SPOT AND LANDSAT STEREO FUSION
FOR DATA EXTRACTION OVER MOUNTAINOUS AREA

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ABSTRACT

In thematic and cartographic applications planimetric features are extracted from multi-sensors images such as SPOT and Landsat, to take advantage of their complimentarities. When no precise elevation data is available, mainly in mountainous area, to ortho-rectify these images, digital photogrammetric stereo workstations (stereo DPWS) are now available for the interactive stereo fusion and plotting of multi-sensor stereo pairs.

This paper presents a method and the quantitative results on the extraction of planimetric and altimetric features from a stereo pair generated with mixed sensors images SPOT-P and Landsat-TM, using the stereo DPWS, the DVP available at the Canada Centre for Remote Sensing.

Results from this mixed sensors stereo pair, which exhibits a base-to-height-ratio of 0.49, in a mountainous area of the Rocky Mountains (Canada) show a planimetric accuracy of 11-12 m for well identifiable cartographic features, and an altimetric accuracy of 37 m for the extracted elevation data.

I INTRODUCTION

The increasing amount of data in raster and vector format needs methods for their fusion, their analysis and the extraction of geophysical information. Most of the development and the applications have focused on the co-registration of the different images using non-parametric rectification, based on tie points and polynomial transformations. When using and integrating already existing or extracted vector information into or, from a map system, a precise geocoding process is then mandatory, and especially in mountainous areas. It requires then a precise parametric relationship between the image reference system and the cartographic reference system. This parametric solution should take into account all the distortions generated during the image formation, including terrain distortions. Consequently, to generate ortho-images in the cartographic reference system, a digital elevation model (DEM) is needed to correct the distortions related to the terrain elevation.

If the DEM does not exist or cannot be produced from the topographic map contour lines, different methods have been developed to extract DEM from remote sensing images. One of the methods, image matching has made significant progress. As reported by Dowman et al. (1992), least square matching has been found to be the most accurate, and feature based matching has not been very popular. More recently, global approaches which perform matching in object space have been studied. Furthermore, image pyramids, scale space algorithms and consideration of breaklines are also used to achieve better and faster results. More considerations on image matching is out of the scope of this paper; Lemmens (1988) and Wrobel (1988) are excellent surveys on images matching from same sensors.

Few results have been published on image matching from multi-sensor data. Welch et al. (1990) or Raggam and Almer (1991) generated DEM from similar spectral bands of mixed sensors SPOT multi-band and Landsat-TM. They reported a moderate success in the correlation step with an 50-100 m accuracy for the DEM.

This error will propagate through the geocoding process, the ortho-images fusion, and the planimetric feature extraction. Figure 1 shows the relationship between the DEM accuracy, the viewing angle of the image in the visible, and the resulting error generated on the ortho-image (Toutin, 1995). As an example, a 50-m error for the elevation due to the DEM accuracy and the interpolation into the DEM generates during the rectification process 7-m error and 15-m positioning error for a Landsat-TM image and a 15° viewing angle SPOT-HRV image, respectively. Consequently, the ortho-images fusion will be generated with an accuracy in the order of 17 m. These planimetric errors are not negligible for SPOT-HRV, nor for the images fusion. Therefore, any planimetric feature (road, power line, river, etc.) cannot be extracted from the Landsat-TM and SPOT-HRV ortho-images fusion with an accuracy better than 20-25 m. Furthermore, resampling during the rectification process degrades the image geometry and radiometry (Gugan and Dowman, 1986).

