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THREE DIMENSIONAL ANALYSIS OF SPACE IMAGERIES

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ABSTRACT

Space imageries with their low costs and availability for every one, provide a good opportunity for topographic mapping of unmapped or poorly mapped areas around the world particularly in the developing countries.

The French SPOT Imaging system is the first space orbiting satellite with stereoscopic capability. Panchromatic stereoscopic pairs with variable base to height ratios are available and can be arranged for any part on the earth's surface.

In this investigation, three dimensional coordinates are extracted from SPOT stereoscopic images using two analytical photogrammetric methods.

In the first method, a stereoscopic model is formed by using the analytical relative orientation technique. Three dimensional model coordinates, then, were fitted into ground coordinates using a number of mathematical models of coordinates transformation.

The second method used is the space intersection, where three dimensional ground coordinates of the intersection point of each two similar rays are computed. This procedure, normally, follows the application of the space resection, where the exterior orientation elements for the two stereoscopic images have to be determined.

To assess the accuracy of the extracted three dimensional coordinates, residuals and their root mean square values in a number of check points were computed and analyzed.

INTRODUCTION

SPOT-1 was launched in February 1986 and followed by SPOT-2 in January 1990. Each one of the two satellites circles the Earth in a synchronous orbit (altitude 832 km) and repeats its coverage every 26 days. SPOT-1 and SPOT-2 carry an identical push-broom sensor system. This sensor system includes two identical optical instruments, the HRV1 and HRV2 (High Visible Resolution). SPOT's sensor produces images in two modes; the panchromatic mode (P) with a single spectral band (0.51 μm to 0.73 μm) and a ground resolution of 10 m and the multispectral mode (XS) with three spectral bands (between 0.5 μm to 0.84 μm) and a ground resolution of 20 m.

The reflected radiation picked up by the optical instrument, for each spectral band, is measured by an array of detectors (6000 for the 'P' mode, 3000 for each of the spectral bands of the 'XS' mode) which forms rows of the image perpendicular to the satellite track (60 km on the ground). The scenes dimension parallel to the satellite track is achieved by movement of the satellite along its orbit. Each SPOT scene covers 60 km by 60 km.

A mirror situated in front of the HRV instrument allows modification of the look direction making an across-track angle with the vertical that can reach ± 27 degrees. So, it is possible to record images of the same ground area at different look angles from different orbits forming a stereoscopic pair from any two of such images.

In this investigation a SPOT stereoscopic pair was used to extract 3-dimensional information by using conventional photogrammetric methods. In the first method, a stereomodel was formed by an analytical relative orientation. Model coordinates, then, were fitted into ground coordinates using 3-dimensional affine and polynomials transformations. In the second method of stereoscopic analysis, ground coordinates, in three dimensions, of check points are computed by space intersection. In this case, the exterior orientation elements of each image is determined, first, by space resection and then used to orient left and right rays through image points to intersect in the ground position of any point. A variable number of ground control points is used to determine the transformation and orientation parameters in each case. A special polynomial was used to correct computed heights derived from the second method. Residuals and their root mean squares in a number of check points were determined and analysed.

MATHEMATICAL MODELS

Conventional photogrammetrical mathematical models were used in this investigation to perform stereoscopic analysis of the SPOT data. There are two well known analytical methods for extracting 3-dimensional ground coordinates from a stereo pair of images. In the first method, a stereomodel is formed and, then, computed model coordinates are transformed into ground coordinates by a mathematical model for absolute orientation. There are a number of ways to solve the problem of relative orientation, coplanirity equation, analytically. In this investigation, the method of fixing the left hand image is adopted and, accordingly, the relative orientation mathematical model can be written as:

$$(xyz)_L \begin{pmatrix} 0 & -Bz & By \\ Bz & 0 & -Bx \\ -By & Bx & 0 \end{pmatrix} \underline{R} \begin{pmatrix} x \\ y \\ z \end{pmatrix}_r = 0$$

where $(x\ y\ z)_L$ and (x y z)r are the image coordinates of any point at the left and right images respectively and Bx is an arbitrary scale factor for the formed stereomodel. The five orientation parameters are; the base component in Y-direction 'By', the base component in Z-direction 'Bz' and the three rotation elements which define the orthogonal rotation martix '$\underline{R}$'. For images collected by scanners, the relative orientation parameters may change along the track direction and polynomials may be considered to represent these changes. In this study, changes in the base components 'By' and 'Bz' are taken into consideration and represented by polynomials.

