

## MAPPING FROM MULTISENSOR STEREO IMAGES WITH ANALYTICAL PLOTTER

R.J.Ackermann, G.R. Venkatesh

ITC, Department of Geoinformatics, Enschede, the Netherlands

### ABSTRACT:

The paper describes an approach for the use of multisensor stereopairs with an analytical plotter and analyses planimetric and height accuracy.

The potential of mapping from satellite imagery has been investigated during the last decade, especially since the launch of SPOT, with its high spatial resolution and stereo capability. Although stereo SPOT may offer the best solution today for data compilation, by either a digital or analytical approach, multisensor stereo images may become interesting alternatives.

A SPOT image, preferably an oblique view, can be associated with a stereomate (Landsat-5 TM or IRS India) which requires preprocessing in order to generate a pseudo SPOT stereopair.

The low B/Z ratio will affect mainly the height accuracy, while the planimetric accuracy is comparable to results obtained by normal stereo SPOT. The heights of SPOT/TM models show local deformations in the order of  $\pm 60$  m, which are inherent to the TM images and are probably due to some geometric errors resulting from the scanning mirror system.

### INTRODUCTION

The mapping potential of satellite imagery has been extensively investigated during the last decade. With the launch of SPOT in 1986, stereo capability has been added to satellite images, which gives an improved visualization, facilitates the interpretability of topographic features and allows for stereo measurements. Many users try to exploit the complementary aspects of various satellite data. Merging, for instance, a TM-Landsat with a SPOT-Pan image will add the high spectral resolution of the first to the high spatial resolution of the second. This approach has been widely used during recent years (Ehlers 1988). By generating multisensor stereo data sets, we add the possibility to create a DEM, which can be used for many applications (Welch, Jordan 1990). The basic idea here is to generate a stereopair, comprising a SPOT oblique view and another high resolution satellite image (generally vertical) and to make use of special SPOT software which is now available on most analytical plotters.

Some preprocessing is required since both images have quite different geometric characteristics. This approach could allow more flexibility in the use of satellite data, creating unconventional stereopairs from any set of overlapping images. Since many users have already, at their disposal, single images, stereo capability could be obtained by adding one image (preferably SPOT) for a selected area.

There is an economic advantage which makes this approach attractive but this should not outweigh as serious loss of accuracy as compared with a stereo SPOT pair. Although the digital method may be more appropriate in handling such unconventional stereopairs, the analytical method offers the following advantages:

- high resolution stereo-observation system
- high precision measurements
- available software for stereo SPOT images

The present paper describes a procedure which makes use of well known image processing techniques to generate a TM/SPOT stereopair. The results obtained in planimetry are very close to earlier evaluations of stereo SPOT, but the results in height reveal unexpectedly large deformations, due most probably to some non corrected geometrical errors in the Landsat-5 TM image.

### DATA SETS AND STUDY AREAS

The first tests were carried out with available data at ITC. The selected area is located in the south of France (north of Marseille) representing a changing relief from flat to hilly and mountainous terrain. Good up to date topographics maps at 1:25 000 and 1:50 000 scales are available for the whole area and they contain plenty of well defined features to be used as ground control points or check points. The two SPOT images, both level 1A, are of excellent quality with no cloud cover; they were recorded in October 1989 with a time interval of 14 days (Table 1).

The Landsat-5 TM data available in system corrected CCT format were acquired from EURIMAGE; they were corrected for radiometric and geometric distortions. The TM and SPOT images overlap by about 95%, but due to cloud cover in the eastern part of the TM images, the useful model size is limited to 60 by 40 km. Other data sets were made available for the experiments:

- Hannover (Germany): SPOT-XS and TM having a very low B/Z ratio
- New-Delhi (India): SPOT-XS, level 1B and IRS image (Indian Remote Sensing Satellite), processed to a level equivalent to SPOT 1B.

In all cases good stereoscopic models were obtained but the fact that we use images for which different geometric corrections have been applied will certainly affect the height accuracy.