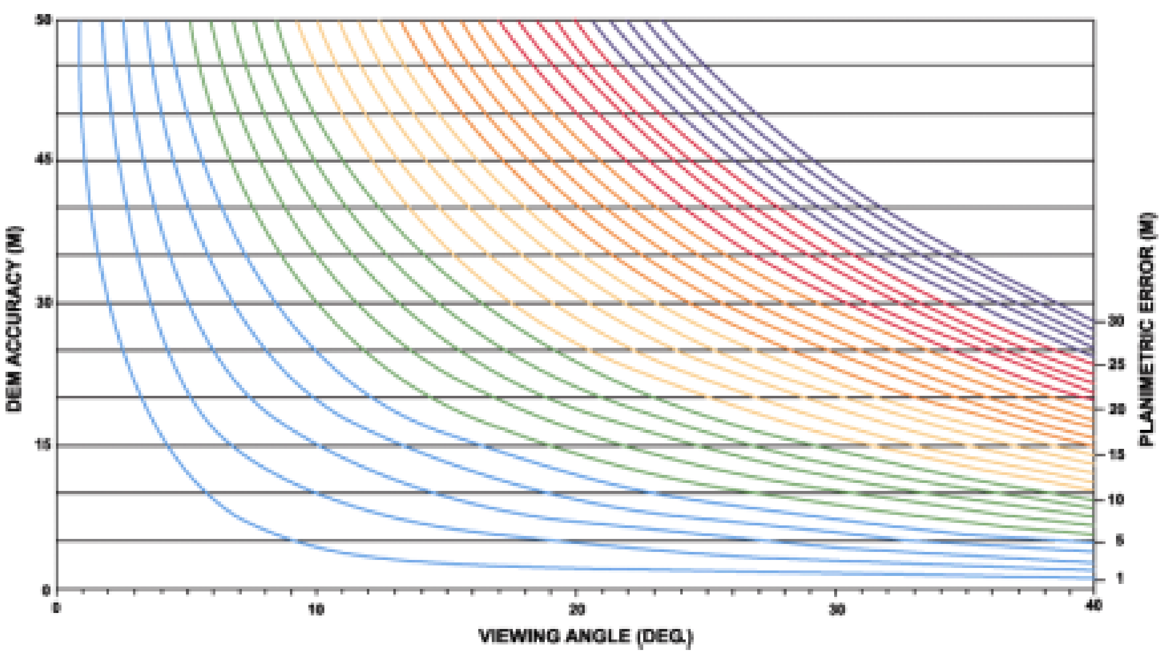

Figure 1: Relationship between the DEM accuracy the viewing angle of the image acquired in the visible, and the planimetric error on the ortho-image

When only two mixed sensor images are available or used on a study site, a complimentary approach to the ortho-rectification and data fusion for planimetric feature extraction based on traditional photogrammetric techniques can be used: the stereoscopic fusion of multi-sensor images provides a virtual three-dimensional model of the terrain surface, and the interactive stereo plotting enables the extraction of cartographic features directly in the map reference system.

The brain can generate the perception of depth with images from different sensors, combining for example the spectral information from the Landsat-TM image and the spatial information from the SPOT-P image for the stereo plotting. Figure 2 is a sub-area (500 pixels by 600 lines) of the multi-sensor stereo pair used in this study: the SPOT-P image on the left and the Landsat-TM1 image resampled at 10-m pixel spacing on the right. It shows the feasability of the stereo-viewing from multi-sensors, since they are close in radiometry even if greater contrast exists on the Landsat-TM image. Forested and cleared areas are well discriminated, and the transportation networks (road, railroad, power line) are bright against the grey surroundings.

