sciences géodésiques et de télédétection de l'Université Laval and the Canada Centre for Geomatics (CCG).

The system enables the on-line three-dimensional reconstruction of a SPOT stereo model, the capture in real time of planimetric and altimetric features and the graphic overlay of vector data on the SPOT stereo model. The mathematical tools and the system have already been described (Toutin, 1983; Toutin et al., 1991), only some principal characteristics are given:

- the geometric modelling is derived from the collinearity condition and takes into account the position and the attitude of the SPOT satellite and sensor;
- as the system uses the raw images, there is no need for resampling along the epipolar curves to cancel the y-parallax;
- the hardware is a 80386 PC computer with an ATI-VGA Wonder graphic card, and a mirror stereoscope (Figure 1).

Figure 1. The DVP system based on personal computer.

The geometric modelling uses the equations developed by Guichard, 1983 and Toutin, 1983. As these equations reflect the physical reality of the viewing geometry (sensor, platform, Earth) and do not use orbital parameter, polynomial transformations, or look-up table corrections between two-dimension image space and three-dimension ground space for orbit computation, they are easily adaptable to different transformations between the raw images and the model.

This geometric modelling allows transformations from image space to ground cartographic space (and back) in a single computation sequence, without going through any geographic or geocentric system. The implementation on a low cost microcomputer is then greatly simplified. The main result is a continuous, computer - controlled real-time positioning of images which gives continuity in the movement of both images of the stereo model.

STUDY SITE AND DATA SET

The study site located in British Columbia (Canada) overlaps two 1:250 000 scale maps: Hope (92H) and Penticton (82E). This area is characterized by a high relief topography where the elevation ranges from 400 metres along Lake Okanagan to 2000 metres on Kathleen Mountain. The land cover consists mainly of a mixture of coniferous and deciduous trees with patches of agricultural land and clearcut areas. The agricultural fields are found mostly along Lake Okanagan, while the clearcut areas, linked by new logging roads, are randomly located within the area. A few lakes and ponds are also found which are connected through a series of creeks engulfed between steep cliffs.

The data set consists of remote sensing data (images, orbit, attitude) and topographic data.

The remote sensing data consists of two SPOT data acquired on July 11, 1989 and September 24, 1990. Both images are raw level - 1 images recorded in panchromatic mode (10-m pixel size). The viewing angles are -10.4^{o} and $+26.2^{o}$, which gives a base-to-height ratio of 0.74. The stereo coverage is about 40 km by 50 km.

The topographic data was obtained from the Canada Centre for Mapping (CCM) covering an area of approximately 36 km by 28 km. The data was originally stereo-compiled from 1:50 000 - scale aerial photographs taken in 1981, as observed on the surface of the Earth in X, Y and Z coordinates and without movement of the element due to a cartographic generalization.

The digital data, Intergraph Graphic Design System files (IGDS), were uncleaned, and did not possess a topological structure. The IGDS file contained a set of planimetric entities stored in several layers. Most layers (roads, hydrography, landcovers, etc.) have a horizontal accuracy of three (3) metres while the layer representing hypsography had a contour interval of ten (10) metres.

A 15 km by 30 km area common to both the SPOT stereo model and the topographic data coverage was used for the evaluation of the photogrammetric restitution. It is located in the vicinity of Penctiton, British Columbia, in the Rocky Mountains.

Since the SPOT-PLA images were acquired at different dates (Fall and Summer), large discrepancies are noted. New roads and clearcut areas are observed, lake shorelines vary and creeks (dry in these seasons) are difficult to identify.

In the same way, there are discrepancies between the 1:250 000 and 1:50 000 maps for the forest and the creeks.

PROCESSING

The processing steps deal with SPOT data, ground control points, aerial photographs, and digital map. The main equipments used for the analysis are digital stereoplotter (on a PC computer) for the raster data, and a Geographic Information System (GIS) (ARC/INFO V6.0.1 on a SUN SPARCSTATION 2) for the vector data.

a) Digital Data Transfer to the SPOT-DVP

The SPOT data were read from magnetic tapes, pre-processed and transferred; only a quarter (2 900 pixels by 2 900 lines) was used of a SPOT-PLA image.

b) Stereo Model Set up

Twelve (12) ground points (mainly road intersections) were first identified and plotted in stereoscopic mode on the SPOT-PLA images. The image coordinate accuracy is half a pixel (5 metres), using an interpolated zoom to a factor of two. Then, the ground coordinates (XYZ) have been obtained using a STK-1 stereo comparator with the aerial photographs at CCM. The root mean square errors in each direction (X, Y and Z) are two metres. Different type of control points can be used. Apart from full control points (XYZ), one can employ also altimetric points (Z) and homologous or tie points (no ground coordinates). These points are useful to reinforce the stereo geometry and fill in gaps where there are no Ground Control Points (GCPs).