Area	TM	SPOT		IRS* India
		Left	Right	
France (south)	22/5/88	31/10/89	17/10/89	
	Vertical 30 m	1A, Pan L17°.2 10 m	1A, Pan R26°.5 10 m	
Hannover (Germany)	27/4/87	17/6/86	28/6/86	
	Vertical 30 m	1A, XS L8°.6 20 m	1A, XS R8°.0 20 m	
New-Delhi (India)			12/5/86 1B, XS R2°.3 20 m	13/11/88  Vertical 36 m

\* = linear array sensor

Table 1 : Landsat-5 TM, IRS and SPOT scene characteristics (acquisition date, product, viewing angle, resolution)

#### IMAGE PREPROCESSING

Image preprocessing deals with the preparation of diapositives to be used on the analytical plotter.

For multispectral images first a choice had to be made by of the proper combination of bands to produce a black and white diapositive with the greatest information content and the least correlated bands. After various trials, bands 2,4,5 and 2,3,4 were selected respectively for TM and IRS images. The usual image enhancement techniques were applied in order to obtain a "sharp" image and to facilitate the interpretation and extraction of linear features. Several operators were tried out on the Context Vision and finally the Wallis operator was accepted for giving the best result for TM and SPOT images, based on visual inspection.

The next step of the image processing dealt with the geometric image transformation. The oblique SPOT image (usually level 1A) was kept as the reference image. The selected image (here TM or IRS) was geometrically transformed into the SPOT image, with the help of some common reference points.

Prior to the resampling, the TM and IRS images were scaled to the higher resolution SPOT image; it was expected that this would lead to reasonably good image quality in the resampled image (Tauch and Kaehler 1988).

Special care is required for the selection of reference points, which is not an easy task, due to the different spatial resolutions of both images. Relief displacement in the oblique SPOT image for height differences of 500 m can lead to shifts of several pixels within scan lines, depending on the viewing angle.

It was therefore important to select the reference points at the same height level. An affine transformation was applied to the six common reference points distributed along the edges of the overlapping images.

Results of these transformations are summarized in table 2.

Data set	Reference image	Transf. image	RMSE (pixel)
1	SPOT Pan R 26°.5	TM	1.0
2	SPOT XS L 8°.6	TM	0.4
3	SPOT Pan R 2°.3	IRS	1.0

Table 2: Image transformations

During geometric transformations and subsequent resampling, some distortions may be introduced to the transformed image. In order to check the magnitude of these distortions a reseau of 25 cross marks at a regular spacing of 250 pixels was created in the original TM image. These points were measured on the analytical plotter DSRI before and after the geometric transformation and resampling. Applying an affine transformation using 6 control points with nominal coordinate values, we obtain the following results:

Original TM: RMSE<sub>xy</sub> = 0,017 mm or 6.8 m  
Transformed TM: RMSE<sub>xy</sub> = 0,018 mm or 7.2 m  
(image scale: 1:400 000)

This shows that there is no significant distortion as a result of the image transformation. But on the other hand, geometric errors introduced during the whole conversion process from analogue to digital are not negligible. Fiducial marks are usually not available on satellite images, although they would be useful even for SPOT images.

When we use transformed images like TM or IRS, they overlap only partly with a SPOT image. It is therefore necessary to create artificial fiducial marks defining a square of the same size as a SPOT image.

#### EVALUATION OF PLANIMETRY AND HEIGHT ACCURACY

Multisensor stereo data sets are recorded by two different scanner systems, from different orbit paths and different heights. This leads to a low B/Z ratio which greatly influences the height accuracy.

Various mathematical models have been developed for the restitution of satellite images on analytical plotter (Konecny 1987); the most popular are the orbital parameter model (Guichard 1984, Guban, 1988) and the extended collinearity model. Our experiments were carried out on a DSRI analytical plotter, using a SPOT software suite developed by the Joanneum Research Center, Graz, Austria. The software uses the extended collinearity model, where the positional and attitude parameters are time dependent and can be modelled by polynomes, allowing for linear or quadratic changes.

No special coordinates transformations are required as is usually the case with the orbital parameter model. The coordinates of the GCPs can be in any map projection system (e.g. Lambert, UTM); they are reduced to a local cartesian system by defining a new origin, (round coordinate values, near the centre of the model); the heights of the GCPs are corrected for the earth curvature. This software suite is flexible and accepts multisensor images, since no orbit constraints are included. The stereoscopic accuracy of SPOT images has been widely assessed during recent years, especially by the National Geographic Institute (IGN) of France (Rodriguez et al. 1988). Results of a large scale experiment (31 scenes, 86 check points) are summarized in table 3.

