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TOPOGRAPHIC MAPPING AT THE SCALE OF 1:50 000 FROM SPOT IMAGERY

CARTOGRAPHIE TOPOGRAPHIQUE A L'ECHELLE DU 1/50 000 A PARTIR D'IMAGES SPOT

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ABSTRACT

SPOT images can be used at the place of aerial photography to make topographic maps at the scale of 1:50 000.

Altimetric and planimetric information can be plotted with an accuracy of around 5m (RMS), provided that good Ground Control Points are available.

The suitable interval between contours is 20m. However, the identification of planimetric information is not as reliable as with aerial photography.

IGN France has set up an operational production chain of topographic maps from SPOT imagery, based on the use of an analytical stereoplotter (Traster system, MATRA). Specific software has been written and implemented. Regular topographic maps and space maps have been produced at the scale of 1:50 000.

This technology can easily be set up in any survey organization, because it doesn't require much additional training for photogrammetry operators used to work with aerial photography and stereoplotter.

The paper:

- describes the technical aspect of topographic map production from SPOT imagery,

- presents the available results in terms of quality, accuracy and efficiency,

- compares the use of SPOT imagery and aerial photography for topographic application.

RESUME

Les images SPOT peuvent être utilisées à la place des photographies aériennes pour faire et réviser les cartes topographiques jusqu'à l'échelle du 1:50 000. Les informations altimétriques et planimétriques peuvent être extraites avec une précision de l'ordre de 5m, à condition que de bons points d'appui aient été acquis. Un intervalle de 20m entre courbes de niveau peut être atteint.

L'identification des détails planimétriques est cependant moins fiable qu'avec des photographies aériennes.

L'IGN (Institut Géographique National) a mis en place une chaîne opérationnelle de production de cartes topographiques à partir d'imagerie SPOT, basée sur l'utilisation d'un restituteur analytique (TRASTER, de MATRA). Un logiciel spécifique pour les images SPOT a été écrit et implanté. Des cartes topographiques régulières et des spatiocartes ont été produites à l'échelle du 1:50 000. La technologie ainsi développée peut facilement être transférée dans n'importe quelle organisation cartographique, car l'investissement en formation est relativement faible si l'on dispose déjà de personnel qualifié en photogrammétrie, possédant une expérience d'utilisation de restituteurs pour l'exploitation de photographies aériennes.

La communication présentée au colloque "PIX'ILES 90":

- décrit l'aspect technique de la production cartographique à partir d'images SPOT,

- présente les résultats disponibles en terme de qualité, précision et rendement,

- compare l'utilisation des images SPOT à celle des photographies aériennes.

INTRODUCTION

Since the launching of the first earth observation satellite, there are still few operational production chains and finished products in the field of remote sensing. More often, remote sensing remains the attribute of research laboratories and its potential users do not integrate it in their activities as an efficient and profit-earning tool.

In the field of topography, the reason was first of all technical : indeed, the first available images were not adapted to the specific needs of map-makers. Their low resolution was the main limitation, even for low scale mapping.

For example, a highway must be represented on any regular topo-map at a scale lower than, let us say, 1:500 000. But it cannot always be seen and interpreted from images with a resolution bigger that 20 meters.

Moreover, these images could not provide stereopair from which elevation can be derived.

More generally, the possibility to use space imagery for topographic purpose depends on three factors, which are :

- the geometrical accuracy that can be reached,
- the accuracy with which altitude can be restored,
- the type and size of the smallest details which can be observed and extracted from images.

Those factors induce an optimal representation scale with respect to the traditional cartographic rules and standard.

With regard to these factors, it is now proved that SPOT is well adapted to topographic mapping at scale 1:50 000 (and lower scales) in most of the countries, on an operational basis.

This is mainly a consequence of the technical features of SPOT which are here quickly reminded :

First, the two "High Resolution Visible" (HRV) images carried by SPOT can operate in either of two modes :

- panchromatic (black & white) mode with 10 meters ground resolution,

- multispectral mode in three spectral bands (green, red, near infrared) with 20 meters ground resolution

This is the finest resolution available from all the operating civilian satellites.