As few as six (6) GCPs, distributed around the perimeter of the stereo model, are enough for the computation of the parameters to set up the stereo model. Previous studies (Toutin and Carbonneau, 1989; Clavet et al., 1993) have already discussed the number, the density and the spatial distribution of the GCPs for the best results. Using GCPs coordinates, attitude and orbital parameters, the geometric modelling of the stereopair is computed with photogrammetric techniques and by least square adjustment (Toutin et al., 1991). The resulting residuals on the twelve (12) GCPs were 6.4 m, 8.6 m and 5.5 m in X,Y and Z direction, respectively. Most of these residuals comes from the image coordinate error (5 metres). As a result, the stereomodel, without y-parallax, is generated directly from the raw images.

c) Feature Extraction in the Stereo Model

The data extraction follows the model set up. For the planimetry, an operator digitizes in stereoscopy different features from the 10-m pixels: roads (small secondary), railroads, creeks, lakes and power lines. For the altimetry, the height measurements are extracted on a ten pixel regular grid on the left image: this generates an irregular grid of points whenprojected to the ground system. Some terrain break lines are also acquired. In this extraction step, no zoom was available.

The result of this feature extraction is files with XYZ ground coordinates. A descriptive code can also be attached to each feature.

d) Transfer to the GIS System

DVP XYZ files are transferred to ARC/INFO using a bi-directional translator developed by ESRI Canada in Montreal. The vector data (roads, creeks, lakes...) are cleaned and edited using different GIS functions of ARC/INFO. The irregular DEM, transferred as a point file, is used to generate a triangular irregular network (TIN). Terrain break-lines, rivers and lakes are also used to refine the interpolation of the TIN. This TIN is then transformed into a 50-m grid file.

In the same way for the topographic data, an IGDS/ARC translator is used to import the Intergraph files into the ARC/INFO environment. Only data common to both the topographic data and the SPOT stereo-model on the DVP were retained.

RESULTS AND ANALYSIS

For each extracted planimetric feature, a first comparison has been done between the map file and the DVP file to compare the omission and commission errors (Table 1).
In a second step, buffered zones centred on the map features were generated at 3, 6, 9, 12, 15, 20 and 30 metres. These buffered zones allowed to quantify the cumulative linear distances of DVP features within each zone; then it gives the percentage of the feature which have errors less than the width of the specific zone. For example, Tables 2 and 3 give the full results for the power lines, and Table 4 gives the results summary for the all features.

TABLE 1: Omission and Commission Results

Features	Length Map(m)	Omission (m) (%)		Length DVP(m)	Commission	
		Length	Percent		Length	Percent
Road	262369	13010	5.0	250816	1457	0.6
Power line	31247	4550	14.6	26697	0	0.0
Railway	19660	55	0.3	19605	0	0.0
Creek	234730	12362	5.3	227340	4972	2.2
Lake	19447	5205	26.8	14006	0	0.0

TABLE 2: Power Line Results

Accuracy (metres)	Distance (metres)	Percentage	Cumulative percentage
3	6845	25.6	25.6
6	4871	18.2	43.8
9	4307	16.1	59.9
12	2423	9.1	69.0
15	1826	6.8	75.8
20	1374	5.2	81.0
30	2836	10.6	91.6
30+	2216	8.3	100.0
Total	26697	100.0	

TABLE 3: Power Line Results after Move

Accuracy (metres)	Distance (metres)	Percentage	Cumulative percentage
3	10661	40.0	40.0
6	5844	21.9	61.9
9	4854	18.2	80.1
12	2703	10.1	90.2
15	1505	5.6	95.8
20	1130	4.2	100.0
30	0	0.0	100.0
30+	0	0.0	100.0
Total	26698	100.0	

TABLE 4: Planimetic Results for SPOT-PLA.

