ANALYTIC STEREOMAPPING USING SPOT IMAGERY

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ABSTRACT

Conventional stereophotogrammetric compilation is extended to acquire cartographic information from SPOT imagery. A practical approach characterized by a set of improved exterior orientation parameters, which are updated with time, and fast coordinate transformation between Gauss-Kruger and distortionless spatial Cartesian systems through polynomials is presented. A software designated to process stereo SPOT images (level 1A) is developed on the JX-3 Analytical Plotter, and an experiment that with images taken in 1986 a topographic map and a digital elevation model which has controlled the ZS-1 Orthoprojector to print an orthophoto, were produced, has proven feasibility of the method.

KEY WORDS: Analytical, Polynormial, Photogrammetry, SPOT, Transformation.

INTRODUCTION

Stereophotogrammetric processing of SPOT imagery using an analytical plotter has been reported in a number of publications. Because of the complexity of SPOT imagery geometry and large ground coverage of each scene, conventional treatments for aerial frame photographs need to be reformed to fit the special requirement. Approaches for this purpose have been established according to different mathematic models, and satisfactory experimental results were obtained, as presented by Konecny et al. (1987), Li et al. (1988), and Kratky (1988). In this paper, a set of improved SPOT imagery orientation parameters and the fast ground coordinate transformation, which have been tested with real image data, are introduced, and the implementation on the JX-3 Analytical Plotter and ZS-1 Orthoprojector manufactured in China is described.

MATHEMATICAL FOUNDATION

In case of aerial frame photography, the only 6 exterior orientation elements of each image of stereo pair are determined by 3 or more control points, and thereupon the stereophotogrammetric terrain model, in which 3-dimensional object coordinates of a ground point are measured, can be reconstructed. A SPOT image, however, is characterized by dynamic scanning, as illustrated in Figure 1. Its exterior

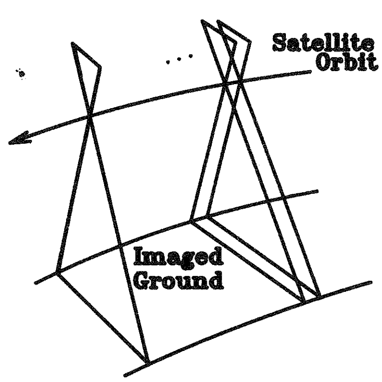

Figure 1. SPOT Imaging and Covered Ground Scene

orientation is variant along the orbital track. In addition, the ground scene of a SPOT image covers 60 by 60 km rather than 10 by 10 km of a usual aerial photograph with which a map projection coordinate system such as Gauss-Kruger is usually used directly for photogrammetric processing. A distortion-free rectangular 3-dimensional coordinate system should be selected for processing SPOT images, and the results are finally converted into desired map coordinates.

Exterior Orientation Parameters

A SPOT panchromatic image, which is scanned by linearly arrayed CCD sensors in continued 9.024 seconds, includes 6000 scanning lines, each of which is similar geometrically to a frame photograph with six elements of exterior orientation (the camera station coordinates Xs, Ys, Zs, and rotation angles Φ, Ω, K). While an image is being taken, the satellite moves steadily along an elliptic orbit, with slightly changing flight attitudes. Within an image, exterior orientations of scanning lines are highly correlated, and each of the six elements of a line is expressed as a linear function of time in most previous treatments. After analyzing the satellite ephemeris and experimenting with a real image pair, the quadric polynomial model is introduced here. Table 1 shows the root-mean-square errors (RMSEs) of experimental results, where $mS=\sqrt{mX^2+mY^2+mZ^2}$.

For SPOT level 1A images, the origin of image coordinates is the scene center, and the y-axis is defined parallel to scanning direction. Therefore, six elements of exterior orientation of any scanline can be expressed separately as a function of image ordinate y:

$$\left.\begin{aligned} Xs &= Xs_0+k_1 y+k_2 y^2 \\ Ys &= Ys_0+k_3 y+k_4 y^2 \\ Zs &= Zs_0+k_5 y+k_6 y^2 \\ \Phi &= \Phi_0+k_7 y+k_8 y^2 \\ \Omega &= \Omega_0+k_9 y+k_{10} y^2 \\ K &= K_0+k_{11} y+k_{12} y^2 \end{aligned}\right\} \quad (1)$$

where

Xs_0, Ys_0, Zs_0, Φ_0, Ω_0, and K_0 represent the elements of exterior orientation of center line of the scene; and k_1, k_2, ..., k_{12} are linear and quadric coefficients of variation.