Second, the capability of off nadir viewing can provide stereoscopic pairs, which can be explored by photogrammetric processing in order to get both planimetric and altimetric information.

But let us see now in more details the different steps of map production from SPOT imagery. These are :

- data acquisition
- geometric modelisation
- information extraction : + altimetry
  + planimetry
  + field checking
- map editing, output and printing.

DATA ACQUISITION

The first advantage of SPOT is the size of the area which is covered by one image, which is 3 600km2 for one aerial photograph at 1:100 000 scale. So, the number of images to manipulate is 6 to 10 times lower ; this is appreciable in a production context.

If specific equipment and staff is not available, an aerial photography campaign is an heavy and expensive operation, and SPOT offers a quicker access to data for a lower price.

Nevertheless, let us remind that SPOT images will not take the place of high scale photographies (as 1:20 000 photographies) for mapping application at scale larger than 1:50 000.

The methodology which is described hereinafter requires the following input images :

- one SPOT stereopair in panchromatic mode, on CCT and films. The scale of 1:400 000 is good, but subimages at the scale of 1:200,000 are better. The suitable viewing angle is discussed in Map Editing,

- although it is not obligatory, one multispectral image on CCT.

The other main input is a set of GCPs, (Ground Control Points) as explained in paragraph geometric modelisation and accuracy.

After data acquisition, the map-maker faces two problems :

- information extraction
- information positioning and plotting

These two problems are mixed, but the second one, closely linked to geometry and accuracy, is first presented.

GEOMETRIC MODELISATION AND ACCURACY

In a traditional process of topo map production, the information extracted from the photographs is laid on map, with an accuracy which depends, among other, on the processing tool (types of stereoplotter for example), and the locations, number and quality of Ground Control Points.

Ground control points (GCPs)

A GCP is a point whose cartographic coordinates are perfectly known, and which can be identified with a good accuracy on the images. Such points are necessary for a good geometric modelling, on which the final accuracy depends (see Geometrical Modelisation).

These points are features easily identifiables on images, as crossroads or bridges.

By using aerial photography, it is necessary to have at least one geodetic point every 30km, and 40 control points for 1 000km2. (This is for a 1:100 000 map, it is more for the scale of 1:50 000)

With SPOT imagery, it is necessary to identify six control points per image ; but if "segments" are processed, that means that if few images of a same path are processed together, the number of necessary GCPs is the same, but these have to be chosen on the upper and lower scenes of the segments.

This means that :

1- The intermediary area can be mapped without any control point.
2- The mean number of points per scene can become 1 or 2.

More often, control points (as crossways or bridges) are permanent features, and they can be found on existing maps (which even may be updated). If no good map is available, it is necessary to go to the field to get a geodetic network. The positions can be measured quite quickly with a sufficient accuracy by satellite positioning system.

Such methodology requires few hours to get the position with an absolute accuracy of 10 meters and a relative accuracy (in a given area) of 1 meter : this is enough for geometrical modelisation of a whole set of SPOT images.

All things considered, compared to methods based on aerial photography, the number of control points can be 10 to 20 times lower. It follows an important time and money saving the determination of control points represents 40% of the total cost of a classical topographic mapping work.

Geometrical modelisation

To reach the best accuracy, it is necessary to modelize the mathematical relation between the coordinates in the image (P,Q) and the cartographic coordinates (X,Y,Z).

The most general relation is:

$$(1) \quad F\ (P\ ,Q\ ,X\ ,Y\ ,Z) = 0$$

How can we determine F ?

SPOT records many information about its own orbit and attitude. These are "ephemeris" (approximate position and velocity) and "attitude" variations (yaw, pitch and roll).

By taking into account these information (which are provided together with the CCT), it is possible to build the geometry of viewing and give a mathematical formula for F. (GUICHARD). This formula has some unknown parameters but can be solved and provide an accurate relationship if at least 6 good GCPs are available.

To summarize, it is possible to calculate a very accurate relation between image coordinates and cartographic coordinates, by taking into account a minimum of 6 Ground Control Points, ephemeris and attitude.

