# 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. A method and the results of the extraction of planimetric and altimetric features from digital stereo SPOT-PLA data in stereoscopic mode are presented. The method uses a photogrammetric approach. The stereo restitution was done with a digital video plotter using low-cost hardware (PC), and comparisons of the results with digital topographic features (precision of three metres in planimetry and five metres in altimetry) were done in the ARC/INFO environment. Results from a SPOT stereopair (B/H = 0.74) in the Rocky Mountains (Canada) showed a planimetric accuracy of 12 metres with 90 percent confidence for well identifiable features and an altimetric accuracy for a DEM of 30 metres with 90 percent confidence. Recent improvements in the system should increase the accuracy to 10 metres and 15 to 20 metres with 90 percent 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..), and 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 of the identified feature in the map system. Considerable effort has been expended to develop this approach using robust and rigorous mathematical models which describe the SPOT acquisition geometry (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 their *XYZ* cartographic coordinates. Different mathematical models describing the SPOT acquisition geometry have been adapted to this photogrammetric approach and have been implemented in 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 in digital stereoplotters (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 had to be resampled to a "common epipolar geometry" in 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 stereoplotter operating on low-cost hardware using raw SPOT imagery (level 1A). Real-time extraction of planimetric and altimetric features can then be accomplished using 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 because there is no resampling which degrades image quality.

As the methodology and the system have already been 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: (1) the planimetric accuracy of features which can be obtained from the stereo model through the geometric correction process, and (2) the accuracy of the digital elevation model and of the contour lines derived from the stereo model.

Using the photogrammetric approach, the system used

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

## DVP-SPOT System

The DVP-SPOT was 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. Because the mathematical tools and the system have already been described (Toutin, 1983; Toutin *et al.*, 1991), only some principal characteristics are given:

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

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

This geometric modeling allows transformations from image space to ground cartographic space (and back) in a single computational 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 a 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 2,000 metres at 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 entrenched between steep cliffs.

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

The topographic data were obtained from the Canada Centre for Mapping (CCM), and cover an area of approximately 36 km by 28 km. The data were 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, in 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 3 metres while the layer representing hypsography had a contour interval of 10 metres.

A 15- 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.

Because the SPOT-PLA images were acquired on different dates (fall and summer), large discrepancies were noted. New roads and clearcut areas were observed, lake shorelines varied, and creeks (dry in these seasons) were difficult to identify. For the same reason, there are discrepancies between the 1:250,000- and 1:50,000-scale maps for the forest and the creeks.

## Processing

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

### Digital Data Transfer to the SPOT-DVP

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

### Stereo Model Set up

Twelve ground points (mainly road intersections) were first identified and plotted in the stereoscopic mode using the SPOT-PLA images. The image coordinate accuracy is half a pixel (5 metres), using an interpolated zoom to a factor of two. The ground coordinates (*XYZ*) were then extracted from the aerial photographs using an STK-1 stereo comparator at the CCM. The root-mean-square errors in each direction (*X, Y*, and *Z*) were 2 metres. Different types of control points can be used. In addition to full control points (*XYZ*), one can also employ altimetric points (*Z*) and homologous or tie points (no ground coordinates). These points are useful for reinforcing the stereo geometry and to fill in gaps where there are no ground control points (GCPs).

As few as six 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 GCP coordinates, attitude, and orbital parameters, the geometric modeling of the stereopair is computed with photogrammetric techniques and by least-squares adjustment (Toutin *et al.*, 1991). The result-

