PHOTOGRAMMETRIC MAPPING OF SPOT IMAGES WITH BINGO IN THE PHOCUS SYSTEM

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ABSTRACT

Stereo images taken by the SPOT satellite can be used for the production and revision of topographic maps at a scale of 1:50,000 and less. Combination with PHOCUS and the Planicomp systems enables on-line plotting of SPOT images in the same way as the plotting of normal photographs. The BINGO software provides the necessary geometric corrections, for which allowance is made on-line by additional programs in the Planicomp system.
The mathematical principles are outlined, and the results and accuracies obtained in practical work are discussed. The paper also describes the possibilities of orthophoto production using SPOT images.

1. INTRODUCTION

When the SPOT satellite was launched in 1986, it was the first ever operational taking system for topographical mapping of the earth's surface. Whereas previous systems were only available for a very limited period of time or featured a far lower resolution, the SPOT images with their ground resolution of 10 m in the panchromatic mode and 20 m in the multispectral mode provide a good basis for the production of topographical maps at scales of 1:50,000 to 1:250,000. The map product may be either a line map or an orthophoto, or a mixed product: an orthophoto map.

The SPOT software is based on the BINGO software package which was developed for the combined adjustment of photogrammetric observations and conditions and of geodetic surveys /Kruck 1984, 1985, 1987/. This ensures that all capabilities of this software can also be used for the SPOT applications. When used in conjunction with the BINGO software package, analytical photogrammetric systems can produce geometrically correct planimetric representations or orthophotos from the images taken with the SPOT satellite.
The height information required for orthophoto production can be measured directly in a SPOT stereomodel.

In February 1988 a new release of the BINGO software package was issued, permitting all plottings in analytical plotters to be performed in the UTM or Gauss-Krüger coordinate system. This means that contour lines can now be followed directly in the SPOT stereo model. Subsequent transformation of the measured data is no longer necessary, which considerably facilitates and speeds up map production.

After an outline of the mathematical fundamentals of SPOT image plotting, a description will be given of the integration and handling of SPOT scenes on the analytical plotters of the Planicomp P-series and C-series and on the Z2 Orthocomp orthoprojector. Finally, a rundown will be given on the experience gained to date in the plotting of SPOT stereomodels.

2. SPOT Triangulation Fundamentals

The SPOT satellite has been orbiting our earth at a height of 820 km since February 1986. The taking system is a CCD line sensor onto which the earth surface is mapped. The earth surface is scanned continuously by the sensor because the platform is moving (Figs. 1 and 2).

All pixels of a line are read in one go at fixed time intervals of 1.5 ms (push broom scanner). The lines are therefore central-perspective, but the perspective center moves from line to line. A shear effect results from the fact that the earth rotates below the satellite while a scene is being taken. The heading h in the orbit (Fig. 3) is not the same as the direction t of the ground track. The difference r is a function of the flying speed, the flying height, the inclination, the angular speed of the earth and the geographical latitude at which the scene was taken. The orbit itself is an ellipse, but irregular accelerations cause minor deviations from the elliptical orbit. Pitch and roll (small variations of ω and φ) further distort the scene geometry.
The ground effects are very small, and corrections are possible because the irregular motion parameters are recorded. Fig. 4 shows the effect of pitch on a scene.

A precise mathematical model should contain a satellite motion equation and allow for the accelerations through unknown parameters that vary over time. The orbit data recordings could be used as observations /Toutin 1985/.
Another image showing the same area from another perspective would be required for later stereo restitution. Such an image pair could be bundle-adjusted with the orientation parameters being time variant variables of the above-mentioned motion equation. However, such a model would be too complicated for photogrammetric practice. Therefore some simplifications are made which, for all practical intents and purposes, do not adversely affect the precision.

The orientation parameters X_0, Y_0, Z_0, φ, ω and κ of a line are highly intercorrelated because the aperture angle is only 4.1 degrees. Since the ground effects are minute (< 20 m), a straight-line track can be admitted, and all irregular affects can be assumed to be variations of the angles φ, ω and κ. The φ angle variations actually are the largest irregular effect (Fig. 4). These angle variations can easily be taken into account additional parameters. This also applies to earth rotation correction and perspective distortions. The question which effects will most likely result from irregular motions leads to a set of 8 additional parameters (Fig. 5).