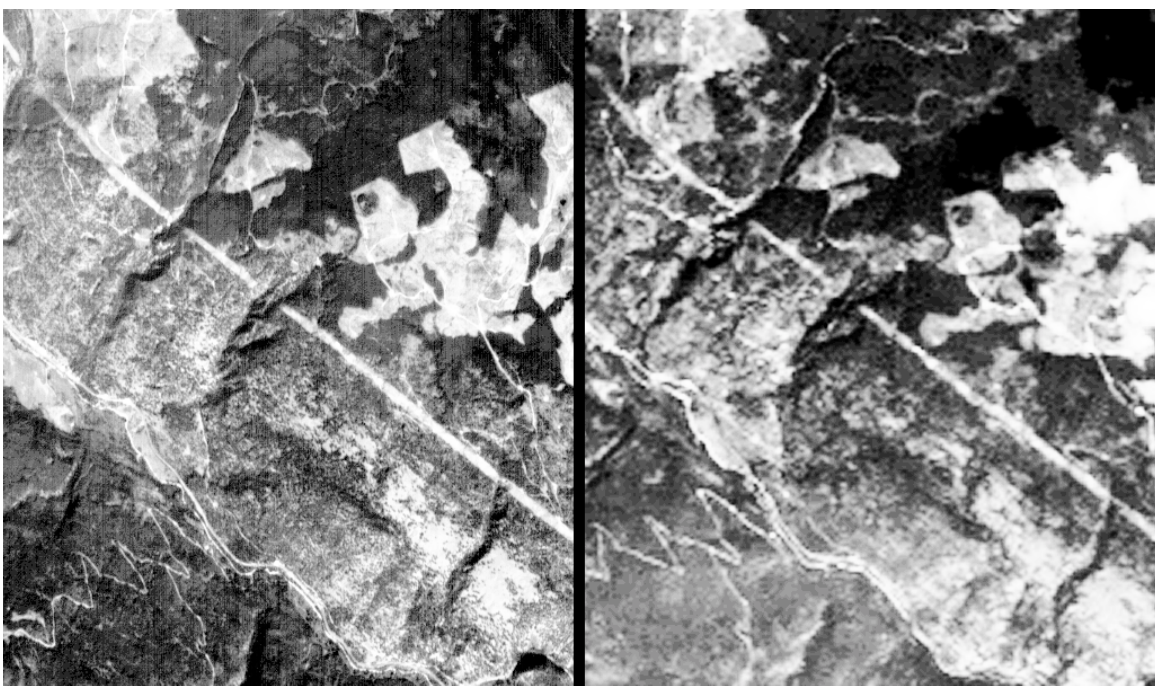

Figure 2: Sub-area of the stereo-pair generated with SPOT-P (left) and Landsat-TM1 (right) images (500 pixels by 600 lines). The Landsat-TM1 has been resampled by cubic convolution with a 10-m pixel spacing.

The advantages of stereo include improved visualization and interpretability of the Earth's surface, and improved extraction of information about the relationships between land shape and structure, slopes and water ways, surface material and vegetative growth, etc. It also enables a better location of ground control points (Welch et al., 1990; Heipke, 1995). Furthermore, Benis et al., 1988, have shown that the interpretation of cartographic information can be facilitated by using three-dimensional or perspective representations, relative to flat 2-D displays. Norman and Draper, 1986, have also shown, that the direct representation of objects (such as the stereo viewing) can better facilitate our understanding and interpretation than the manipulation of information related to these objects (such as the DEM and ortho-image generation).

To achieve stereo fusion and restitution of cartographic features digital photogrammetric stereo workstation are largely available (Dowman et al., 1992; Heipke, 1995). Some of them have developed solution to process stereo pairs from mixed sensors, such as the DVP available at the Canada Centre for Remote Sensing (CCRS). The system (Gagnon et al., 1990; Toutin et al., 1993) and the mathematical equations and modelling (Toutin, 1983; 1995) similar to the photogrammetric equations (collinearity and coplanarity conditions), which drives the DVP, have been already described in details. This paper will then expand on the feasibility and usefulness of the stereo fusion and restitution from mixed sensors stereo pair generated with SPOT-P and Landsat-TM images. The main objectives of this paper is then to present a quantitative study of the type and quality of data which can be interactively extracted from the mixed sensor stereo-pair SPOT and Landsat, and to assess and discuss the accuracy for each extracted planimetric and altimetric feature (road, railroad, power line, spot elevation, DEM).

II 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 characterised by a rugged 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. Roads are mainly loose or stabilised surface roads with two (2) lanes or less, but a few are hard surface roads with two (2) lanes or less. A few lakes and ponds are also found which are connected through a series of creeks flowing between steep cliffs.

The data set consists of remote sensing data (images, ephemeris, attitude) and topographic data. The SPOT-HRV image was acquired on September 24, 1989 with a viewing angle of +26.2°. It is a raw level-1 image with ephemeris and attitude data recorded in panchromatic mode (10-m pixel size). The Landsat-TM scene was acquired on July 13, 1990. It is a bulk level-4 quad-image with ephemeris data. The stereo pair generated with these two image exhibits base-to-height ratio of 0.49, over an area of about 40 km by 50 km.

The topographic data was obtained from the Canada Centre for Topographic Information (CCTI) 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 cartographic X, Y and Z co-ordinates and without movement of the element due to a cartographic generalisation.

The digital cartographic data, stored in an Intergraph Graphic Design System file (IGDS), were not cleaned, 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 and Landsat stereo-model and the topographic data coverage was used for the evaluation of the photogrammetric stereo restitution. It is located in the vicinity of the city of Penctiton (Canada).