After determining the relative orientation elements, 3-dimensional model coordinates of any image point in the overlapping area between the two images can be computed. The mathematical models used for model coordinates transformation into ground coordinates are:

(i) The three-dimensional transformation in the form:-

E = a1 + a2.Xm + a3.Ym + a4.Zm,
N = b1 + b2.Xm + b3.Ym + b4.Zm, and
N = c1 + c2.Xm + c3.Ym + c4.Zm

(ii) The Three-dimensional second order polynomials in the form:-

E = a1 + a2.Xm + a3.Ym + a4.Zm + a5.Xm**2 + a6.Ym**2 + a7.Xm.Ym,
N = b1 + b2.Xm + b3.Ym + b4.Zm + b5.Xm**2 + b6.Ym**2 + b7.Xm.Ym, and
N = c1 + c2.Xm + c3.Ym + c4.Zm + c5.Xm**2 + c6.Ym**2 + c7.Xm.Ym.

where (E,N,H), (Xm,Ym,Zm) are, respectively, the ground and model coordinates of any reference point and the remaining elements are the transformation parameters or constants. This method, sometimes, is called 'the two steps orientation'.

In the second method of extracting 3-dimensional coordinates from a stereo pair, sometimes is called 'the one step orientation', the following procedure has to be followed.

(i) The orientation elements of each image have to be determined by applying the space resection equations:

$$X+X_p = C \cdot \frac{r11(Xs-Xg) + r21(Ys-Yg) + r31(Zs-Zg)}{r13(Xs-Xg) + r23(Ys-Yg) + r33(Zs-Zg)}$$

and

$$Y+Y_p = C \cdot \frac{r12(Xs-Xg) + r22(Ys-Yg) + r32(Zs-Zg)}{r13(Xs-Xg) + r23(Ys-Yg) + r33(Zs-Zg)}$$

where (X,Y), (Xg,Yg,Zg) are the image and ground coordinates of any control point, (Xp,Yp,C) are the interior orientation elements of the image and (Xs,Ys,Zs,$\underline{R}$) are the exterior orientation elements of the same image. It is obvious that the rotation matrix $\underline{R}$ is an orthogonal and is defined by three independent parameters. Thus, a total number of 9-orientation elements will define the attitude for each image.

(ii) The oriented (rotated) image coordinates of any point (X',Y',C'), then, computed as:

$$\begin{pmatrix} X' \\ Y' \\ C' \end{pmatrix} = \underline{R} \begin{pmatrix} X+X_p \\ Y+Y_p \\ C \end{pmatrix}$$

(iii) Ground coordinates of any reference point (Xg,Yg,Zg) can be computed using the following equations:

Zg = [Zs"*(X"/C") - Zs'*(X'/C') + Xs" - Xs']/[X"/C"-X'/C'],
Xg = [Xs' - X'*{Zg-Zs'}/C'] and
Yg = [Ys' - Y'*{Zg-Zs'}/C'].

(' and " refer to image number one and image number two respectively).

To correct computed heights (Z-coordinates) from the effects of applying approximate scale factor and from parallaxes, a polynomial in the form:
dZ = a1 + a2.X + a3.Y + a4.Z + a5.X**2 + a6.X.Y ; is used. Another

form of the heights correction polynomial, where observational errors in X-direction are considered, is also tested. This polynomial is in the form:

$$dZ = a1 + a2.X' + a3.X'' + a4.DX' + a5.DX'' ;$$

where, (dZ) is the error in computed height (X',X") are the rotated image coordinates and (DX',DX") are the residuals in image coordinates. The signs ' and "" refer to image number one and image number two respectively. This last polynomial can not be applied, in practice, since the computation of residuals in image coordinates require the availability of ground coordinates. So, this polynomial is applied only to test the effects of observational errors on the computed heights.