B/Z ratio	Raw Residuals			Filtered Residuals		
	X	Y	Z	X	Y	Z
1 (27°/-27°)	8.1	5.5	4.3	3.8	4.2	3.4
0.5 (0°/27°)	7.8	7.2	8.3	4.6	4.4	6.7

Table 3: Influence of B/Z ratio with SPOT stereopairs

The conclusion was that 6 to 8 GCPs are required to obtain a reliable modeling with RMSE of residuals of less than 10 m in planimetry and height. The GCPs were determined by photogrammetric method with accuracies better than 3 m in planimetry and 1.5 m in height.

More recent experiments, within a joint French-Canadian project, have led to similar results (X=6m, Y=5 m, Z=8 to 9 m) and confirmed the high geometric precision of SPOT images (Begin 1991). Observations were made at ITC (Venkatesh 1992) using different models, stereo SPOT and TM/SPOT. Part of the results are summarized in table 4.

Area	B/Z ratio	No of points	Check Points			
			X (m)	Y (m)	Z (m)	
France	SPOT/SPOT	0.8	29	8.7	6.7	8.8
	TM/SPOT	0.5	26	11.8	7.2	27.4
Hannover	SPOT/SPOT	0.3	33	12.4	9.2	17.2
	TM/SPOT	0.15	24	15.8	12.9	46.6

Table 4: Summary

The orientations of all four models were done with 9 to 12 control points; both TM/SPOT models were parallax free. The analysis of the check points leads to the following comments:

- the results of stereo SPOT compares well with previous experiments
- the TM/SPOT accuracy deteriorates by about 25% in planimetry and about 65% in height, compared to stereo SPOT.

This is a good result for planimetry but indicates some systematic errors affecting the heights, which is of course not unexpected. Sources of these systematic errors can be found in the:

- different processing levels of the two images (TM and SPOT -1A)
- geometric distortions of the TM image
- different resolutions of the two images
- low B/Z ratio

But a careful visual inspection of the TM/SPOT models reveals more serious "anomalies" in the terrain relief.

#### ANALYSIS OF MODEL DEFORMATIONS

There is no clear pattern of model deformation which could be easily recognised by visual inspection except for some flat areas (e.g. canal, airport), showing an undulating aspect in the north-south direction (fig. 1a, 1b).

There is a clear pattern of deformation in the Y-direction with a constant width of 500 m, although not regular; this corresponds to the 16 scan lines of the TM image.

By close examination of some linear features running north-south, in some critical areas one can observe a pixel shift for a whole scan line, but the extent of the deformation within a scan line can not be determined visually.

This problem of pixel shift is apparently well known by TM users and often attributed to the resampling method (Hill and Aifadopoulou 1990). Our TM data produced by EURIMAGE have been resampled by the nearest neighbour method. The assumption that part of the deformations could be attributed to the procedure of image transformation can not be totally rejected; this aspect needs further investigation. In order to get a clearer picture of the pattern and the magnitude of the deformations four tests sites were selected (fig.2) for carrying out:

- grid measurements, with an interval of 200 m
- profile measurements, along the axis of the scans; the distance between profiles and points equals 500 m.

The same measurements were performed in the normal stereo SPOT and the TM/SPOT models. From these two sets of observations height difference models were computed, using the SCOP software:

DIFGRID = SPOT/SPOT - TM/SPOT

DIGPRO = SPOT/SPOT - TM/SPOT

The measurements of profiles along the axis of scan lines required some special preparation; by assigning the same DN values for every 16th line in the original TM image, we obtained a stripped image with all 16 line sets delimited by white lines. In this way the axes of profiles in the TM/SPOT model were clearly defined and the same profiles could be easily measured in the stereo SPOT model. Results of the computations are summarized in tables 5 and 6