Accuracy (meters)	CUMMULATIVE PERCENTAGE (%)					
	Power Line	Power Line after correction	Road	Railroad	Lake	Creek
3	25.6	40.0	36.8	22.9	27.6	12.0
6	43.8	61.9	61.3	44.8	46.7	22.6
9	59.9	80.1	77.4	68.0	65.3	32.2
12	69.0	90.2	87.2	83.8	78.4	40.9
15	75.8	95.8	92.9	91.3	87.8	48.5
20	81.0	100.0	97.0	97.1	95.6	59.1
30	91.6	100.0	98.7	99.9	99.5	73.8
30+	100.0	100.0	100.0	100.0	100.0	100.0

a) Power lines: the 14.6% omission error results from underground gas pipelines. Table 2 shows that 69.0% of the power lines have errors less than 12-m accuracy and that 24.1% have errors greater than 20 metres. To understand this 24.1%, the map file is imported into the DVP. It shows a 30-m offset of the "map power line". As a second verification at CCM, conventional photogrammetric methods using the original aerial photographs attributed the 6-km-long 30-metre error to the topographic map. By removing this error, new statistics were generated, and Table 3 shows now that 90.2% are within 12-m accuracy.

b) Roads: the 5.0% omission error results from the forest regeneration on the old logging roads. The aerial photographs and the SPOT data were taken 8-9 years apart. As the objective of the study was not to update the map, new roads were not extracted. Consequently, there is only a 0.6% commission error. Table 4 shows that 87.2% of the roads have errors less than 12-m accuracy and that 6.9% are greater than 20 metres. Each linear entity that had an error greater than 20 metres is visually compared by importing the map file into the DVP. The origins of most of these errors are due to the topographic map, to the interpretation variation in locating curves and intersections and to physical changes in position between 1981 and 1989-90. This type of errors cannot be attributed to SPOT data and the DVP system. If corrections were made, results and accuracy would improve in the same way as the power lines.

c) Railroads: the 0.3% omission error results from a service road. Table 4 shows that

83.8% of the railroads have errors less then 12-m accuracy and that 8.7% have errors greater than 20 metres. The difficulty to identify the railroad when it is located along a cliff (shaded area) or close to a road explain this 8.7% error. The 10-m pixel size and the HRV sensor radiometry range do not posses sufficient resolution to provide details in this case.

d) Creeks: the least accurate results (5.3% omission; 2.2% commission; 40.9% within 12 m; 51.5% over 20 m) results from the particular physical characteristics of the creeks: they are small in width (less than 10 m), dry most of the time and their origin is almost impossible to locate. The creeks are extracted by following the thalwegs as it is done with aerial photographs. For this feature, the accuracy described in Table 4, then, combines planimetric, altimetric, image content and interpretation errors, in which the last three play a larger role than for the other features.

Thus, these results for the creeks do not reflect the general restitution accuracy of SPOT data with the DVP system, but are specific to this feature. Previous studies (Bégin et al., 1988; Salgé and Ross-Josserand, 1988) have also mentioned the difficulty in extracting intermittent watercourses, and have obtained less accurate results.

e) Lakes: the 26.8% omission error results from intermittent marshes and swamps, which are not visible in July and September SPOT data. Table 4 shows that

78.4% of the lakes have errors less than 12-m accuracy and 12.1% have errors greater than 20 metres. The origin of this 12.1% error is the variation in shape (already noted between the two images): they "shrank" during the summer and the fall (the total surface is smaller by 2% when compared to the map lakes). On the SPOT data, the shape of the lake is determined by the current shoreline, because the "high water limit" is not visible.

For the height measurements, a first evaluation was performed to quantify the altimetric pointing accuracy. Twenty (20) points, which span different features and cover type, such as wood, rock or clearcut area, roads, cliff... were chosen. It should be noted that these are not necessarily identifiable features. Pointing these points ten (10) times, one gets ± 2.7-m pointing precision. Furthermore, 14 well-identifiable check points with known ground coordinates (accuracy of two metres) are plotted on the stereo model five (5) times to quantify the absolute altimetric error on spot elevation. A root mean square error of 3.4 metres is obtained. As part of this error is the 2-m error of the check points. It is worth noting that the stereo images have a base-to-height ratio of 0.74, and the altimetric digitizing accuracy with a 10-m pixel size is ± 8 metres.

About 12 000 points (irregular DEM) are acquired on the stereomodel and directly compared to the DEM generated from the 10-m contour lines. This avoids errors generated by any processing to transform this irregular DEM into a regular grid. Table 5 gives the statistics resulting from this comparison.

