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Pecora Symp. file

IC 10-142

Monsieur Allen WATKINS
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AN/7356

Saint Mandé, le 19 octobre 1983

Dear Mr. Watkins

I was pleased to attend the last PECORA VIII Symposium and to give a presentation during the SPOT session. Unfortunately my paper was not yet typed and I had to take it back with me in France. Now it is ready and you will find it enclosed, hoping that it is not too late to publish it in the proceedings.

I thank you in advance to do your best.

Sincerely,

A. Baudoin

A. BAUDOIN

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Integration of Oblique Space Imagery
Into Geographic Data Bases

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Abstract

The interest of oblique views from a satellite such as SPOT is described : large areas can be covered with high quality images (without clouds) much faster than with the use of vertical views only. Some particular interesting areas can be surveyed very frequently with SPOT. In this case most of the images are oblique.
Oblique views are also needed to get stereo pairs used for mapping purposes and to study radiometric properties of land cover (stereoradiometry).
These oblique images have to be corrected : geometric distorsions can be removed using a digital terrain model, or can be evaluated from several images of the same area : for example a D.T.M. can be computed from stereo-pairs. Rectified images can be compared to other images or other geographic data bases in order to get a better interpretation of the image and therefore a better up dating of these data bases.

Introduction

Up to now earth observation satellites (LANDSAT) gave vertical images. Users begin to know how to use them but they also need other kinds of data to get better results. For many applications oblique views could be interesting. For this reason, at the request of French users the near future satellite SPOT will have a pointing mirror in each sensor which allows it to get either vertical views or off nadir images of the earth. This opportunity could be very useful but needs to be well understood : oblique views have special caracteristics and their processing is more difficult than for vertical images. But with the help of other geographical data they can give better up to date information. Even with few additionnal data the study of several oblique views of the same area can give new kinds of information, not yet known with the same accuracy.

I - INTEREST OF OBLIQUE VIEWS

SPOT will have two identical sensors : H.R.V.s (High Resolution in the Visible). Each sensor has a pointing mirror which allows side looking images from - 27° to+27°. From its 822 km hight orbit these images cover an area of 60 km by 60 km (at the nadir) or of 60 by 80 km (at 27°). This area belongs to the potential field of view of the satellite which is more than 900 km wide, 450 km from each side of the SPOT's track.
The 26 days cycle of the satellite gives the opportunity to get a world wide coverage (except polar areas) with vertical images. In this case the two H.R.V.s are working together in order to cover a trip of 117 km (2 images of 60 km with an overlap of 3 km).
The use of oblique views is interesting to get a faster coverage of a whole region and also :

- to survey very frequently some particular areas
- to get stereoscopie pairs for mapping purposes
- to study radiometric properties of land covers in relation with the view angle (stereoradiometry).

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I - 1 - COVERAGE OF LARGE AREAS

The main problem to get good pictures of the earth from space in the visible spectrum is to avoid clouds. Without this cloud problem SPOT would cover the whole world within 26 days.
The study of cloud cover statistics shows that a very important delay is necessary to cover very large areas without any lack of information. This delay depends on the climate of the area.
As an example CNES has studied the coverage of the french territory using SPOT (Réf.1). The main geographical caracteristics of FRANCE are recalled here :

Area : 550,000 km2
Average latitude : 47° (North)
Climate : moderate
The average number of days without any clouds is between 35 and 40 per year.

The results are the following :

- delay to cover 100 % of the area with vertical views of less than 1:8 cloud cover :
  20 to 32 months
- delay to cover 100 % of the area with either vertical or oblique views of less than 1:8 cloud cover :
  7 to 11 months

The delay is reduced by a factor 2 to 3 with oblique views : we are almost sure to get at least one good image per year for any place in France. Most of them can be covered by a vertical view (95 %) but for the remaining 5 % they have to be covered by oblique views the same year or by vertical views the next year.
To study the evolution of vegetation and crops more than one coverage per year is needed : it is impossible to get one image per season everywhere in France but within 3 months (*) :

- less than 40 % of the area can be covered by vertical images
- 30 % of other areas can be covered by oblique views
- 30 % of the country is not covered.

In this case the use of oblique views allows to get almost twice good images than with vertical views only.