These additional parameters have been included in the BINGO bundle program. The SPOT application also required the perspective center shift to be allowed for.

$$X_{0,i} = f(\text{time } i) = f(x_i') \tag{1}$$

The image vector then is $\mathbf{x}' = (0,\ y',\ -c)$ (2)

This approach allows the angles φ, ω and κ to be considered invariable over time. If there is a sufficient number of homologeous image points, the image geometry can be determined completely assuming that the basic SPOT level 1a images that are not geometrically corrected are used.

The measured image coordinates can also be corrected beforehand for the known minor distortions of a scene (Fig. 4). Ignoring the ground elevation is permissible because the corrections are small (Fig. 4) and the resulting errors are of the order of some centimeters. SPOT IMAGE offers this prior correction on the new product level 1p. The contrast is balanced in addition to geometrical correction. At an identical pixel size of 25 μm the images are supplied in the aerial photo size of 22.5 cm x 22.5 cm. Thus one pixel corresponds to about 6.7 m on the ground compared to 10 m for level 1a.
Detail visibility has been improved in particular by local contrast enhancement. The scale 1:266 000 images allow the production of scale 1:50 000 maps without any restrictions.

The product level 1p images thus correspond precisely to the mathematical concept of bundle adjustment with continuously moving perspective center and constant orientation angles φ, ω and κ described in this paper and used in BINGO.

The Planicomp analytical plotter can be used for producing line maps from SPOT models. The specific SPOT geometry has to be allowed for in on-line plotting, i.e. the basic real-time LOOP program, which uses the fixed-point central perspective required for conventional photogrammetric photos has to be modified.
Basically there are two approaches to this problem. One solution would be to continuously vary the coordinates of the perspective center according to its current location in the image. Another approach is to describe the differences between the aerial photograph geometry and the SPOT scene geometry determined by BINGO by means of correction matrices using a mean perspective center $X_{0,p}$ (Fig. 6) and taking into account that differences in elevation affect the SPOT image geometry not in the same way as the aerial photo geometry (Fig. 6).
In aerial photographs, differences in terrain elevations cause a radial offset of the photo coordinates, while in SPOT images the offset is normal to the flying direction.

It follows that the ground elevations should be known for establishing a correction grid. Since the elevations cannot be assumed to be known already, two correction grids are computed: one for the lowest possible ground elevation and another one for the highest possible elevation. Both are based on the image coordinates. The correction of a point P_k depends on its location in the image and its elevation Z_G in the ground system.

$$dx', dy' = f(x', y', Z_G) \qquad (3)$$

The correction is computed by means of a square column (Fig. 7) /Konecny, Kruck, Lohmann 1986/ as a grid within the correction grids.

The correction grids are established by a separate program using the following procedure:

1. Determination of the lowest ground elevation Z_{min}.
2. Establishment of a regular grid in the image.

3. For each grid point:

3.1 Computation of the associated ground coordinates X_G, Y_G using the given elevation $Z_G = Z_{min}$, the mean perspective center $X_{0,P}$ (Fig. 10) and the collinearity equation for aerial photographs.
3.4 Recomputation of the X_G, Y_G, Z_G point into the SPOT image using the shifted perspective center $X_{0,i}$ governing the representation of this point, again using the collinearity equation.
3.5 Computation of the difference between the image coordinates obtained in step 3.4 and the grid point image coordinates used in step 3.1 for the initial computation.
3.6 Computation of the effects of the additional parameters at the grid point, and addition of these corrections to the differences computed in 3.5.
These values form the final correction for an image point x_i', y_i' with the ground elevation Z_G.

4. Storage of the correction matrix.
5. Repetition of steps 2 to 4 for the same image but using elevation Z_{max} instead of Z_{min}.
6. Repetition of steps 1 to 5 for the second image.

In the real-time loop the corrections are continuously computed by an independent program and used for correcting the photocarriage coordinates.

This correction results in the SPOT stereomodel being oriented absolutely and without parallaxes in the Planicomp. All existing Planicomp programs can be used for plotting, and elevation and planimetry can be plotted as usual.

A digital elevation model (DEM) can be measured in a SPOT stereo model. As a result, an anchor point file which also contains the SPOT coordinates for each point of a regular grid in the ground coordinate system can be generated for the control of the Orthocomp. The file thus contains all the information on image matching required for the control of the orthoprojector.

A special control program is responsible for the real-time control of the Orthocomp. The development work necessary for Orthocomp and for plotting in the UTM coordinate system was performed by H. Engel at the University of Hanover and will be published in detail shortly as part of a thesis.