Fig. 1a



Fig. 1b

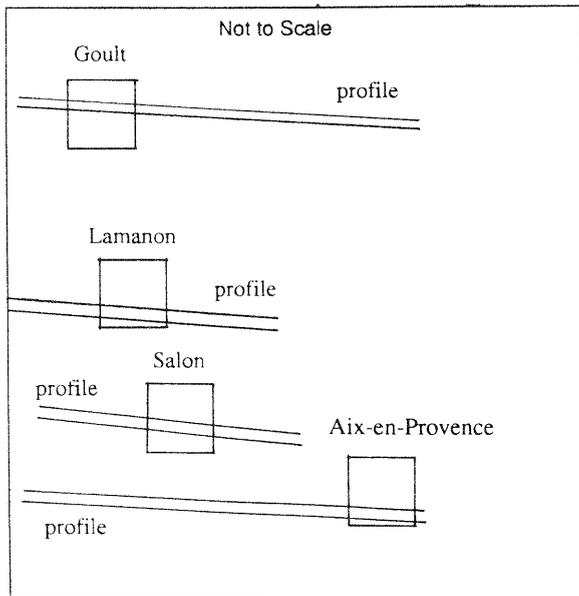
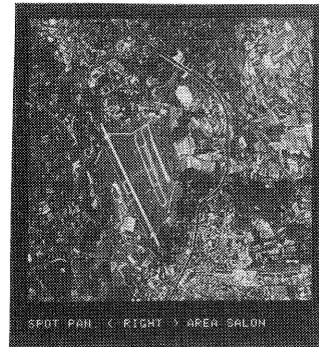
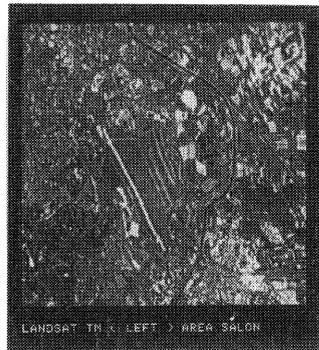


Fig.2: Test sites for grid and profile measurements

Area	Size (km)	No of pts.	Zmin (m)	Zmax (m)	Std.dev. (m)
AIX	5*5	603	-57.6	50.2	22.6
GOULT	5*5	612	-52.4	53.4	22.3
LAMANON	6*6	761	-62.4	78.4	30.6
SALON	6*6	736	-49.7	55.4	21.7

Table 5 : Summary of grid computations

Area	Prof. (km)	No of pts.	Zmin (m)	Zmax (m)	Std.dev. (m)
AIX	36	174	-46.0	47.6	18.5
GOULT	36	152	-57.3	55.3	27.9
LAMANON	17	122	-60.1	43.2	21.0
SALON	24	93	-56.9	50.0	23.0

Table 6 : Summary of profile computations

Both grid and profile measurements in the TM/SPOT are burdened with systematic errors in some areas due to a radiometric imbalance between the TM image (May 1988) and SPOT image (Oct. 1989).

Outliers had to be rejected; therefore tolerance values were set to 2.7 of the standard deviation.

Disregarding the grid measurements of LAMANON, showing very large height discrepancies, we can accept an average standard deviation of 22 m, defining tolerance values of  $\pm 60$  m. The outputs of the height difference models, previously corrected for bias have been visualized in two ways:

- by grid stereograms obtained from two perspective views (fig. 3)
- by profiles showing the direction of the scan lines in the transformed TM image (fig. 4).