I - 2 - SURVEY OF A PARTICULAR AREA

Some applications need to get as many images as possible on few particular areas. Test fields for crop forecasting, volcanos or flooding areas are some examples.
If you want to take an image of one particular area everytime it is possible from SPOT, this means that you could not do anything else with one of the two HRV's but, depending on the latitude you can point your area of interest : (see ref.2)

- 7 times each cycle (26 days) at the equator
- 11 times each cycle at 45°
- 28 times each cycle at 70 ° (once a day and twice during two days)

Among these opportunities only one per cycle is vertical.
In reality the number of good images which could be taken depends on the cloud cover of the area. For some applications this cloud cover could be greater (3 or 4/8) than for a cartographic coverage of an area (1/8).

(*) This is an average : during the summer the coverage is greater, during the winter much lower.

.../...

The total number of these images can differ from one climate to another but the proportion of vertical and oblique views remains the same for one choosen latitude.
This shows that an average of only one vertical image for ten obliques views is what it is to be expected if we want to survey very carefully these areas.

I - 3 - STEREOSCOPY

In order to get accurate maps in many countries where the existing cartography is poor SPOT could be used. Oblique views can give stereoscopic pairs of images : the same area is viewed from two different points, (the distance between these two points is the base).
The two images look the same but the relief of the terrain creates some geometric distorsions between them (parallaxes).
These parallaxes are used to visualize the relief and to measure it. The best results are given with stereopairs which have the greater base which corresponds to the extreme looking angle : + and - 27°.
But to avoid radiometric differences between the two images it is better to have them taken with a delay as short as possible : one day or two.
The orbit of SPOT was choosen to get the best ratio base over height (B/H) for consecutive views at the equator : during one cycle of 26 days there are four possible stereopairs with a delay on one day and with a base over heigt ratio (B/H) of 0.75.
The number of possible "one day" stereopairs increases with the latitude but the B/H ratio decreases

6 per cycle at 40° with a B/H of 0.57
13 per cycle at 60° with a B/H of 0.38

with a two days delay between the two images of the stereopairs it is possible to get better B/H ratio :

1 per cycle at 40° with a B/H of 1.14
8 per cycle at 60° with a B/H of 0.76
(See fig. 1).

I - 4 - STEREORADIOMETRY

The reflectance of a terrain element depends on the sun illumination angle (changing with the season for sun synchromous satellite such as SPOT and LANDSAT), but also on the view angle and on the slope of the terrain. The effect of the view angle can be described by a function : the bidirectional reflectance distribution.
This function is difficult to measure but laboratory experiment showed that :

- Different kinds of land cover have different bidirectional reflectance distribution.
- The study of this distribution can give information on the texture of the vegetation which could be very interesting for some users.

It is very difficult to study these phenomena with LANDSAT images and SPOT will give an appropriate tool to test some theorical models (Suits model for example) and to use these models for the interpretation of the space imagery.