III PROCESSING

The processing steps deal with SPOT and Landsat data, ground control points, aerial photographs, and digital cartographic data. The main equipment used for the analysis are: a traditional stereo plotter for the aerial photographs, a digital photogrammetric stereo workstation (on a PC computer) for the remote sensing raster data, and a Geographic Information System (GIS) for the vector data.

a) Digital Data Transfer to the DVP

The SPOT and Landsat data were read from magnetic tapes, radiometrically pre-processed (linear stretched over 8 bits) and transferred to the DVP. Furthermore, the Landsat-TM image has been resampled by cubic convolution with a 10-m pixel size to generate the stereo pair with an equivalent pixel spacing. Ephemeris data and attitude data (for SPOT) are also read and pre-processed to initialise the geometric modelling. An example of the SPOT-P and Landsat-TM stereo pair is given in Figure 2.

b) Stereo Model Set up

Fourteen (14) ground points (mainly road intersections) were first identified and plotted in stereoscopic mode on the SPOT and Landsat-TM stereo-pair. The image co-ordinate accuracy is half a pixel (5 metres), achieved using an interpolated zoom. Then the ground co-ordinates (XYZ) were acquired on a traditional stereoplotter using the aerial photographs at CCTI. The cartographic co-ordinate accuracy is better than five (5) metres. Different types of control points can be used. Apart from full control points (XYZ), one can employ also altimetric points (Z) and homologous and tie points (no ground co-ordinates). 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 SPOT-P and Landsat-TM stereo model, are enough in general for the computation of the parameters and 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 co-ordinates, attitude and orbital parameters, the geometric modelling of the stereo-pair is computed with photogrammetric techniques (co-linearity and co-planarity conditions) and by an iterative least squares adjustment (Toutin et al., 1993). The resulting root mean square (RMS) residuals on fourteen (14) GCPs and seven (7) tie points were 11.7 m, 6.2 m, and 21. 3 m in X,Y and Z directions, respectively. The maximum residuals were -19.9 m, 14.0 m and -33.0 m. These residuals which are in the same order of magnitude of the GCP accuracy and which represent an a-priori stereo mapping error are then a good indication of the final results. As a consequence, the SPOT-P and Landsat-TM stereo-model, without y-parallax (less than one pixel) is generated directly from the raw images.

c) Feature Extraction in the Stereo Model

The data extraction follows the stereo-model set up. For the planimetry, an operator interactively digitizes in stereoscopy different features from the 10-m pixels: roads (small secondary), railroads, power lines. Depending on the thematic application, other planimetric features could be extracted taking into account the radiometry of both sensors. 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. Unfortunately, no zoom was available in this feature extraction step.

The result of this feature extraction is files with XYZ ground co-ordinates in the map reference system. A descriptive code can also be attached to each feature.

d) Transfer to the GIS System

The XYZ files are transferred to the GIS using a bi-directional translator. The vector data (roads, railroads, power lines) are cleaned and edited using different GIS functions. The irregular grid DEM is directly transferred as a point file.

In the same way for the topographic data, a translator is used to import the Intergraph files into the GIS environment. Only data common to both the topographic data and the SPOT and Landsat stereo-model were retained. The vector data are also cleaned and edited. The contour lines are used to generate a triangular irregular network, which is then transformed into a 5-m grid file. This grid spacing avoids errors in the DEM comparison generated by any processing to transform the irregular DEM into a regular grid. The DEM are therefore compared directly point by point without any interpolation.

IV RESULTS AND ANALYSIS

For each extracted feature, a first comparison is done between the topographic file and the DVP file to compute the omission and commission errors (Table 1). The commission error comes from the over-estimation and the omission error from the under-estimation. In a second step, buffered zones centred on the topographic file were generated at 3, 6, 9, 12, 15, 20 and 30 metres. 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. For example, Table 2 gives the full results for roads and Table 3 gives the result summary for all features.