3. SYSTEM ENVIRONMENT

Whereas the plotting of SPOT images with BINGO on the C100 Planicomp and Z2 Orthocomp has been ready for application since late 1986, integration into the new PHOCUS operating software of the Planicomp P-series had to be newly implemented. Special attention had to be given to the fact that the real-time loop in the Planicomp P-series does not run in the host computer but in the Planicomp P-processor. However, this does not result in any major difference for the user, except that operation benefits from the simplicity and flexibility of the PHOCUS software.

4. EXPERIENCE

Various studies have shown that the accuracy of SPOT image plotting is perfectly adequate for map production at a scale of 1:50,000. 6 to 10 ground control points ensure an accuracy of approx. 8 m in planimetry and elevation. The use of 10 ground control points per stereo model is recommended to increase the reliability. The specified accuracy is valid for any ground point. Higher accuracies can be obtained with sharply defined points, permitting precise positioning.

Small terrain features can easily be recognized and transferred to the map. Problems however may arise in interpretation however if, for example, a road and a railway line run close to each other and touch or intersect in some areas. In the model it is hardly possible to distinguish between the road and the railway line.

The identification of small details which are usually still represented at a scale of 1:50,000 may prove difficult. This applies particularly to small rivers, narrow roads etc.

In many countries, however, the demand for maps of the scale 1:50,000 is still so great that it seems advisable not to insist in all cases on the extremely high quality standards set for topographical maps in Europe; it would be more appropriate to make full use of the present possibilities of map production. Otherwise there is scarcely any hope of meeting the worldwide demand for maps in the next 20 years.

Height information can be obtained from SPOT stereo models by grid measurement or by direct following of contour lines. Whereas measurement normally presents no problems in areas with natural surfaces, the effect of a time interval between two surveys (usually about 3 to 4 weeks) is slightly greater in areas with artificially structured surfaces (fields, roads, towns). Systematic falsifications of a few meters may occur here in the elevation measurement.

Direct plotting of a SPOT stereo model in UTM or Gauss-Krüger coordinates is considered a significant advantage. In the marginal regions of a meridonal zone system BINGO offers the choice of using either of the two systems for plotting. Moreover, the plotted data can be subsequently transformed into the adjacent system or any other coordinate system.

The output of SPOT images on the Z2 Orthocomp offers an economy-priced alternative for the production of line maps. The multispectral images of the SPOT satellite are particularly suitable for interpretation. In addition to their good interpretation possibilities, such orthophotos also feature a high geometrical accuracy.