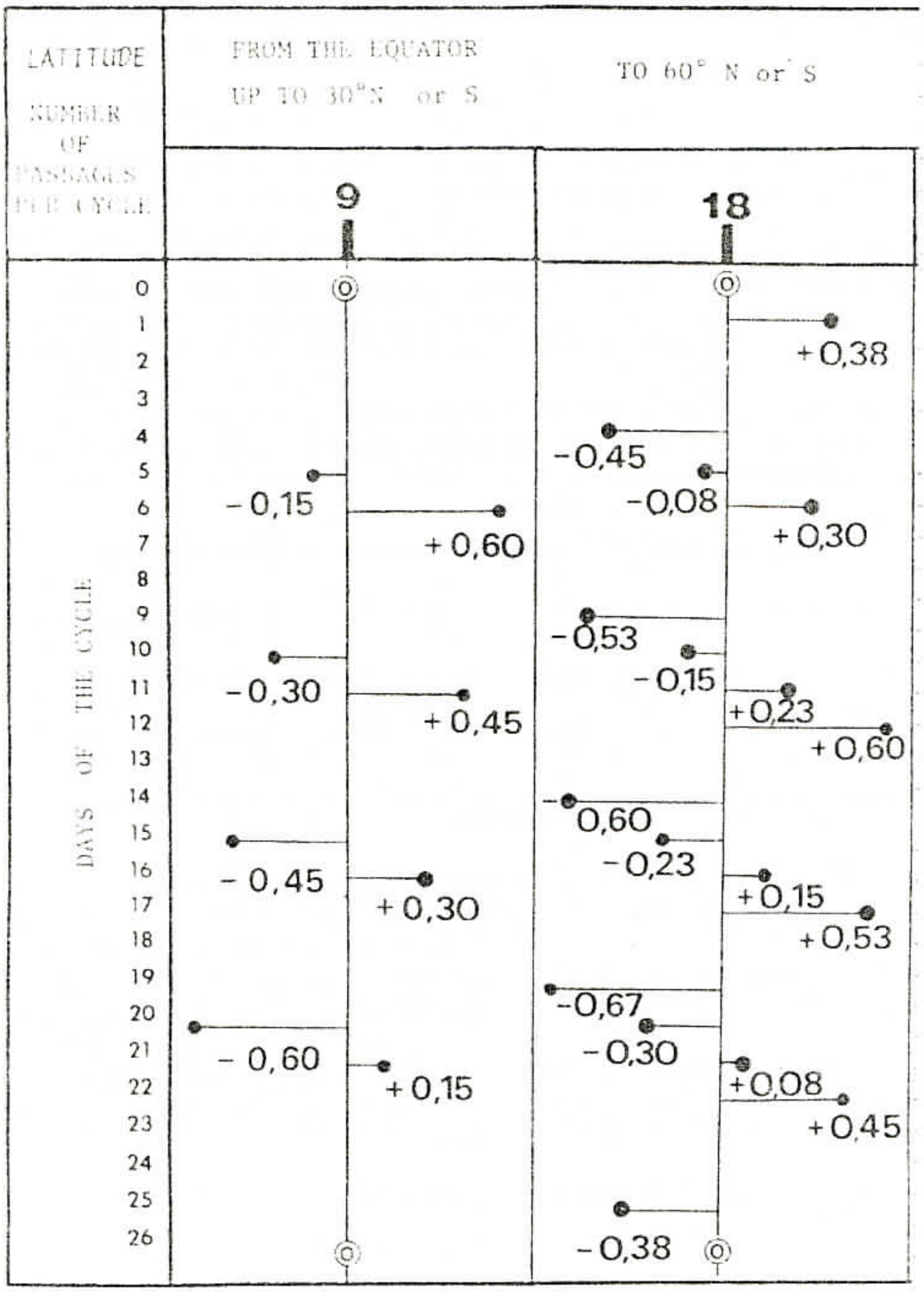

Fig. 1 – Stereopairs with B/H ratio within a SPOT cycle (26 days).

II - DISTORSIONS OF OBLIQUE IMAGES

The effect of the relief is much more important on oblique images than on vertical ones. Two kinds of distorsions can be distinguished :

- Geometric distorsions (parallaxes)
- Radiometric effects.

Geometric distorsions

The geometry of SPOT images can be modelized with the following functions : XS (t), YS (t), ZS (t) give the location of the satellite for each time t.

$\lambda(t)$, $\tau(t)$, $\rho(t)$ are the yaw, pitch and roll for each time t.

Knowing these functions it is possible to give the relation between the three-dimensional coordinates (X, Y, Z) of a point on the ground and its coordinates in the raw image (n : line number and y : pixel number).

$(x, y) = \Phi(X, Y, Z)$

For vertical views the influence of the altitude Z is negligeable at the nadir of the satellite and increases with the view angle.

For oblique images the effect of the relief is important :

VIEW ANGLE (*)	Altitude 100 m	500 m	1 000 m	5 000 m
0°	4	18	36	180
10°	21	107	214	1069
20°	41	203	405	2027
30°	63	313	626	3132

Greatest distorsion (meters)

(*) This angle is measured on the ground : it is greater than the view angle from the satellite, due to the earth curvature (A pointing angle of 27° corresponds to a view angle of 31°).

In order to compare SPOT images with other geographic files a geometric accuracy of about 10 m is needed to be compatible with a cartography at the scale of 1:50 000.

To get this accuracy it is possible to rectify the image with ground control points (G.C.P.) and if possible with a digital terrain model (D.T.M.). This kind of rectification is called level 3 preprocessing by IGN.

The need of this level 3 preprocessing is shown in the following table.

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View Angle	Accuracy of D.T.M. needed to get distorsions less than 10 m
0	277 m
5°	81 m
10°	47 m
15°	32 m
20°	25 m
25°	20 m
30°	16 m

(See Also Ref. 3 and 4).