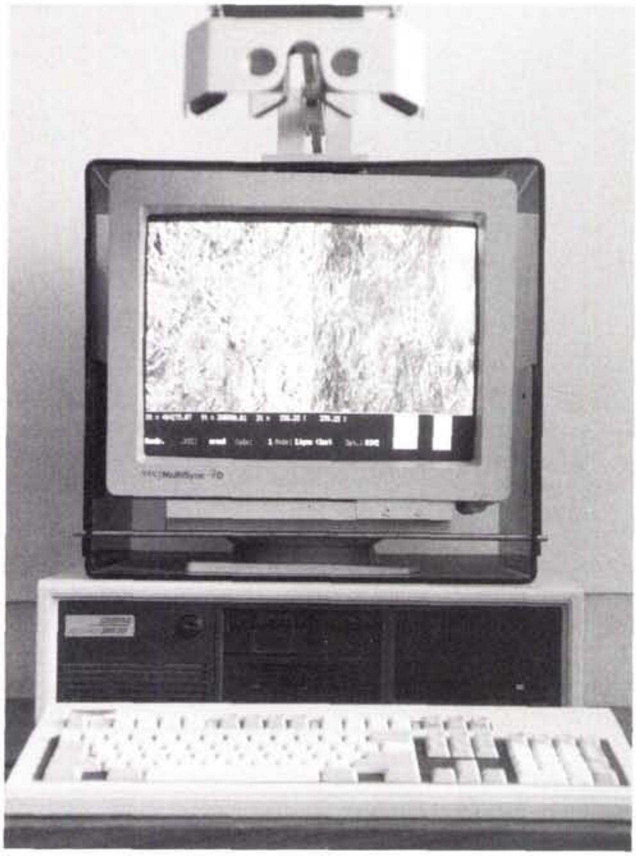

Figure 1. The DVP system based on a personal computer.

ing residuals for the 12 GCPs were 6.4 m, 8.6 m, and 5.5 m in *X,Y*, and *Z* directions, respectively. Most of these residuals come from the image coordinate error (5 metres). As a result, the stereomodel, without *y*-parallax, were generated directly from the raw images.

#### 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 when projected 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 are files with *XYZ* ground coordinates. A descriptive code can also be attached to each feature.

#### Transfer to the GIS System

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

In the same way for the topographic data, an IGDS/ARC translator was 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 was made between the map file and the DVP file to compare the omission and commission errors (Table 1). In a second step, buffered zones centered on the map features were generated at 3, 6, 9, 12, 15, 20, and 30 metres. These buffered zones allowed for the quantification of the cumulative linear distances of DVP features within each zone; it then gave the percentage of the features which had 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 all features.

- *Power Lines.* The 14.6 percent omission error resulted from underground gas pipelines. Table 2 shows that 69.0 percent of the power lines have errors less than 12 m and that 24.1 percent have errors greater than 20 m. To understand this 24.1 percent, the map file is imported into the DVP. It showed 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-m error to the topographic map. By removing this error, new statistics were generated, and Table 3 shows that 90.2 percent are now within 12-m accuracy.
- *Roads.* The 5.0 percent omission error resulted from forest regeneration on the old logging roads. The aerial photographs and the SPOT data were taken 8 to 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 percent commission error. Table 4 shows that 87.2 percent of the roads have errors less than 12 m and that 6.9 percent are greater than 20 m. Each linear entity that had an error greater than 20 m was visually compared by importing the map file into the DVP. The origins of most of these errors were 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. These types of errors cannot be attributed to SPOT data and the DVP system. If corrections were made, results and accuracy would improve as they did for the power lines.
- *Railroads.* The 0.3 percent omission error resulted from a service road. Table 4 shows that 83.8 percent of the railroads had errors less then 12 m and that 8.7 percent had errors greater than 20 m. The difficulty in identifying the railroad when it was located along a cliff (shaded area) or close to a road explains this 8.7 percent error. The 10-m pixel size and the HRV sensor radiometry range do not posses sufficient resolution to provide details in this case.

TABLE 1. OMISSION AND COMMISSION RESULTS

| Features | Length (map) (m) | Omission Length (m) | Omission Percent | Length (DVP) (m) | Commission Length (m) | Commission Percent |
|---|---|---|---|---|---|---|
| Road | 262,369 | 13,010 | 5.0 | 250,816 | 1,457 | 0.6 |
| Power line | 31,247 | 4,550 | 14.6 | 26,697 | 0 | 0.0 |
| Railway | 19,660 | 55 | 0.3 | 19,605 | 0 | 0.0 |
| Creek | 234,730 | 12,362 | 5.3 | 227,340 | 4,972 | 2.2 |
| Lake | 19,447 | 5,205 | 26.8 | 14,006 | 0 | 0.0 |

TABLE 2. POWER LINE RESULTS

| Accuracy (metres) | Distance (metres) | Percentage | Cumulative percentage |
|---|---|---|---|
| 3 | 6,845 | 25.6 | 25.6 |
| 6 | 4,871 | 18.2 | 43.8 |
| 9 | 4,307 | 16.1 | 59.9 |
| 12 | 2,423 | 9.1 | 69.0 |
| 15 | 1,826 | 6.8 | 75.8 |
| 20 | 1,374 | 5.2 | 81.0 |
| 30 | 2,836 | 10.6 | 91.6 |
| 30+ | 2,216 | 8.3 | 100.0 |
| Total | 26,697 | 100.0 | |

TABLE 4. PLANIMETRIC RESULTS FOR SPOT-PLA

| | Cumulative Percentage (%) | | | | | |
|---|---|---|---|---|---|---|
| Accuracy (metres) | 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 |

- *Creeks.* The least accurate results (5.3 percent omission; 2.2 percent commission; 40.9 percent within 12 m; 51.5 percent over 20 m) resulted from the particular physical characteristics of the creeks: they are small in width (less than 10 m), they are dry most of the time, and their source is almost impossible to locate. The creeks were extracted by following the thalwegs, as 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 they do for the other features.