But the objective of geometric modelling is actually to derive cartographic coordinates (X,Y,Z) from the image coordinates. This is not possible with one image, since three unknown values cannot be derived from two variables (P,Q).

There are therefore several kinds of modelisation :

1- If variations of altitude are neglected, we assume that the area is flat and equation (1) can be solved so that we get

$$\begin{pmatrix} X \\ Y \end{pmatrix} = FL\ (P * Q)$$

The Planimetric coordinates are derived from the image coordinates, the deformation due to relief is neglected.

This is called level 2.

2- SPOT can record stereoscopic images. This allows elevation restitution:

If stereopair is available, it is then possible to derive three coordinates (X,Y,Z) from the two images :

(X,Y,Z) = F2 (P ,Q ,P',Q') where (P,Q) are the coordinates in the first image, and (P',Q') the coordinates in the second image.

3- If a DEM (Digitized Elevation Model) is available, then for each (X,Y), Z can be calculated and therefore it is possible to get a very accurate relation: (X,Y) = F3 (P ,Q) where the relief effect is taken into account.

This is called level 3.

The geometric modelling is thus calculated from GCPs and orbital and attitude parameters. It can then be used for geometric corrections or photogrammetric application :

- Geometric corrections provide "rectified" images, which can be superimposed on maps. Depending on the nature of relief and the required accuracy level 2 or level 3 corrections are suitable. With good control points, geometric accuracy of rectified images is often better than accuracy of available maps. The accuracy which can be reached is half a pixel : 5m for panchromatic images and 10m for multispectral images.

- Photogrammetric application consists in plotting both planimetric information and level contours, from stereopair. The level contours can then be used to make a DEM, which allows level 3 geometric corrections.

RELIEF PLOTTING

As SPOT images are cylindrical perspectives (and not conical perspectives) they are not well adapted to analogic stereoplotter. But the geometric modelisation software can be implemented on analytical stereoplotter, as it was done by IGN on the analytical stereoplotter Traster (Matra).

The use of the plotter is very simple: attitude and orbital parameters are automatically loaded from the CCT into the computer ; control points are interactively designed and entered ; then, the geometric modelling is computed. Standard images on films at scale 1:400 000 are used. The operator follows with a cursor any contour or detail identified on the stereopair (he sees in three dimensions). The relative positions of the images on the plates are automatically regulated.

The operator has the same feeling as when he works with aerial photography. Only the scale is different.

As output, the contours are automatically drawn on a sheet, and stored in a digital form. They can be transformed in "raster mode" to provide a DEM (Digitized Elevation Model).

It is important to see that the use of such a technology is relatively simple for photogrammetrists. Indeed, the survey organizations can use SPOT very quickly : their staff, which is already familiar with stereoplotter, need a little training to use SPOT imagery. No need to be a computer scientist, provided that specific software has been implemented on an analytical stereoplotter.

The accuracy that can be reached is 5m, with good GCPs. see Map Editing). This allows an interval between contours of 20m and is compatible with the standards of the scale 1:50 000.

PLANIMETRIC PLOTTING (LANDSCAPE FEATURE PLOTTING)

The first way to get the topographic information is to use the images as photographies and to work by visual interpretation. This can also be made on an analytic restitution system. With an image processing system, some of the information can be extracted by such methods as classification, pattern recognition, i.e. automatic image analysis.

The possibility to extract the landscape details depends mainly on the size, the shape and the radiometric reflectance of the object, in regard with its neighbourhood. For example, a house in the middle of a field can be identified ; the same house in the middle of a village cannot be isolated, but the village limits and the main streets can be seen.

Some general rules can be given :

- The linear features as roads, rivers, natural limits, urban borders can be extracted from the panchromatic images, usually by visual or interactive interpretation (on analytic restitution system : Traster in IGN). This is fully operational. The automatic extraction of linear features from panchromatic images is also possible, but is not yet used in a repetitive production context : experiences are being conducted, and improvement has still to be made to use such a method in an operational topographic production chain.