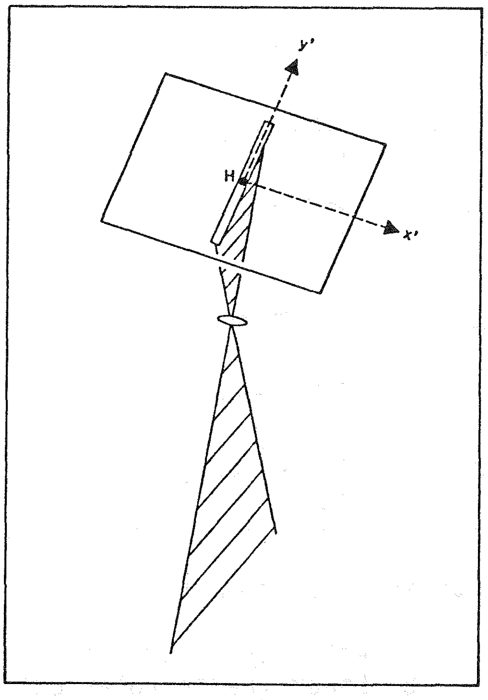

Fig. 1 Line Sensor

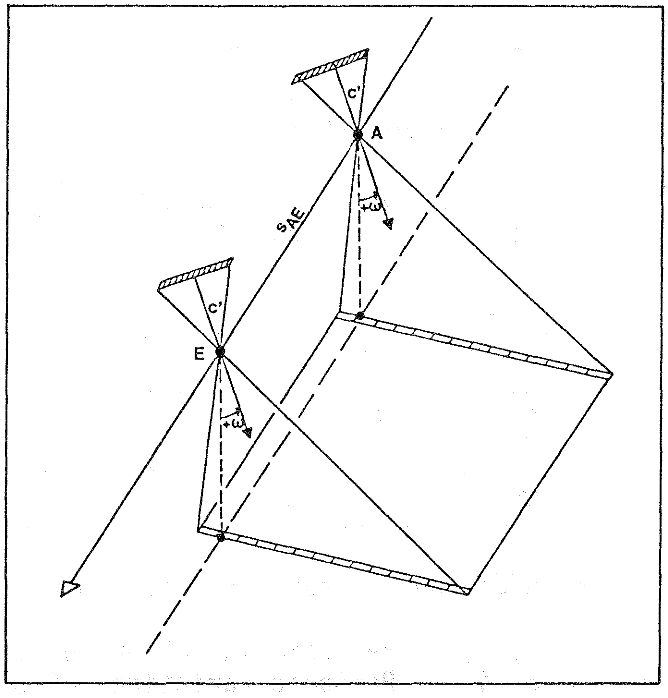

Fig. 2 SPOT Scene

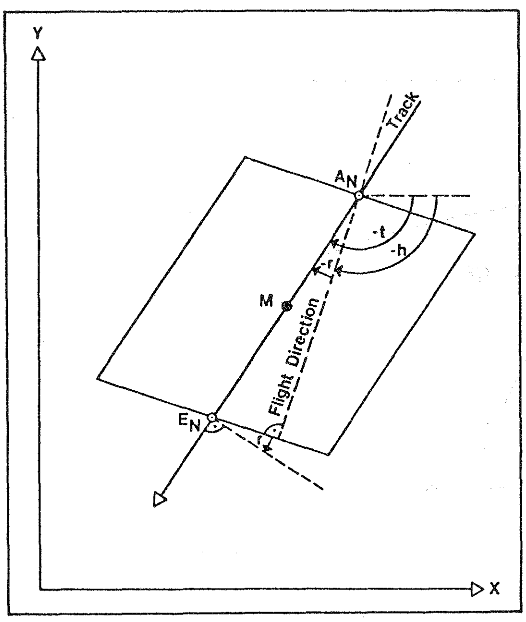

Fig. 3 Flying Direction and Track

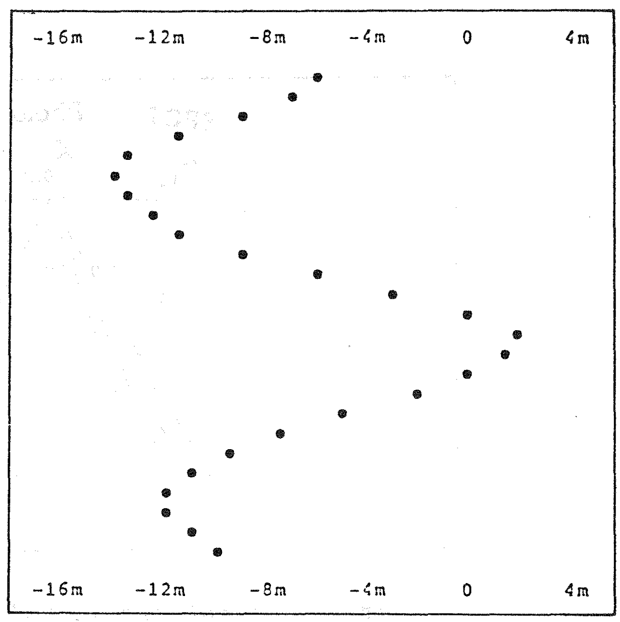

Fig. 4 Effect of Pitch

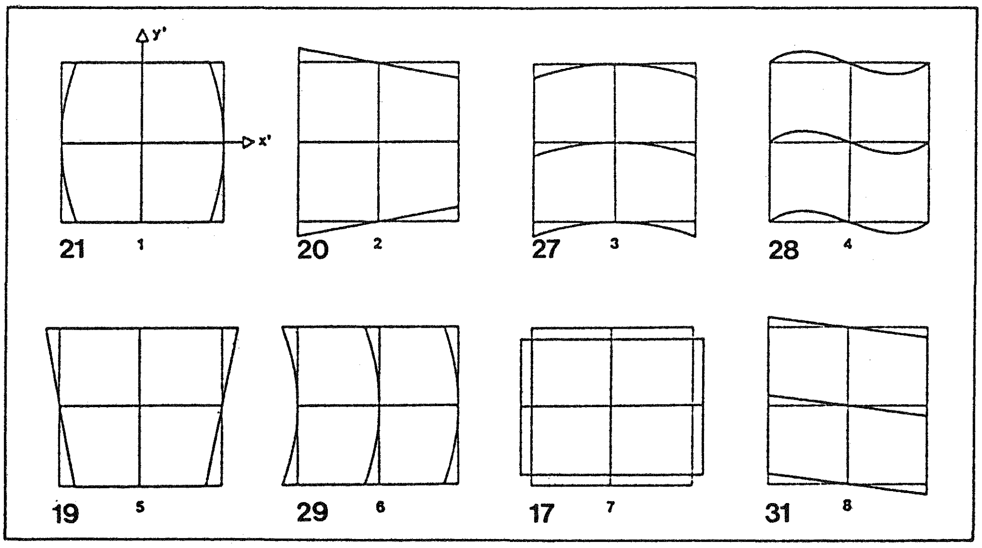

Fig. 5 Additional Parameters Describing Irregular Platform Motions