  Thus, these results for the creeks do not reflect the general restitution accuracy of the 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.
- *Lakes.* The 26.8 percent omission error resulted from intermittent marshes and swamps, which were not visible in the July and September SPOT data. Table 4 shows that 78.4 percent of the lakes had errors less than 12 m and 12.1 percent had errors greater than 20 m. The origin of this 12.1 percent error is the variation in the shape of the lakes (already noted between the two images): they "shrank" during the summer and the fall (the total surface was smaller by 2 percent when compared to the map lakes). On the SPOT data, the shape of the lakes was determined by the current shoreline, because the "high water limit" was not visible.

For the height measurements, a first evaluation was performed to quantify the altimetric pointing accuracy. Twenty points, which span different features and cover types, such as wood, rock or clearcut area, roads, cliffs, etc., were chosen. It should be noted that these are not necessarily identifiable features. By pointing on these features ten times each, one gets ± 2.7-m pointing precision. Furthermore, 14 well-identifiable check points with known ground coordinates (an accuracy of 2 metres) were plotted on the stereo model five times each to quantify the absolute altimetric error in spot elevation. A root-mean-square error of 3.4 m was obtained. A part of this error was 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 m.

About 12,000 points (irregular DEM) were extracted from 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.

Compared to the absolute altimetric error (3.4 m for spot elevations), some of the errors given in Table 5 are very large. By displaying on the DVP the 690 points which had an error greater than 40 m, it may be seen that they are spatially rather than randomly grouped in the stereo model. These errors are mainly human errors due to different reasons (operator fatigue, poor contrast, etc.), and replotting 10 percent of these points confirmed this, because the results improved.

TABLE 3. POWER LINE RESULTS AFTER MOVE

| Accuracy (metres) | Distance (metres) | Percentage | Cumulative percentage |
|---|---|---|---|
| 3 | 10,661 | 40.0 | 40.0 |
| 6 | 5,844 | 21.9 | 61.9 |
| 9 | 4,854 | 18.2 | 80.1 |
| 12 | 2,703 | 10.1 | 90.2 |
| 15 | 1,505 | 5.6 | 95.8 |
| 20 | 1,130 | 4.2 | 100.0 |
| 30 | 0 | 0.0 | 100.0 |
| 30+ | 0 | 0.0 | 100.0 |
| Total | 26,698 | 100.0 | |

## Conclusions and Recommendations

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) has been demonstrated.

The results (12 m and 30 m with 90 percent confidence for planimetry and altimetry, respectively, and a 3.4-m RMS error for spot elevations) are quite encouraging, mainly because of the difficult test site in the Rocky Mountains (high

TABLE 5. ALTIMETRIC RESULTS FOR 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 |

elevation variation, feature characteristics, image content, and variations in SPOT and topographic data). Recent improvements have been incorporated to the DVP system to increase further the final accuracy:

- During the orientation process, an interpolated zoom to a factor of four, instead of two, 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* directions, respectively. These residuals are better than those (6.4 m, 8.6 m, 5.5 m) from the stereomodel used for the feature extraction.
- During the stereorestitution process, an interpolated zoom to a factor of two 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 $\pm$ 5 m to $\pm$ 2.5 m, and the altimetric digitizing error from $\pm$ 8 m to $\pm$ 4 m ($B/H$ = 0.74), thus increasing the restitution accuracy. It will also help 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 for 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 on the order of 10 m with 90 percent confidence for most of the easily identifiable planimetric features such as roads (main and secondary), power lines, railroads, rivers, lakes, etc., and on the order of 5 m for spot elevations and of 15 to 20 m with 90 percent confidence for a DEM. The resulting contour lines could have an interval of 30 m.

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

- The quality control of the map produced by traditional photogrammetric methods. As was done for this test site with the power lines and the roads, the SPOT-DVP combination 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.
- The evaluation of change and the update of topographic maps. By importing the map files into the DVP, the different features can be updated and exported back into the topographic map environment.
- The Canadian National Topographic Data Base (NTDB) generation. The NTDB standard specifies that 90 percent 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 also be used as an additional layer in a spatial database.
- The generation of a DEM with a 15 to 20 m accuracy with 90 percent 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, and interaction with a GIS.