- The zonal themes (water, agriculture, vegetation, forests, urban areas, land use) can directly be mapped from the image by visual interpretation or through an image processing system. Depending on the themes which have to be extracted, this is more or less operational and adapted to a production.

The accuracy of position of identified planimetric details (which is not the possibility to identify the details) is linked with the accuracy of geometrical correction, and is 5 meters in panchromatic mode, and 10 meters in multispectral mode on level 3 processed images ; it is entirely compatible with the 1:50 000 standards.

On the other hand, some details which are currently drawn on 1:50 000 scale maps cannot always be seen, and therefore, compared to a process based on aerial photography, the field checking remains absolutely necessary and is even heavier.

This is the main disadvantage of SPOT when compared to aerial photography.

MAP EDITING

This phase is not specific to SPOT and is therefore not described in this paper. Nevertheless, let us remind that, when SPOT is used through an analytical stereoplotter through an image processing system, all the extracted cartographic information are on a digital form, and can then directly be inserted in a "Geographic Information System" or used in a automated mapping system, with which map editing and film production are very fast and efficient.

RESULTS AND ACCURACY

IGN France has implemented the geometric modelisation in a specific software, on an analytical stereoplotter Traster (Matra). As explained above, it needs, for each stereopair, the orbital and attitude parameters of the satellite and a set of at least 6 GCPs. The methodology was tested and the main results are provided hereafter :

60 stereopairs were formed from combinations of 31 scenes, with each scene able to be used in more than one stereopair, with the following viewing angles :

14 stereopairs	+ 27° / - 27°
42 stereopairs	0° / - 27°
4 stereopairs	+ 13° / - 13°

The R.M.S. of modelling residues over all 561 measurements is of 4.5m in X, and 4.1m. in Y and Z.

More generally, it may be said that :

- 6 to 8 GCPs are sufficient to obtain a reliable modelling.

- The residue values obtained for the stereopairs (-27/ +27) (B/D = 1) are significantly lower than for the other stereopairs (B/D = 0.5). This probably owes something to the convenience of the plotting (non - tilted stereomodel, exaggerated relief).

Finally, it can be seen that the R.M.S. residues for Ground Control Points are, for each modelling, almost all lower than 6 meters, for whatever the number of GCPs, the Base/Distance (B/D) ratio, the geographic area and the spectral mode.

Generally speaking, it can be seen that RMS residues of less than 6m are obtained once at least 8 GCPs are used for constitution of the model.

Best results were obtained when the interval between viewing was the smaller.

Special emphasis was given to examining the effect of the B/D ratio on the restitution quality. The table below shows this to have an important bearing above all in Z :

Configuration	Parallax (P) and standard deviations		
+ 27° / -27°	B/D = 1	X : 3.9 m	Z : 3.5 m
		Y : 4.4 m	P : 3.9 m
0° /+ - 27°	B/D = 0.5	X : 4.9 m	Z : 6.5 m
		Y : 4.5 m	P : 4.4 m

Finished products

By using its SPOT based topomap production chain, IGN has produced several kinds of maps.

The procedure which is now operational is summarized hereafter :

- Contours with an interval of 20m are extracted from stereopair, on an analytical stereoplotter. This is done by visual interpretation from the Panchromatic images on film at 1:400 000, while the CCT provide ephemeris and attitude. This requires at least 6 GCP.

- DEM is derived from the contours, on an image processing system.

- Linear information and some areal information are extracted by visual interpretation of stereopair, on analytical plotter.

- Some areal information are extracted from the multispectral image by computer assisted interpretation on image processing system, mainly by supervised classification.

- Using the DEM and GCP, all images (and derived information) receive a level 3 geometric correction, on image processing system.

Then, several maps can be produced and printed :

- line map,

- space-map, where the background is the geometrically corrected image.

The teaching of the real production allows the following general conclusions :

1- Provided that good GCPs can be obtained, the accuracy of 5m can be reached both on planimetry and altimetry. This is compatible with the scale of 1/50 000.

2- Most of the planimetric information can be extracted by visual analysis of stereopair through an analytical stereoplotter. Nevertheless, field checking is still necessary.