These 18 parameters give the exterior orientation of a SPOT iamge.

Mutual Transformations between Gauss-Kruger and Spatial Cartesian Coordinates

Gauss-Kruger projection is used in topographic maps of 1:500,000 and larger scales in China. A topocentric Cartesian system (TCS) (shown in Figure 2) whose origin is located at the center of stereopair overlap is preferably chosen as an object-space

Table 1. Ground Residuals (RMSE:m) after Exterior Orientation

Degree of Polynomial for Image Parameters	17 Control Points				40 Check Points			
	mX	mY	mZ	mS	mX	mY	mZ	mS
Linear	3.56	6.29	23.61	24.69	8.48	6.82	20.23	22.97
Quadric	1.69	3.87	2.60	4.96	8.51	7.01	8.10	13.68

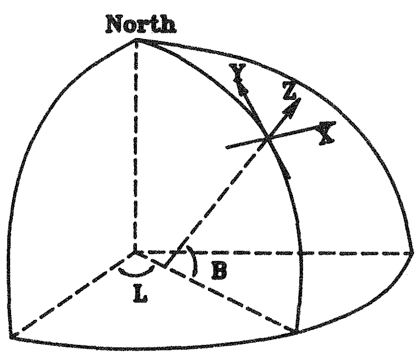

Figure 2. Topocentric Cartesian System

coordinate system of photogrammetric computation while processing SPOT imagery. Rigorous mutual transformations between map projection and TCS coordinates involve following conversions:

Gauss-Kruger Coordinates and Normal Height (Xg,Yg,h) ⟷ Geodetic Latitude, Longitude, and Height (B,L,H) ⟷ Geocentric Spatial Rectangular Coordinates (Xc,Yc,Zc) ⟷ TCS Coordinates (X,Y,Z).

The formulations are described in detail by Xiong. It is much time-consuming to perform these calculations, and especially some conversions require iterative refinement. A fast algorithm to substitute for the above complicated computation is required to meet the realtime needs of on-line photogrammetric mapping. One method that quadric polynomials perform the conversion between Gauss-Kruger and the TCS planimetric coordinates (Xo,Yo) on the reference spheroid, and then the elevation is considered, is proposed in this article. From (Xg,Yg) to (Xo,Yo), the conversion is:

$$Xo=A_0+A_1 Xg+A_2 Yg+A_3 Xg^2+A_4 XgYg+A_5 Yg^2, \quad Yo=B_0+B_1 Xg+B_2 Yg+B_3 Xg^2+B_4 XgYg+B_5 Yg^2 \tag{2}$$

and reversely

$$Xg=A'_0+A'_1 Xo+A'_2 Yo+A'_3 Xo^2+A'_4 XoYo+A'_5 Yo^2, \quad Yg=B'_0+B'_1 Xo+B'_2 Yo+B'_3 Xo^2+B'_4 XoYo+B'_5 Yo^2 \tag{3}$$

where coefficients A_i, B_i, A'_i, and B'_i ($i=0, 1, \ldots, 5$) are solved in advance from rigorously computed coordinates of a number of known standard ground points (from scene parameters or existing maps) evenly distributed over the imaged area. Considering the influence of height (illustrated in Figure 3 where the reference spheroid is approximately considered as a sphere whose radius R is equal to the average size of the spheroid), the TCS coordinates of a ground point are

$$X=Xo(1+\frac{H}{R}), \quad Y=Yo(1+\frac{H}{R}), \quad Z\approx H-\frac{1}{2R}(1+\frac{H}{R})(Xo^2+Yo^2) \tag{4}$$

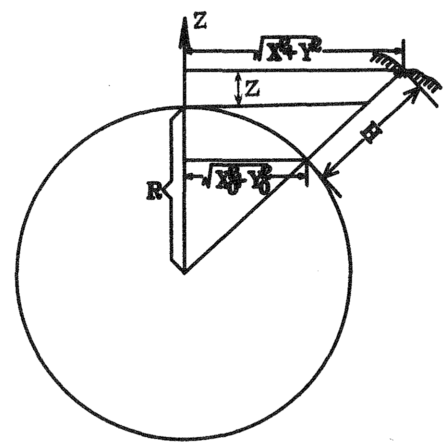

Figure 3. Plane Section through Z-Axis and a Ground Point

where H=h+ha (ha is the height anomaly of the area), and the reverse transformation begins with

$$H\approx Z+\frac{X^2+Y^2}{2(R+Z)}, \quad Xo=X\frac{R}{R+H}, \quad Yo=Y\frac{R}{R+H} \tag{5}$$

then h=H-ha and formula (3) are used.