TABLE 5:Altimetric Results on the Height Measurements (B/H=0.74)

Errors (metres)	Occurence	Cumulative Occurence	Percentage	Cumulative Percentage
0 - 5	3 945	3 945	32.31	32.31
5 - 10	2 770	6 715	22.69	55.00
10 - 15	1 864	8 579	15.27	70.27
15 - 20	1 205	9 784	9.87	80.14
20 - 25	817	10 601	6.69	86.84
25 - 30	426	11 027	3.49	90.33
30 - 35	288	11 315	2.36	92.69
35 - 40	203	11 518	1.66	94.35
40 - 50	233	11 751	1.91	96.26
50 - 60	136	11 887	1.11	97.37
60 - 70	88	11 975	0.72	98.09
70 - 80	67	12 042	0.55	98.64
80 - 90	47	12 089	0.38	99.03
90 - 100	34	12 123	0.28	99.30
100 -	85	12 208	0.70	100.00

Compared to the absolute altimetric error (3.4 m for spot-elevation), some of the errors given in Table 5 are very large. Displaying on the DVP the 690 points, which have an error greater than 40 metres, it may be seen that they are spatially and not randomly grouped in the stereo model. These errors are mainly human errors due to different reasons, (operator's tiredness, poor contrast, etc.), and replotting 10% of these points confirms this, because the results improve.

CONCLUSIONS AND RECOMMENDATIONS

This article has shown the stereo extraction of planimetric and altimetric features from

SPOT data using a photogrammetric approach and a fully digital environment (topographic and remote sensing data, DVP on PC and ARC/INFO).

The results (12 m and 30 m with 90% confidence for planimetry and altimetry, respectively, and a 3.4-m RMS error for spot elevations) are quite encouraging, mainly with this difficult test site in the Rocky Mountains (high elevation variation, features characteristics, image content, variations in SPOT and topographic data). Recent improvements have been incorporated to the DVP system to increase further the final accuracy:

1) during the orientation process, an interpolated zoom to a factor of four (4), instead of two (2), can now be used for the acquisition of image coordinates. Using the same combination of GCPs and homologous points, a new orientation was performed and the residuals were 4.7 m, 4.0 m and 3.7 m in X, Y and Z direction, respectively. These residuals are better than those (6.4 m, 8.6 m, 5.5 m) of the stereomodel used for the feature extraction;

2) during the stereorestitution process, an interpolated zoom to a factor of two (2) can now be used for the capture of the XYZ ground coordinates, resulting in a better sub-pixel accuracy. This new zoom will then decrease the planimetric digitizing error from ± 5 m to ± 2.5 m, and the altimetric digitizing error from ± 8 m to ± 4 m (B/H = 0.74), thus increasing the restitution accuracy. It will also help for the interpretation and the smoothing of the curves and the intersections, where most

of errors for the roads were encountered.

Finally, according to the statistical results on this test site, taking into account the improvements discussed and with a better base-to-height ratio, one can expect to improve the restitution accuracy using this new technology SPOT-DVP. The projected increase in accuracy would be in the order of 10 metres with 90% confidence for most of the easily identifiable planimetric features as roads (main and secondary), power lines, railroads, rivers, lakes, etc. and in the order of 5 metres for spot elevations and of 15-20 metres with 90% confidence for a DEM . The resulting contour lines could have a interval of 30 metres.

For some specific features, the image content (as with creeks), the interpretation (as with lakes) or the cartographic standard (as with forests) can decrease this geometric accuracy, as the results obtained for lakes and creeks have shown.

What is the potential of this combination SPOT-PLA data and DVP-PC system? In topographic mapping, four possibilities can be considered:

1) the quality control of the map produced by traditional photogrammetric methods. As it was done for this test site with the power lines and the roads, the combination SPOT-DVP can be used to check the different features in a global context (60 km by 60 km), by importing the map files into the DVP;

2) the evaluation of change and the update of topographic map. By importing the map files into the DVP, the different features can be updated and exported back into the topographic map environment;

3) the Canadian National Topographic Data Base (NTDB) generation. The NTDB standard specifies that 90% of the features should have a 10-m planimetric accuracy. The stereorestitution of SPOT data with the DVP system can then be used to "feed" the NTDB.

   Another useful product would be an image map on which the extracted planimetric features or the NTDB can be overlaid: it could be also used as an additional layer in a spatial data base;

4) the generation of DEM with 15-20 m accuracy with 90% confidence and of 30 m contour lines. This DEM can be used to generate a geocoded ortho-image.

In thematic mapping, the altimetric information can be used from a qualitative point of view to help the operator in the interpretation of features (e.g.: terrain morphology, geological structure, landform identification, etc.), and from a quantitative point of view to produce DEMs for the generation of ortho-images from different satellite data (SPOT, Landsat, ERS-1, etc.). As in topographic mapping, the import (or export) of files into (or from) the DVP can be done to perform different tasks: feature interpretation or extraction, map updating or creation, interaction with a GIS.

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