II - 2 - RADIOMETRIC DISTORSIONS

The radiometric effects of the relief and of oblique views are not yet very well known but it is possible to distinguish two main factors :

- the looking angle : its effect is almost the same for a whole image (its variation from one side of the image to the other is only 4.13°, the field of view of HRV).
- the slope and orientation of the terrain : this is the main effect within the image and the more inconvenient. The same land cover has different spectral signatures in a south versant and in a north versant. At the contrary different kinds of vegetation could have the same spectral signatures in some particular sun illumination conditions. This leads to get misclassifications without taking in account this phenomena.

III - GEOMETRIC CORRECTIONS

III - 1 - GEOCODED DATA BASE

In order to use SPOT images in relation with other images or other geographic data it is necessary to have a common cartographic reference in which all these data could be described, and compared together.

One convenient way to described these geographical data is to create a geocoded data base.

A geocoded data base has two main functions :

- each element of the data base can be easily located in the cartographic reference
- for any earth location it is possible to find quickly all the informations related to this point.

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It is possible to distinguish two kinds of data files : vector files : each data is splited into points, and each point located
- raster files : for each point of a regular grid an information is given.

III - 2 - Integration of images into geocoded data bases

Space images are raster data but the location of each pixel is not very well known in the raw image.

There are two way to integrate an image in the data base.

-1) To save the raw image itself, with a formuld which allows to compute the geographic location of each pixel (the direct location function), and another which allows to find the pixel corresponding to a geographic location (the in verse location function)

-2) To save a rectified image in which each pixel belongs to a regular grid related to the cartographic reference.
In this case the size and location of rectified pixels are implicit : for example
- Landsat MSS could be resampled with a pixel size of 50 m
- SPOT Panchromatique " " " " of 10 m
For one MSS pixel there are exactly 25 SPOT pixels.

III - 3 - IMAGE GEOMETRY MODELIZATION

In both cases the location functions (direct and inverse) have to be known.

The geometric processing of SPOT images has already be described in several payers (see ref. 3, 4). We can point out that these location functions could be represented by a regular grid on which the values of the functions are computed and which allows a bilinear interpolation between the positions of the grid.

The size of the grid depends on the spatial frequency of the geometric distorsions and should be in agreement with the Digital Terrain Model.

The level 3 processing system which is under development at I.G.N. will use a D.T.M. with a step of 100 m for flat areas and 50 m for mountainous areas. The inverse location function, called the Geometric Interpolation Grid (G.I.G.) will have the same step.

The G.I.G. is computed with the help of a modelization of the view geometry.

From the satellite and control station the ephemeris and attitude parameters are measured with an average accuracy. As the satellite is expected not to have high frequency movements the differences between measured and true parameters could modelized with few unknown parameters. (See ref. 5).

These new unknown parameters are computed using a least square method from observations on ground control points.

It is now expected that it could be possible to modelized a strip of ten consecutive images with less than ten G.C.P. s.

The Ground Control Points used in this modelization could be measured from existing maps (at the scale of about 1:25 000), and then put into a data base in order to get a faster result another time.

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From the view geometry modelization it is possible to compute :
- either the direct location function.

The location and direction of the beam associated with a pixel can be computed. Then its intersection with the D.T.M. gives its ground location.
- or the inverse location function (G.I.G.).

For each point of the grid the cartographic coordinates (X,Y) are known and the altitude Z is given by the D.T.M.

Then from (X,Y,Z) it is possible to compute the image location of the corresponding pixel with the parameters of the view geometry modelization.

The expected accuracy of this modelization is between 0.5 and 1 pixel for countries where good maps exist (with an accuracy better than 3m).

III - 4 - RECTIFICATION

For many applications a pixel to pixel registration is required (for multitemporal analysis for example). In this case a rectified image has to be saved in the data base.

From the G.I.G. it is easy to interpolate and know the raw image location of each new pixel of the data base. The real problem is how toresample the radiometric values of the pixels ?

The nearest neighbour resampling doesn't damage raw radiometry but leaves small high frequency geometric distorsions (less than 0.5 pixel).

The bicubic resampling gives a smoother geometry but could introduce small radiometric distorsions at the edge of some bright or dark areas.

The two kinds of resampling will be available in level 3 preprocessing in I.G.N.

IV - USE OF STEREO PAIRS

The integration of oblique views into geographical data bases is possible only if a Digital Terrain Model of the covered area is available. This D.T.M. can be obtained from the digitization of existing topographic maps. For example the contour lines of french maps at the scale of 1:25 000 are now digitized by I.G.N. Already three quarters of the french territory is covered by these altimetric files and it is expected that 100% of the area will be covered next year.