Computation has demonstrated that in an area (central B=39°46'and L=118°17.5') of 60 by 60 km the maximal residuals (compared with rigorous transformation) are 0.25m of planimetric coordinates and 0.2m of elevation, much smaller than observation errors, and only occasionally existing far from the TCS origin.

Solution of Exterior Orientation Parameters

Instead of conventional relative and absolute orientations of stereophotogrammetry, the image orientation parameters of two SPOT images are directly solved by means of spatial resection. For each point, its collinearity equations of left or right image are

$$\left.\begin{aligned} x&=-f\frac{a_1(X-Xs)+b_1(Y-Ys)+c_1(Z-Zs)}{a_3(X-Xs)+b_3(Y-Ys)+c_3(Z-Zs)} \\ 0&=-f\frac{a_2(X-Xs)+b_2(Y-Ys)+c_2(Z-Zs)}{a_3(X-Xs)+b_3(Y-Ys)+c_3(Z-Zs)} \end{aligned}\right\} \tag{6}$$

where

f is the focal length; Xs, Ys, Zs are dynamic exposure station coordinates calculated by (1); a_i, b_i, and c_i ($i=1, 2, 3$) are direction cosines (Wang 14) determined by dynamic attitude Φ, Ω, K calculated also by (1); and X, Y, Z are TCS coordinates of the corresponding ground point.

By linearizing (6) combined with (1), orientation parameters of two images, whose initial values may be obtained from orbit data, are computed in iteration with the use of known image and object-space coordinates of adequate control points, by least square.

REALTIME IMAGE POSITIONING

As we know the LOOP program which runs with a certain frequency over 50 times per second in order to dynamically keep the conjugate relationship of identical object and left and right image points is the core of an analytical plotter. It may include the input of map or object-space coordinates, solution of left and right image coordinates, and closed-service for driving the left and right photocarriages, and the drawing pen when on-line mapping, onto the positions just calculated. For frame imagery, rotation matrice (consisting of direction cosines) and exposure station coordinates are fixed in all points of an image and image coordinates can be easily solved through collinearity equations of central perspective (Wang 5) from ground coordinates. For SPOT imagery, however, since elements of exterior orientation are y-dependent, exact image coordinates cannot be computed simply by direct solution of the equations (6) combined with (1). Mathematically, time-consuming iteration, i.e.

y=0;
repeat:
   calculate (1) and a_2, b_2, c_2, a_3, b_3, c_3,
   calculate Δy equal to the right expression of second equation in (6),
   refine $y=y+\Delta y$,
until Δy is negligible (almost equal to zero);
calculate a_1, b_1, c_1;
calculate x by first equation in (6).

is adopted to find the solution. This procedure greatly slow down the execution frequency of LOOP so that stereoscopic visual perception is apparently trembling or un-continuous. An approach that a fictitious central perspective image whose six elements of exterior orientation are same as those of center line of SPOT images is considered, and differences between central perspective and SPOT geometry are next compensated by bilinear interpolation with regard to ground (or image plus height) coordinates from tables computed before LOOP runs, as described in detail by Konecny (1987) and Li (1988), is substituted for the iteration algorithm. In addition, before computing image coordinates, Gauss-Kruger coordinates and height have to be converted into TCS coordinates. Based on the method here, a LOOP program for SPOT imagery whose operational sequence is shown in Figure 4 is coded in C.

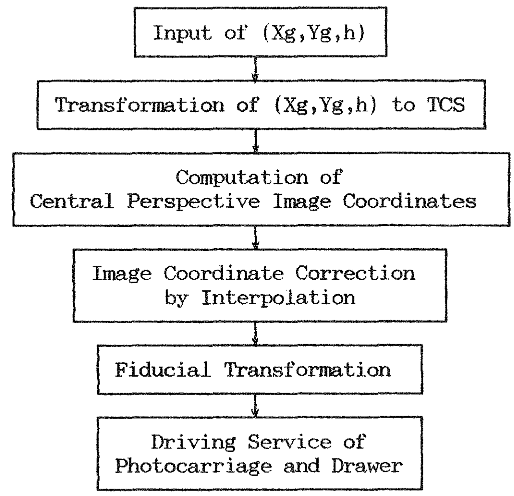

Figure 4. Schematic Diagram of LOOP Program

It runs with 7ms per cycle on an AT personal computer (10MHz) which controls the JX-3.