Table 1: Omission and Commission Results

Features	Omission			Commission		
	Length Topo (m)	Omitted Length (m)	Percent	Length DVP (m)	Committed Length (m)	Percent
Roads	263,241	45,826	17.4	238,664	40,518	17.0
Power Line	31,249	4,550	14.6	26,699	0	0
Railroad	19,473	55	0.3	19,418	0	0

Table 2: Results of the Comparison for Roads Extracted from the SPOT-P and Landsat-TM Stereo-Pair with the Checked Topographic Data

Accuracy (metres)	Distance (metres)	Percentage	Cumulative Percentage
3	37,746	19.0	19.0
6	36,211	18.3	37.3
9	31,706	16.0	53.3
12	26,615	13.4	66.7
15	19,319	9.8	76.5
20	22,081	11.1	87.5
30	17,344	8.8	96.4
30+	7,125	3.6	100.0
Total	198,147	100.0	

a) Roads Accuracy

The 17.4 percent omission error resulted mainly from forest regeneration on the old logging roads, but also from non-visibility of roads in the forest. The 17 percent commission error comes from the new logging roads visible on the stereo-pair: the aerial photographs and the satellites data were taken 8 to 9 years apart, and the area has an intensive forestry activity. Table 2 shows a 12 m RMS accuracy (66%), and that there is no bias (larger than 3 m) because the percentage for each 3 m zone decreases from the "0-3" zone to the "over 30" zone, except for the "15-20" zone which is not considered to change the bias. At the bottom of Table 2, one can note that 12.5 percent have errors greater than 20 m, and visually we have checked that few have errors larger than the tolerance (±3 times the RMS error). Each linear entity that had an error greater than 20 m was visually compared, by importing the topographic file into the DVP. Then, the origins of most of these errors were due to the topographic data, to physical changes in position between 1981 and 1989-90, to the interpretation variation in locating curves and intersections, and to the definition of logging roads in their context.

Table 3: Results of the Comparison for all Planimetric Features Extracted from the SPOT-P and Landsat-TM Stereo-Pair with the Checked Topographic Data

Accuracy (metres)	Cumulative Percentage (%)		
	Roads	Railroads	Power Line
3	19.0	23.1	20.4
6	37.3	44.1	37.8
9	53.3	60.1	55.5
12	66.7	71.9	70.5
15	76.5	82.6	81.6
20	87.5	93.4	94.5
30	96.4	99.8	98.2
30+	100.0	100.0	100.0

b) Railroads Accuracy

The 0.3 percent omission error resulted from a 55-m service road, invisible on the images (few pixels). Table 3 shows an 11 m RMS accuracy, with no bias for the same reason previously mentioned, and there is almost no error (0.2%) larger than the tolerance. The 6.6 percent error greater than 20 m is related to the difficulty in identifying the railroad when it was located along a cliff (shaded area) or close to a road. The 30-m pixel resolution of the Landsat-TM and the HRV sensor radiometry range do not provide enough details in this case.

c) Power Lines Accuracy

The 14.6 percent omission error resulted from underground gas pipelines. Table 3 shows an 11-m RMS accuracy, with no bias error for the same reasons previously mentioned. Only 5.5% have error greater than 20 m, and few have been visually checked out of the tolerance. The origin of these errors is mainly due to the fact that power lines that are not visible are extracted as being the middle of the clearcut, which is not always the physical reality.

As Table 3 shows comparisons for the different features, the better results (5-6% difference) obtained with the railroads and the power lines resulted from the definition of these both features: they are more consistent in size, shape and direction with less changes and "small curves" than secondary or logging roads.

d) Elevation Accuracy

For the height measurements, a first evaluation was performed to quantify the altimetric pointing accuracy. Fifty 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 at these features five times each, one gets ±6.6 m altimetric pointing precision. Furthermore, 50 well identifiable check points with known ground co-ordinates (accuracy of 5 m) were plotted on the stereo-model two times each to quantify the absolute altimetric error for spot elevation. A RMS elevation error of 29.4 m was obtained with a bias of -9.6 m. It is worth noting that the stereo images have a base-to-height ratio of 0.49, which gives an altimetric digitising accuracy with a 10-m pixel size of 20 m, and that the original pixel spacing of Landsat-TM is 30 m.

About 9100 points (irregular DEM) which cover an area of 12 km by 11 km, were extracted interactively from the stereo-model, and directly compared to the 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. Table 4 gives the statistical results of this comparison. A bias of 4 m is found, and minimum and maximum errors are -173 m and +197 m, respectively.