From these vector files it is now easy to compute a raster file (D.T.M.) in any cartographic reference (U.T.M. or Lambert).

In many countries such D.T.M. does not exist and (or) topographic maps are not accurate enough. In this case stereo pairs from SPOT could provide a digital terrain model.

The processing of stereo pairs in order to get a D.T.M. is called level 4 (processing) by I.G.N. which studies and develops equipment and software to be ready to process SPOT images as soon as possible.

IV - 1 - COMPUTATION OF A GROUND CONTROL POINTS NETWORK

Before being able to process SPOT stereopairs it is necessary to have a minimum number of ground control points, which cartographic coordinates are very well known. This number is about the same as for level 3 processing : at least 6 points and between 1 and 2 point per scene within a strip.

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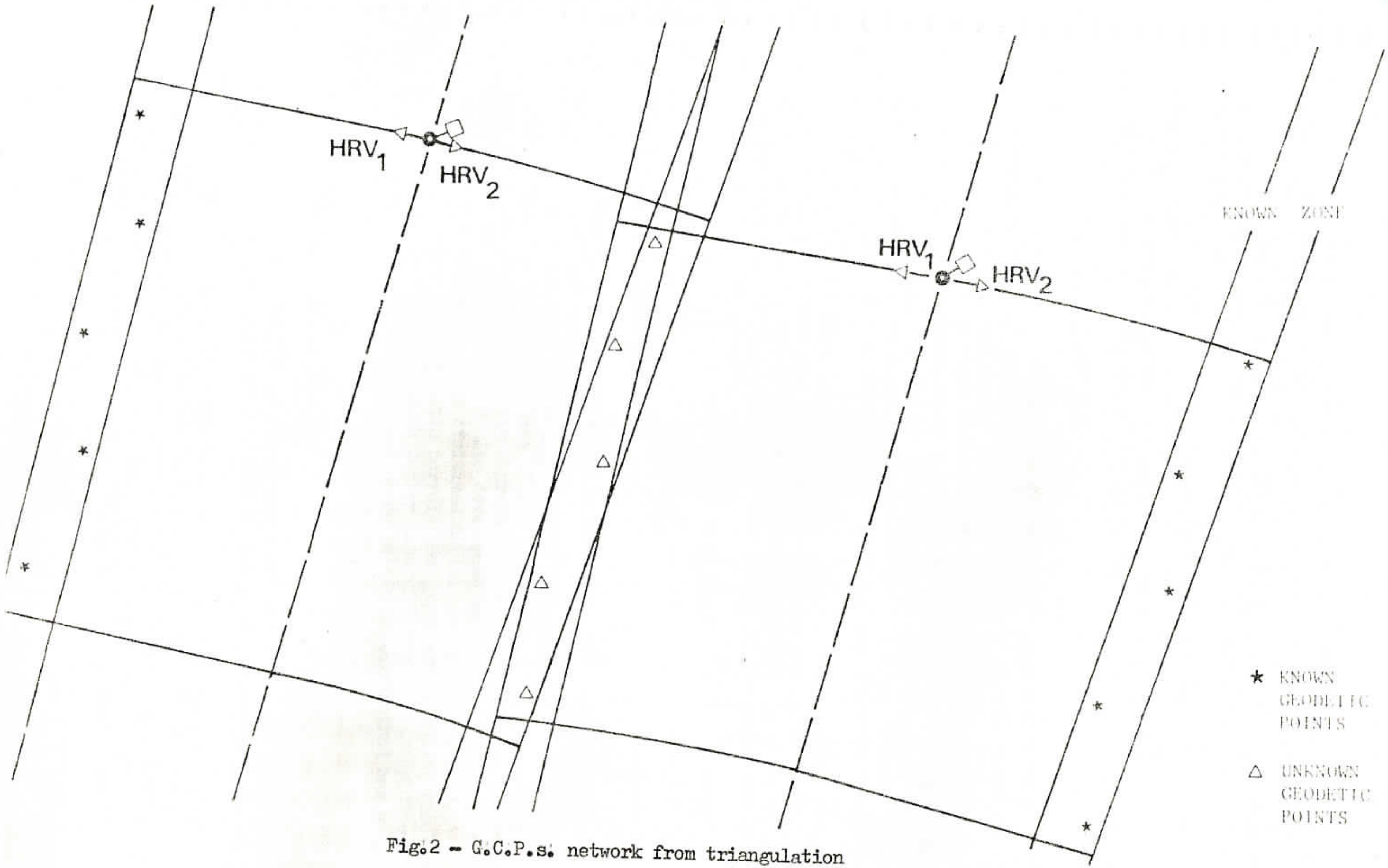

Fig. 2 - G.C.P.s. network from triangulation

It seems that it could be possible to locate these G.C.P.s from SPOT images themselves, with the help of ground measurements (on geodetic points with Doppler receivers).