IMPLEMENTATION ON JX-3

According to the restitution discussed above, a software running on the JX-3 was designed by the author to produce topographic maps and digital elevation models (DEMs) from SPOT stereo images. The program structure and implementation procedure are illustrated in Figure 5. Except those that closely relate to hardware and hence are programmed in Assembly, all other subroutines and programs are developed in C (Microsoft C5.0 Version). All functional modules are integrated and managed under a main menu. No additional hardware is required.

EXPERIMENT AND CONCLUSION

A SPOT stereopair (duplicate) of the Tangshan area taken in May, 1986, with a base-to-height ratio of 0.5 and a percentage overlap of 90%, was provided for experiment. The ground coordinates of control and check points are acquired from existing maps at scales of 1:10,000 and 1:50,000 compiled in 1970s. 17 control points distributed as in Figure 6 were used to compute the exterior parameters of images. 80 independent points were checked by comparing the ground coordinates separately acquired from the orientated stereoscopic model and the existing maps, and statistic RMSEs (m) are

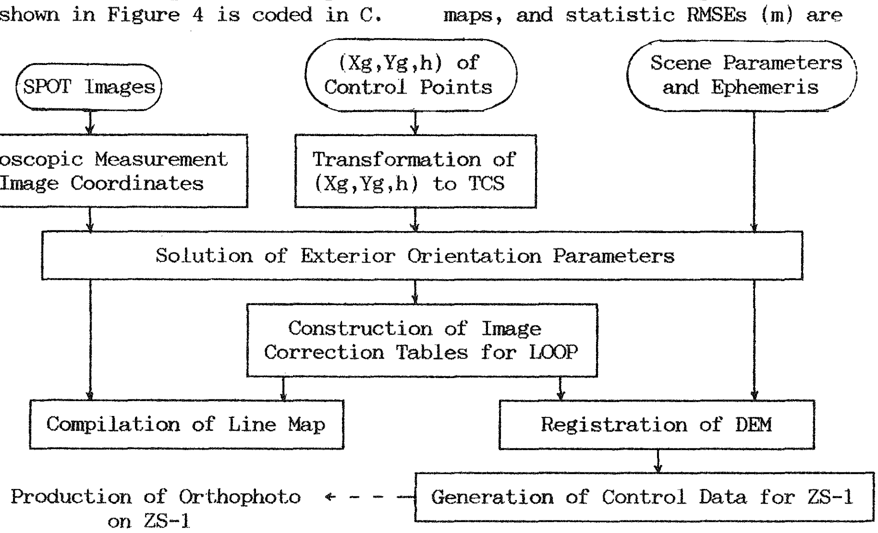

Figure 5. Organization Chart of Implementation

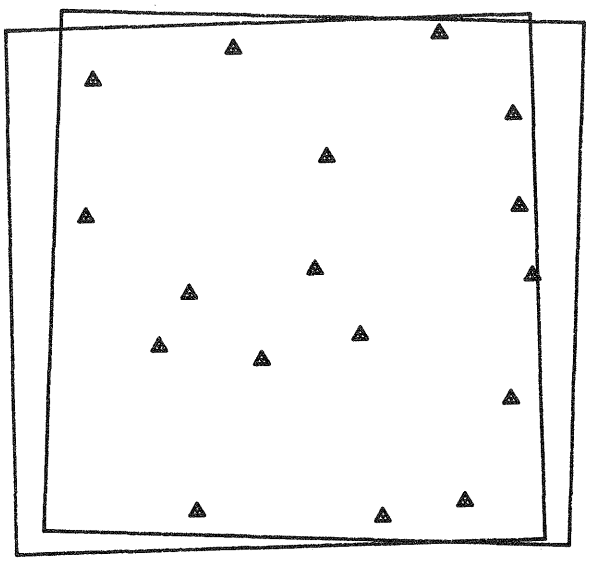

Figure 6. Distribution of Control Points and Ground Scenes of Two Images

40 points compared with 1:10,000 maps:
mX=8.13, mY=8.16, mh=5.71
40 points compared with 1:50,000 maps:
mX=11.90, mY=12.65, mh=6.92

A line map at the scale of 1:100,000 was compiled with all index and partial standard contours, some habitations, roads, and hydrography features, etc. (Figure 7). In addition, a DEM was registered from the stereo images, and then used to generate the control data of ZS-1. An orthophoto (Figure 8) at the scale of 1:50,000 was printed, and the residual RMSEs (mm) according to 26 check points are

mx=0.24, my=0.26

The experimentation shows that the approach described in this paper is successful in processing SPOT imagery and the achieved accuracies might meet specifications even up to a scale of 1:25,000. Unfortunately, the (ground 10m) resolution of SPOT images supplied currently is not clear enough to well identify many details, such as habitations, riverets, and village roads, which have to be precisely located for maps of these scales, and consequently, using SPOT imagery for line mapping is partly restricted unless images of higher resolution are available. Nevertheless, DEM registration and orthophoto printing are much effective.