3- The use of SPOT imagery through an analytical stereoplotter is fully operational, and easy for photogrammetry specialist, because it is close to the work on classical plotter with aerial photography.

Therefore, survey agencies which want to use SPOT should not need a long transition phase.

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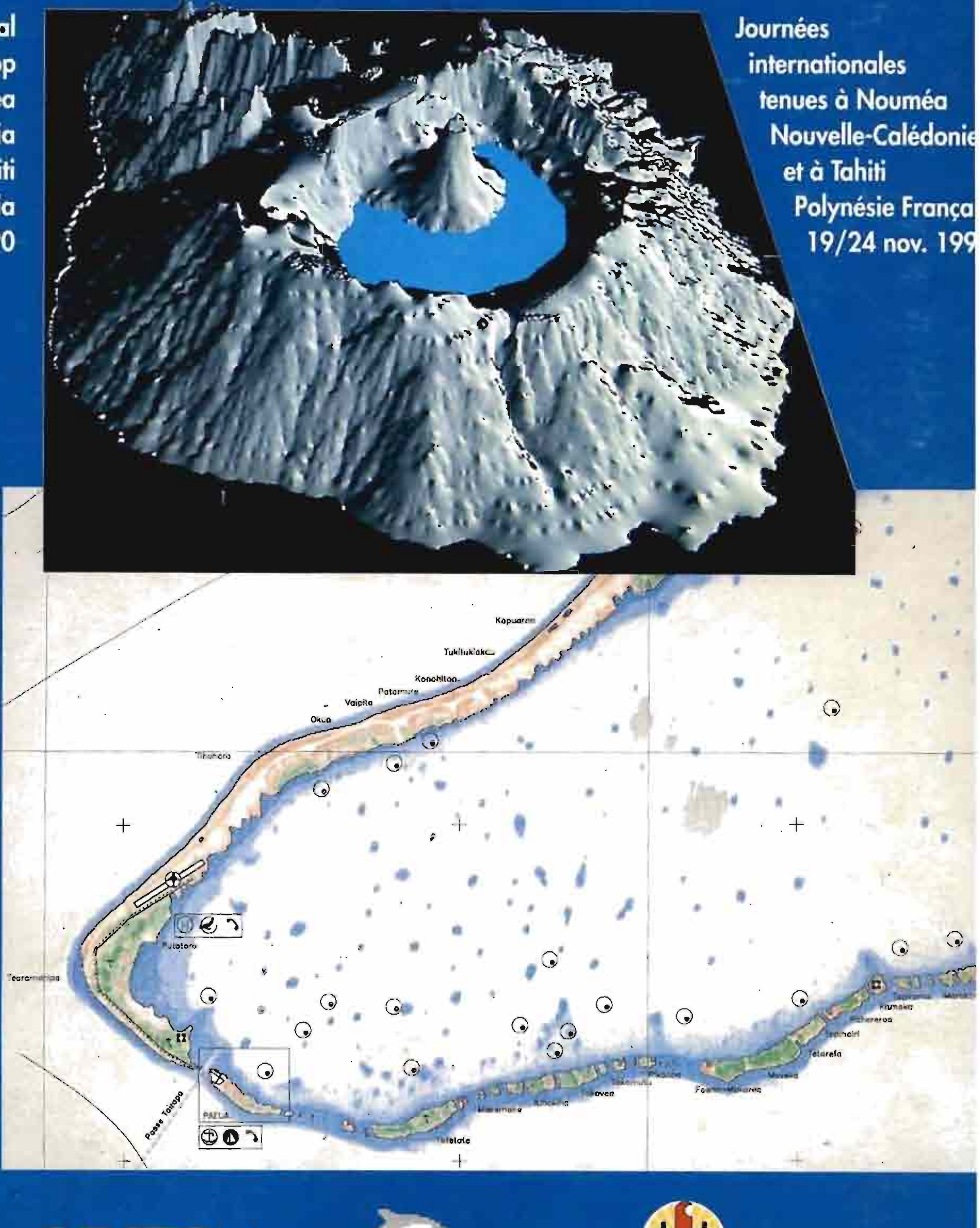

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