Using triangulation techniques such as those which are used in aerial photogrammetry it could be possible to get a good G.C.P.s network on very large areas.

The number of ground measurements could be very small by using at the same time the two HRVs looking at different areas (see fig.2).

As ground measurements are very expensive the interest of SPOT is obvious, compared to the use of aerial photos.

IV - 2 - ANALOG STEREO PLOTTING

From two SPOT images of a stereopair it is possible to get a D.T.M. either with photographic products (films) and an analytical stereoplotter, or with digital images and a specialized software.

The use of a stereoplotter is interesting because this equipment is well known from cartographers and it gives directly contour lines and planimetric features, plotted by the photogrammetrist and stored in vector. files. But it needs two films (processed at lev 1 1B) and at least two G.C.P.s in order to know the location and direction of these films in the geometry of the plotter.

I.G.N. has developped a special software on the TRASTER from MATRA which accepts any kind of image geometry modelized with a three dimensional grid : each point of the grid is associated with its locations in the two images of the stereopair and other points of the ground can be interpolated within the grid.

The expected accuracy of this kind of plotting is about 10 to 15 meters (see ref. 6).

IV - 3 - DIGITAL STEREO PLOTTING

The use of a stereoplotter is convenient for mapping purposes but rather slow and expensive.

It is possible to use only digital data (level 1A images) in order to compute the D.T.M. Rejean SIMARD from C.C.R.S. has already studied this technique bases on automatic correlation of the two images, and Gaston MASSON D'AUTUME from I.G.N. has also developped an efficient software to process either SPOT imagery or digitized aerial photos (see ref. 5).

It seems that automatic correlation gives more accurate results : 3 to 8 meters (in altitude), much faster than with analog stereoplotters (7 to 8 time). But the operationnal capabilities of this method has still to be proved.

IV - 4 - USE OF STEREORADIOMETRY

An other interest of stereopairs, and of multi-angle views is that they can give informations about the bi directionnal reflectance of each pixel.

The processing of these images has to be developped taking in account existing works on Landsat (see ref.7), and theoritical researches (see ref.8). Such studies can be made on some particular test sites, using a maximum of images with different sun angles. To compare all these images they have to be processed at level 3 and put into the geocoded data base.

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V - USE OF SPACE IMAGERY WITH OTHERS GEOGRAPHIC DATA

Oblique views (and vertical ones too) can be put into a geocoded data base with others geographic data to up date these data and to get pertinent and accurate informations needed by the users.

V - 1 - UP DATING OF GEOGRAPHICAL FILES

The assesment of SPOT simulations has shown that SPOT images could be used to up date existing maps : topographie maps at a scale of 1:100 000, sometimes at 1:50 000.

This revision could be done on level 3 images using visual interpretation (see ref. 9) and automatic classification (*).

A supervised classification needs having several training areas of each theme to classify. If the map to be revised is already into the geocoded data base it could be used as followed :

- the comparaison of the map and the image could give permanent and changed areas
- changed areas are classify using permanent areas as training sites.

A fully automatic classification is not yet possible (if ever possible ?) and an interactive image processing system is necessary to control and correct the results. (See fig. 3).

V - 2 - THEMATIC INTERPRETATION OF IMAGES WITH THE GEOCODED DATA BASE

Space imagery can be used to up data geographical files. On the other hand these geographical files could be used to get better results in the thematic analysis of the image.

For example to study forest (deseases, timber estimation etc...) it is first necessary to known where wooden areas are. This can be done with several images and the existing data files with a great accuracy (but with a non negligeable cost). Having selected then the "best" image from the data base a simple mask and a radiometric stretching, only on the wooden areas, could give the desired information.

CONCLUSION

SPOT will give a large amount of images. To get the best from this earth observation system it will be necessary to use either vertical or oblique views. Oblique images are more complicated to study than vertical views but they can give new informations about the relief and the radiometric properties of the land cover.