1, 2, 6	Periodic variations of φ	7	Affinity (overscan)
3, 4	Periodic variations of ω	8	Shear (earth rotation)
5	Periodic variations of κ		

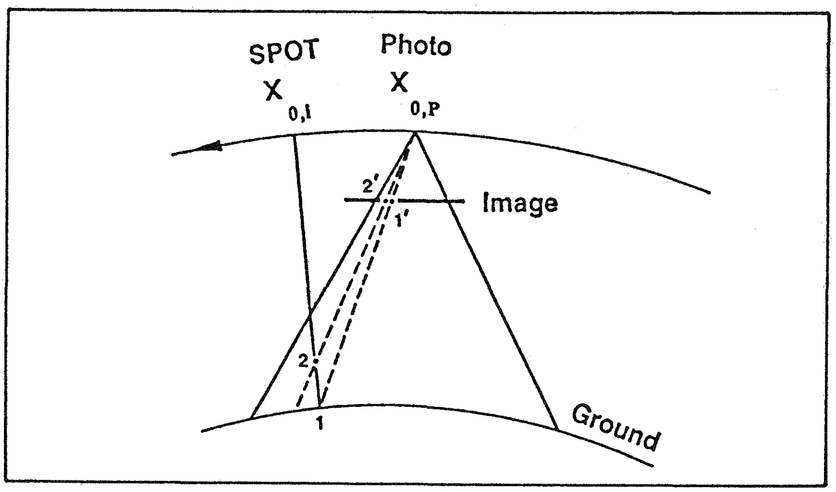

Fig. 6 Offset due to Differences in Elevation

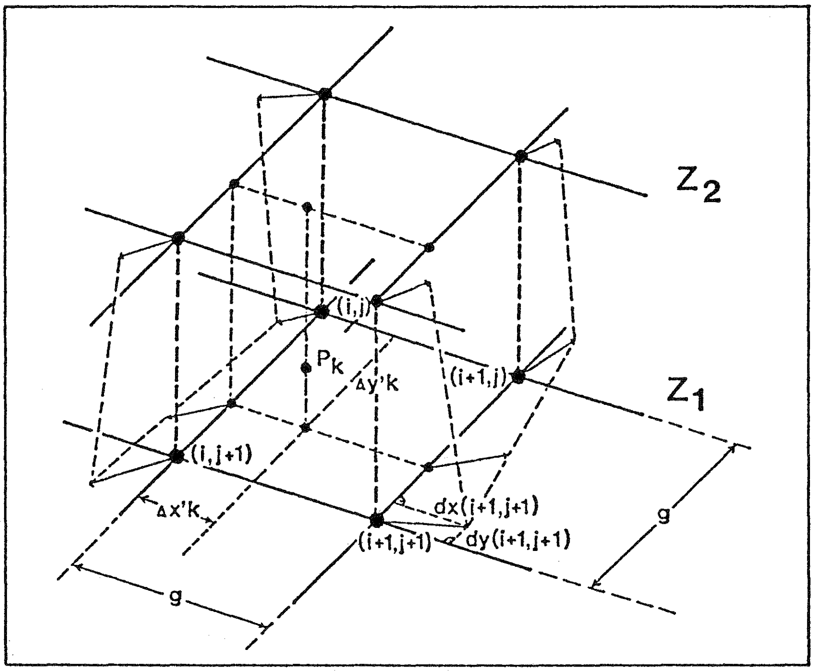

Fig. 7 Correction of the Photocarriage Coordinates during Real-Time Processing

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