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## References

Ahac, A., R. Defoe, and M.C. van Wijk, 1992. Consideration in the Design of a System for the Rapid Acquisition of Geographic Information, *Photogrammetric Engineering & Remote Sensing*, 58(1):95-100.

Begin, D., Y. Boucher, J. Brodeur, C. Girard, D. Lapierre, J.-P. Lemieux, and J.R.R. Gauthier, 1988. Experiences franco-canadiennes: précision géométriques des données SPOT, *Actes du Symposium international sur les applications topographiques des données SPOT*, pp. 169-180.

Clavet, D., M. Lasserre, and J. Pouliot, 1993. GPS Control for 1: 50,000-Scale Topographic Mapping from Satellite Images, *Photogrammetric Engineering & Remote Sensing*, 59(1):107-111.

Dowman, I.J., and D.J. Gugan, 1985. Application Potential of SPOT Imagery for Topographic Mapping, *Advanced Space Research*, 5(5):73-79.

Gugan, D.J., and I.J. Dowman, 1986. Design and Implementation of a Digital Photogrammetric System, *Proceedings of Commission 2 ISPRS Symposium*, Baltimore, Maryland, pp. 100-109.

Guichard, H., 1983. Etude théorique de la précision dans l'exploitation cartographique d'un satellite à défilement: application à SPOT, *Bulletin de la Société Française de Photogrammétrie et de Télédétection*, (90):15-26.

Konecny, G., 1988. Geometric Evaluation of SPOT Imagery, *Proceedings of the SPOT System and its Cartographic Applications Symposium*, Saint-Mandé, France, pp. 19-53.

Konecny, G., P. Lohman, H. Engel, and E. Kruck, 1987. Evaluation of SPOT Imagery on Analytical Photogrammetric Instruments, *Photogrammetric Engineering & Remote Sensing*, 53(9):1223-1230.

Kratky, V., 1987. Rigorous Stereophotogrammetric Treatment of SPOT Images, *Compte rendus du Colloque International sur SPOT-1: utilisation des images, bilans, résultats*, Paris, France, pp. 1281-1288.

Lohmann, P., G. Picht, J. Weidenhammer, K. Jacobsen, and L. Skog, 1988. The Design and Implementation of a Digital Photogrammetric Stereo-Workstation, *Proceedings of 16th ISPRS Congress*, Kyoto, Japan, 27:II-155-II-164.

Masson d'Autume, M.G., 1980. Le traitement géométrique des images de télédétection, *Annales des Mines*, Paris, France, 2:53-62.

Paderes, F.C., E.M. Mikkhail, and J.A. Fagerman, 1989. Batch and On-Line Evaluation of Stereo SPOT Imagery, *Proceedings of the ASPRS/ACSM Convention*, Baltimore, Maryland, 3:31-40.

Priebbenow, R., and E. Clerici, 1987. Cartographic Applications of SPOT Imagery, *Compte-rendus du Colloque International sur SPOT-1 : Utilisation des images, bilans, résultats*, Paris, France, pp. 1189-1194.

Salgé, F., and M.J. Roos-Josserand, 1988. Apport des images satellites à la base de données cartographiques de l'IGN: résultat de l'expérience franco-canadiennes sur le contenu des images, *Actes du Symposium international sur les applications topographiques des données SPOT*, Sherbrooke, Québec, pp. 181-208.

Sarjakoski, T., 1981. The concept of a completely digital stereoplotter, *Photogrammetric Journal of Finland*, 8(2):95-100.

Sharpe, B., 1988. Geometric Processing in MacDonald Dettwiler's

Meridian-GICS System, *Actes du Symposium international sur les applications topographiques des données SPOT*, Sherbrooke, Québec, pp. 76-85.

Toutin, Th., 1983. *Analyse mathématique des possibilités cartographiques du satellite SPOT*, Mémoire du diplome d'Études Approfondies, École Nationale des Sciences Géodésiques, Saint-Mandé, France, 74 p.

Toutin, Th., and Y. Carbonneau, 1989. La multi-stéréoscopie pour les corrections d'images SPOT-HRV, *Journal canadien de télédétection*, 15(2):110-119.

Toutin, Th., C. Nolette, Y. Carbonneau, and P.-A. Gagnon, 1991. La restitution stéréoscopique des données SPOT avec un vidéo restituteur numérique, *Compte-rendus du 7ième Congrès de l'Association québecoise de télédétection*, Montréal, Québec, pp. 111-123.

Vigneron, C., and P. Denis, 1984. Stéréorestitution d'images SPOT à l'aide du logiciel TRASTER IGN/Matra, *Proceedings of the 18th International Symposium on Remote Sensing of Environment*, Paris, France, 1:455-464.

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