Cartographic processing (level 3) of oblique and even vertical images is needed to integrate them into a geographic data base in order to up date planimetry and land use files.

This geocoded data base could be a "reference" system for many users (or a base map) which would allow them to get better results as they could emphasize their own fvields of interest.

(*) This automatic classification can used multispectral, or multitemporal data, texture analysis and take in account the effects of the relief with the D.T.M.

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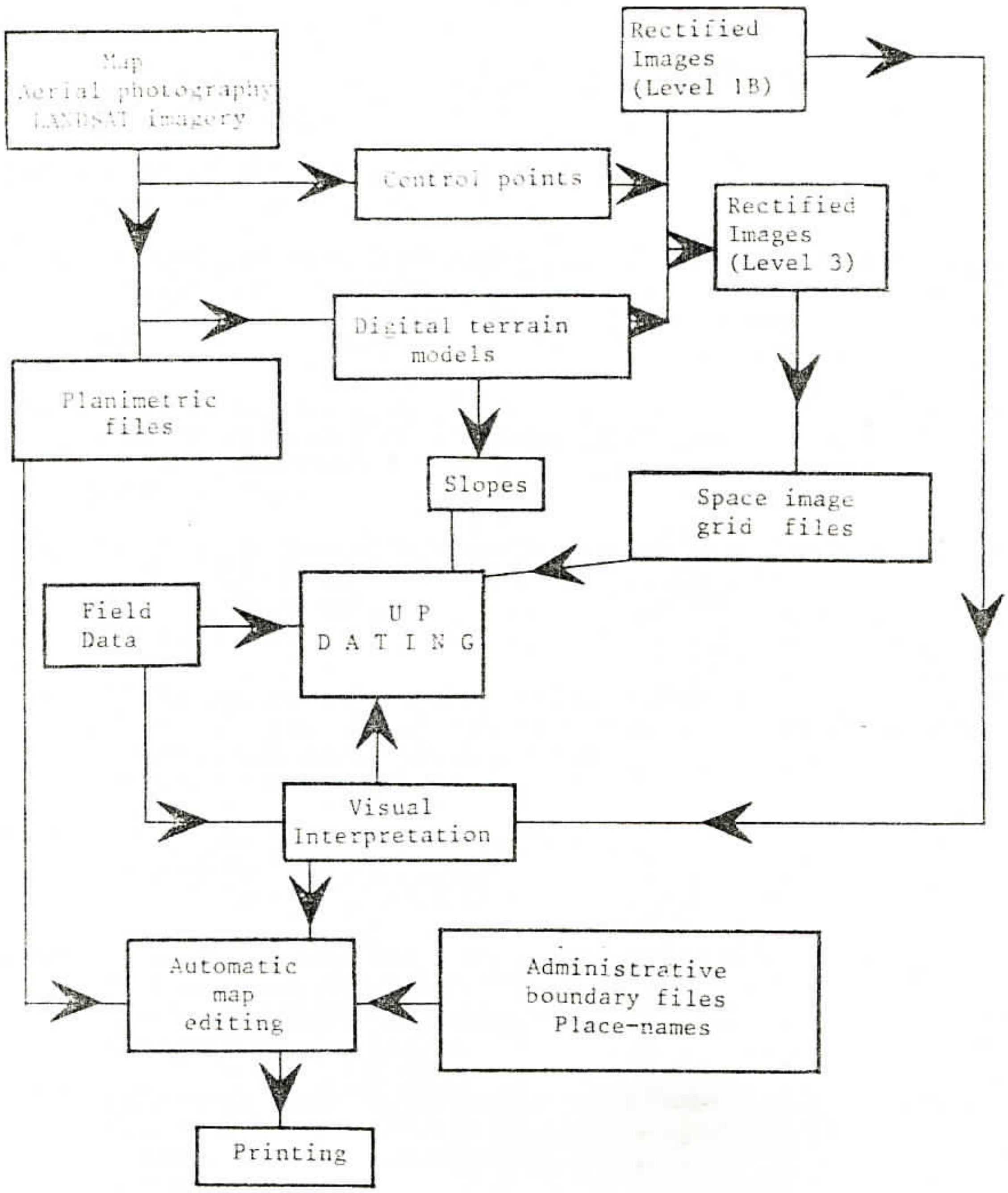

Fig. 3: Up-dating of cartographic files.

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