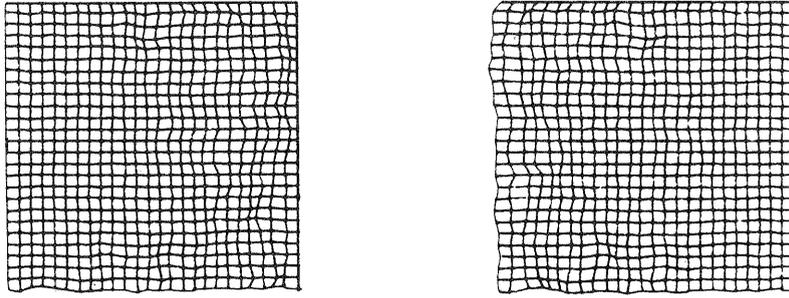


Fig. 3: Stereogram showing the height deformations

around Aix-en-Provence

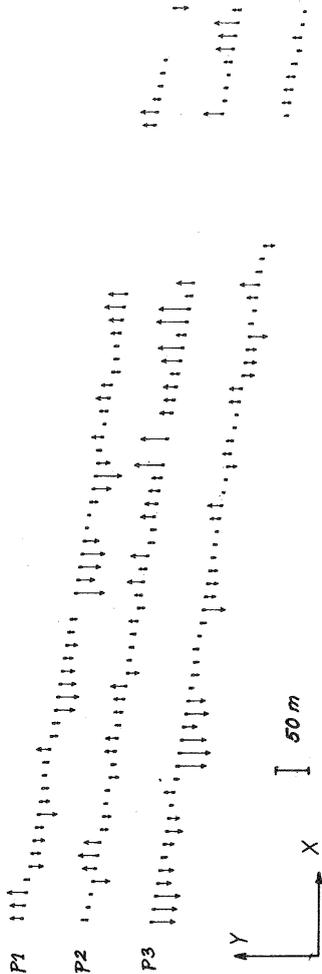


Fig. 4: Height deformations along profiles near Aix-en-Provence

Analysis of the profiles shows a systematic pattern of deformation; yet some changes in the magnitude or sign of the systematic errors occur often every 5 to 6 intervals of 500 m.

Converting a height error into a parallax error, by applying, with some approximation, the formula used in photogrammetry, we write:

$$\Delta p = B/Z * \Delta Z$$

for  $B/Z=0.5$  and  $\Delta Z=60.0$  m  $\Delta p = 30.0$  m

A parallax of 30 m corresponds exactly to a one pixel shift in the original TM. Apparently we are confronted here with an old problem of pixel shift (1-1.5 pixels) which becomes critical only if we want to use Landsat-5 TM data for height measurements and DTM generation.

#### CONCLUSION

The present approach for the use of multisensor images offers an interesting alternative next to Stereo SPOT. Accuracy performances obtained with stereo TM/SPOT compares well with stereo SPOT images in planimetry, but the heights show an irregular pattern of deformations with maximum values up to  $\pm 60$  m. Some of these areas of deformations can be easily located, especially in flat terrain. Unless some improvement can be made in the geometric processing of the Landsat-5 TM data, to correct for some system errors, the height inaccuracy will be the limiting factor for mapping applications.

There is actually a growing interest for stereo images and there will be new satellite images available in 1992 (e.g. Landsat-6 ETM) with new possibilities for using multisensor stereo images.

Although the digital approach for handling such data sets seems more appropriate, we believe that for the time being and for some years to come, the analytical plotter with its SPOT software will be used for data acquisition from satellite imagery.

#### REFERENCES

- Begin D. 1991: Expériences Franco-Canadiennes; précision géométrique des données SPOT; résultats canadiens. CISM Journal Vol 45 No 2
- Ehlers M. 1988: Multisensor Image Fusion Techniques in Remote Sensing. ISPRS, Commission VII, Kyoto
- Gugan D.J. 1988: Topographic Mapping from SPOT Imagery with the Kern DSR Analytical Plotter System. ISPRS, Kyoto
- Guichard H. 1984: Etude mathématique des possibilités cartographiques de SPOT. (SPOT IMAGE)
- Hill J., Aifadopoulou D. 1990: Comparative analysis of Landsat-5TM and SPOT-HRV1 data for use in multiple sensor approaches. Remote Sensing Environment 34:55 1990
- Konecny G. 1987: Geometric evaluation of SPOT Imagery (Hannover University)
- Rodriguez V., Gigord P., de Gaujac A.C., Munier P. 1988: Evaluation of the Stereoscopic Accuracy of the SPOT satellite. PE&RS Vol.54 No 2
- Tauch R., Kaehler M. 1988: Improving the Quality of Satellite Image Maps by Various Processing Techniques. ISPRS Commission IV, Kyoto
- Venkatesh G.R. 1992: Evaluation of Multisensor Stereo Data Sets using Analytical Plotter. M.Sc. thesis ITC
- Welch R., Jordan T. 1990: Geocoding and Stereo Display of Tropical Multisensor Datasets. PE&RS Vol.56 No 10