Compared to the spot elevation accuracy computed previously (±29.4 m), the 37 m RMS error (66%) computed from Table 4, is consistent. The difference is due to the fact that DEM points are rarely well identifiable points unlike the points used to compute the spot elevation accuracy. But, some of the errors from Table 4 are large (over 100 m). By selecting and displaying on the DVP these 100 points which had an error greater than the tolerance (bias ±3 RMS error), it may be seen that they are spatially grouped rather than randomly distributed in the stereo model. These small errors are mainly human errors due to different reasons (operator's fatigue, poor contrast, clouds and shadows, etc.), and replotting 50% of these points confirmed this, because the results improved.

Table 4: Altimetric Results of the Comparison for the Irregular DEM Extracted from the SPOT-P and Landsat-TM Stereo-Pair with the Topographic DEM

Errors (metres)	Occurrence	Cumulative Occurrence	Percentage	Cumulative Percentage
0-10	1805	1805	19.9	19.9
10-20	1726	3531	17.0	38.9
20-30	1576	5107	17.4	56.3
30-40	1300	6407	14.3	70.6
40-50	861	7268	9.5	80.1
50-60	618	7886	6.8	86.9
60-70	389	8275	4.3	91.1
70-80	267	8542	2.9	94.1
80-90	169	8711	1.9	95.9
90-100	109	8820	1.2	97.1

V CONCLUSIONS AND DISCUSSION

Due to the lack of a precise DEM, multi-source ortho-images generation and their fusion cannot be sometimes realised with (sub-) pixel accuracy. This effect is most emphasised in mountainous areas, where large slopes can generate more errors during the interpolation process in the DEM coarse grid spacing. These errors then propagate through the extraction process of planimetric topographic features: it results in an accuracy which does not meet the standard of mapping or a GIS. Therefore, this paper has demonstrated the feasibility to extract information from two different sensors in the visible with a digital photogrammetric stereo workstation: using a combination of mixed sensors SPOT-P and Landsat -TM images to generate a stereo-pair (base-to-height ratio of 0.49) and to extract planimetric and also altimetric features.

From the raw images, the cartographic information has been interactively stereo-extracted taking into account the complementary, geometric and radiometric, characteristics of the two sensors, and then transferred into a GIS environment. Comparisons have been made with digital topographic data, including planimetric and altimetric accuracies of roads, railroads, powerlines, spot elevations and DEM.

In planimetry, statistical results of extensive stereo extracted data (239 km of roads; 27 km of powerlines and 20 km of railroads) show an accuracy of 11-12 m, with no bias larger than 3 m. Few features (less than 1%) were out of tolerance. The origins of the larger errors were due to the topographic data, physical changes in the feature position between 1981 and 1989-90, and the limitation of the sensors in terms of geometry and radiometry. The use of a zoom in the extraction process should help to improve this accuracy because the planimetric digitising error will be reduced by a factor of at least two (from ±5 m to ±2.5 m).

In altimetry, results over a set of 50 points shows an accuracy of ±6.6 m, and ±29.4 m with a -9.6 m bias for the relative altimetric pointing and the absolute spot elevations accuracies, respectively. Furthermore, based on 9100 points an accuracy of 37 m for an irregular DEM has been achieved. In this case, using a zoom would only reduce the spot elevation accuracy. Operator's fatigue, poor contrast, variation between the two images, clouds and shadows typical from visible images are the main problems in the DEM extraction.

In comparison with the multi-source ortho-images generation and fusion approach, an 11-12 m accuracy for planimetric feature could be only obtained for this study site and data set with a 10-m accurate DEM (Figure 1) on a 10-m grid spacing, because the SPOT-P was acquired with 26.2° viewing angle and the test site has slopes in the order of 45°. On the other hand, the 38-m accurate DEM generated from the SPOT-P and Landsat-TM stereo-pair will create errors of 25 m and 4 m on the SPOT-P and Landsat-TM ortho-images, respectively. This would result for the ortho-images integration:1) in an error of about 25 m, and 2) in problems of mixed pixels. Therefore, the planimetric features extraction on these integrated ortho-images would not have been better than 30 m: a three-fold degradation relative to the results achieved directly with the stereo restitution from the raw images.

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