Figure 7. Partial Original Map (1:100,000) Compiled with SPOT Images

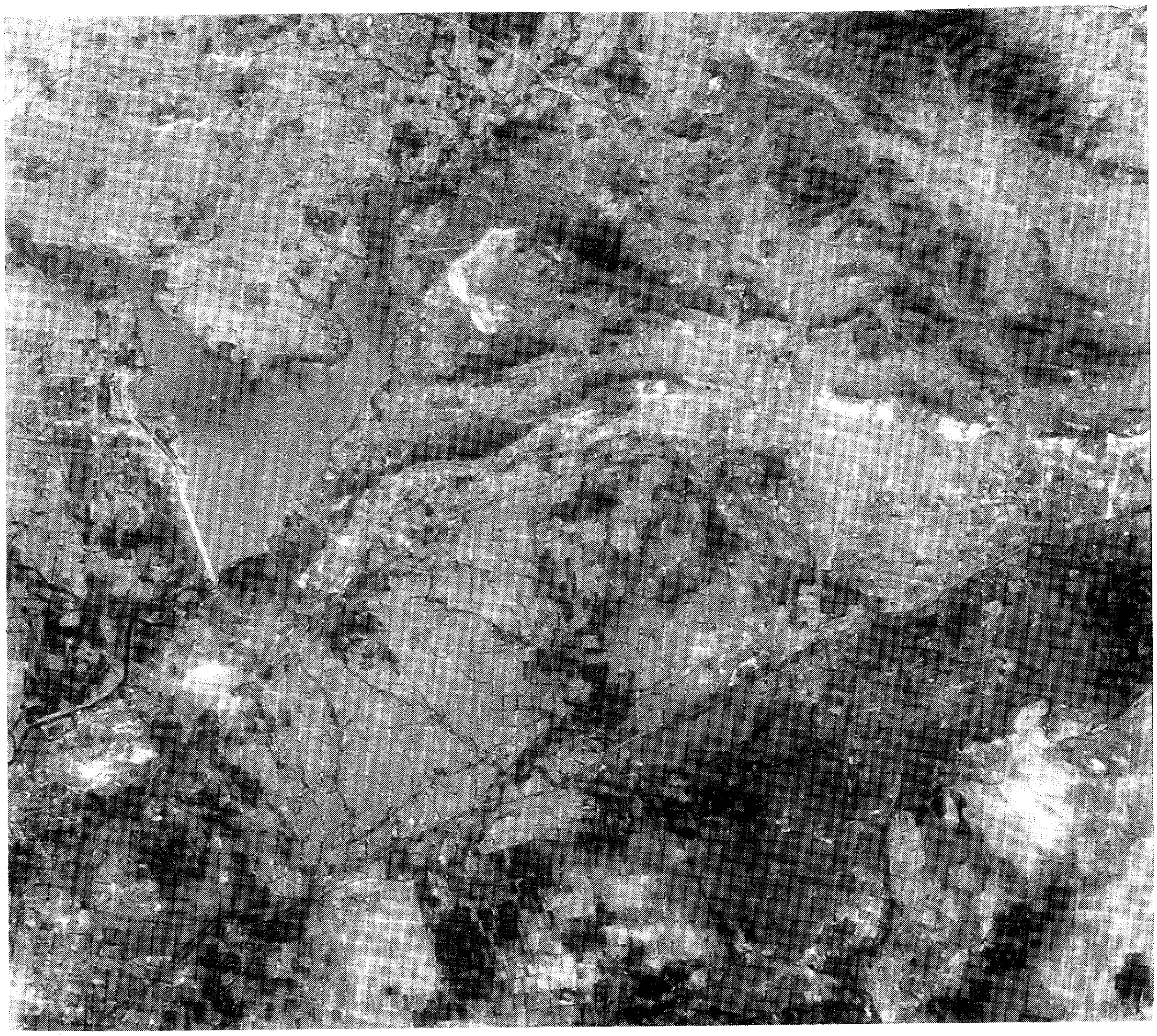

Figure 8. SPOT Orthophoto (original scale 1:50,000)

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