RESULTS

Reference points used in this experiment are classified, according to their identification qualities, into two groups. The first group is formed from a 23 well-identified points. The second patch is formed by adding another 9 points, of moderate identification quality, to the first group making a total of 32 reference points.

The stereomodel was formed, first, by conventional analytical relative orientation procedure. A modified method for analytical relative orientation, then, was applied. In this modified approach, the base components, By and Bz, are represented by second-order polynomials in order to take into accounts changes with time. Table (1) shows the root mean squares values of the computed Y-parallax in each case.

Computed model coordinates are fitted into ground coordinates using three-dimensional affine and polynomials transformations. Residuals and their root mean squares values, of coordinates of check points, are computed and shown in Table (2).

In the second method for extraction three-dimensional coordinates out of SPOT stereo pair, ground coordinates of check points are computed by the intersection of oriented rays after applying space resection. Computed heights are adjusted by using a second-order polynomial. The effects of observation errors, in measured coordinates, on computed heights are tested by applying another correction equation which takes into consideration these errors. Root mean squares of residuals at check points are computed, Table (3).

Table 1: Root Mean Squares in Y-Parallax at check Pints after Applying the Conventional and the Modified Relative Orientation Methods

Number of Check Points	Root Mean Squares in Y-Parallax (μm)	
	Conventional Relative Orientation	Modified Relative Orientation
37	50.5	12.2
23	39.9	3.0

Table 2: Root Mean Squares Values of Residuals at Reference Points after Fitting Model Coordinates into Ground Coordinates using Three-dimensional Affine and Second Order Polynomials Transformations

Number of Reference Points	Root Mean Squares (meter)					
	Affine Transportation			Second-order Polynomials		
	Rx	Ry	Rz	Rx	Ry	Rz
37	55	58	19	38	39	18
23	40	47	17	24	29	13

Table 3: Root Mean Values of Residuals at Reference Points Computed after Applying the Space Resection-Intersection Method

Number of Reference Points	Number of Orientation Elements	Number of Control Points	Root Mean Squares (meter)			
			Rx	Ry	Rz	Rz'
32	4	6	61	85	21	--
		10	45	77	26	--
		15	59	89	13	14
		20	52	81	10	20
		32	50	81	09	09
	6	10	45	40	15	--
		15	34	46	13	13
		20	35	43	12	10
		30	34	37	10	12
		32	33	25	09	09
23	4	6	50	67	20	--
		10	52	65	21	28
		15	43	60	20	22
		23	42	59	19	20
	6	6	46	24	22	10.3
		10	45	23	18	2.3
		15	27	20	15	1.7
		20	27	19	14	1.7
		23	25	19	14	1.6

Rx Root mean square error in easting,
Ry Root mean square error in northing,
Rz Root mean square error in heights, and
Rz' Root mean square error in heights after reducing effects of the observation error.

DISCUSSION AND CONCLUSIONS

Obtained results indicated that modified relative orientation method, where changes with time in base components are represented by polynomials, reduces Y-parallax considerably. However, by applying three-dimensional polynomials for the transformation of model coordinates into ground coordinates, obtained accuracy are, approximately, identical regardless of the used orientation method.

Obtained heights accuracy in the two methods of stereoscopic analysis are, almost, equal and compatible with accuracy obtained in other investigations. For images with low to medium contrast, heighting accuracy of 10 m can be obtained. With high contrast images and, accordingly, with less observational errors in image coordinates, accuracy of heights will be limited mainly by the precision of ground coordinates and can be increased to about 2 m. So, it is important to include image enhancement in the photogrammetric processing of the SPOT images.

The first procedure for the extraction of three-dimensional coordinates, the two steps orientation, is more simple to apply on analytical plotters and needs less computer time and storage.

The second approach, the one step orientation method, is flexible and allows for more parameters to be included in the adjustment. It requires more computer time and needs more storage capacity.

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