Mapping From SPOT Images Using Digital Photogrammetric Workstation

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Abstract

This paper describes our mapping tests from SPOT stereo image pairs using a Digital Photogrammetric Workstation (DPW).

The components of our DPW are briefly reviewed at first, then the procedure of SPOT stereo image pairs is introduced. Epipolar image is an essential and very useful concept in a DPW particularly in stereo view and image matching processing. Due to the different geometry between SPOT and airphotos, new relative, absolute orientations and epipolar images' resampling techniques are studied and new software is developed. A adapted relaxation method is used in our grey based global image matching algorithm, it also combines image features so that the image matching reliability and accuracy both are improved. As a result of new epipolar image resampling the SPOT image matching can keep a very high efficiency (400 points per second).

The SPOT mapping products include DEM (Digital Elevation Models), Orthophotos, Contour lines and Perspective View. The results indicate less 6 meters or 0.4 pixel accuracy of heights can be obtained by DPW.

1. Introduction

During the past few decades, photogrammetry has grown tremendously and become a dominate mapping tool all over world. We are now witnessing the advent of a new era, that of Digital Photogrammetry. The concept of a digital photogrammetric workstation has been around for more than ten years. Publications of Sarjakoski (1981) and Case (1982) mark the beginning of the digital photogrammetry era, In recent years, digital photogrammetry has established important strategic alliances with Remote Sensing and Geographic Information Systems (GIS).

The Space Centre for Satellite Navigation at Queensland University of Technology is a research and development institute mainly in two aspects: 3D reconstruction from stereo images and GPS. A digital photogrammetric software package called *VirtuoZo* (formerly *WuDAMS*) is the result from the cooperation with Wuhan Technical University of Surveying and Mapping (WTUSM). The paper organised as follows: firstly, The components of *VirtuoZo* are discussed; after that, some techniques are introduced; and finally, The results of our test for SPOT images are presented.

Digital Photogrammetric workstations (DPW) are becoming the more useful tools for mapping from single or stereo digital or digitised images. A DPW is a system combining advanced computer technology and photogrammetric softwares, it's independent from any parts of classical photogrammetric instruments, A DPW not only can be used for mapping using traditional photos (frames) but also suitable for satellites' images for example, SPOT and MOSS data. A DPW usually includes several modules described as follows:

Input:

Digital (scanned) stereo pairs of positive or diapositive photography, or SPOT satellite imagery.
Camera calibration contents (for metric cameras).
Control coordinates (e.g. ground control).

Photogrammetric Processing:

Orientation (including interior, relative and absolute orientations)
Epipolar image's resampling.
Image Matching and measurement.

Output:

Digital Elevation Models (DEM), Orthophotos, contour lines, and XYZ coordinates of points.

We currently developed a series of theories for non-frame photos' mapping processing, they are successful in mapping from SPOT stereo images. In the following sections we will first discuss the theories and algorithms of extracting 3D terrain models from stereo SPOT images, including relative/absolute orientations, stereo epipolar images' rectification, image matching, generating DEM (Digital Elevation Models), and some other products' creating like orthoimages and contour lines, then we present some results of extracting 3D terrain models from stereo SPOT images.

2. Fundamental SPOT Photogrammetric Equations

SPOT images are so-called scanning line images i.e. each image line is built up over time. Each line of a SPOT image is a processed "range line" comprising the reflective intensity of the corresponding terrain zone in a given direction at a given time. Thus the two major axes of any SPOT image are time (or flying path) and range. If we arbitrarily assign the range in the x direction and time in the y direction we can represent any point (x, y) in the image using collinearity equations as:

$$
\begin{aligned}
x &= -f\frac{a_{11}(X-X_S)+a_{21}(Y-Y_S)+a_{31}(Z-Z_S)}{a_{13}(X-X_S)+a_{23}(Y-Y_S)+a_{33}(Z-Z_S)} \\
y &= -f\frac{a_{12}(X-X_S)+a_{22}(Y-Y_S)+a_{32}(Z-Z_S)}{a_{13}(X-X_S)+a_{23}(Y-Y_S)+a_{33}(Z-Z_S)}
\end{aligned}
\qquad (1)
$$

where (X,Y,Z) is arbitrary ground point located on the corresponding terrain zone which is imaged into the current image scan line, and (X_S,Y_S,Z_S) are the temporary perspective centre of current image scan line, a_{ij} is the elements of rotate matrix based on three rotated angles φ,ω,κ at the same line on which the point (x, y) locates, and y always keeps 0 in Eq.(1).

Eq.(1) is suitable for both left and right images. and assume each image line's orientation parameters $(X_s,Y_s,Z_s,\varphi,\omega,\kappa)$ are known prior, once a corresponding point is found between left and right images, we can build four equations (two of them are based on left image and other two are based on right image), to compute this point's ground coordinates *(X,Y,Z)* using least squares adjustment. The collinearity equation is the fundamental of SPOT images' photogrammetric processing.

3. Stereo View of SPOT Images

In principle, photogrammetric fusion of two SPOT images which are captured from two different orbits but cover the same area enables the reconstruction of three-dimensional object coordinates. To get stereo view of a stereo SPOT image pair in a DPW, attention must be paid that each of them is transferred using the respective sensor model, it's hard to view under stereo model due to there are variable two-dimensional parallaxes in an original stereo SPOT image pair, and it also causes time consume when two-dimensional image matching algorithms are performed. In order to get "epipolar images" from stereo SPOT images, a flexible method of generating epipolar lines was developed in Wuhan Technical University of Surveying and Mapping (Zhang and Zhou, 1989). The following is the final formula used in epipolar lines' generating in our DPW.

a1, a2 are the left and right image points of a ground point A, x_1, y_1 denote left image coordinates of a1 and x_2, y_2 denote the right image coordinates of a2, two of collinearity equations are obtained for both corresponding points a1 and a2, and finally, from these equations we can describe the y_2 by using a polynomial series:

$$y_2 = c_1 + c_2x_2 + c_3y_1 + c_4x_2^2 + c_5x_2y_1 + c_6x_2^2y_1 + c_7x_2^3 + c_8x_2^3y_1 \tag{2}$$

where $c_i(i = 1,2,...,8)$ are the coefficients of the polynomial.

However, these conditions can not always exist in practice, so that the errors are raised, if the relief is less than 100 meters and the orientation angles are less than 1 degree, the error will be about 0.25 pixel (about 1 meter in the ground), and within 1,000 meters on relief, the error will reach 2~3 pixels (about 20~30 meters). This could be tolerated by stereo viewing.

In fact the polynomial fitting method of epipolar lines extraction is not only suitable to SPOT images, but also can be considered as a general procedure for generating stereo viewing from scanning images.

To perform epipolar lines' extraction, only at least 8 conjugate points are measured or matched automatically, then $c_i(i = 1,2,...,8)$ are solved by least squares adjustment if there are more than 8 points measured. Once get all polynomial parameters, epipolar lines can be extracted and resampled from original images.

4. Exterior Orientation for SPOT images

A number of papers have been published on different approaches to modelling SPOT satellite geometry. In every case models are used which describe the orbit in terms of orbital parameters or coordinates with constraints, represent attitude in terms of a polynomial and relate object space to image space with collinearity equations (Dowman, 1991). The methods differ in the use of constraints and in the method of determining the initial values of the unknowns. Gugan(1991), Trider *et al.* (1988), Konecny et al. (1987) and Neto and Dowman (1991) treat the correction of SPOT data with an approach adapted to analytical photogrammetric instruments. Picht et al. (1991) describe an approach similar to the use of aerial photographs, with additional parameters used to account for the different geometry of SPOT. This paper describes a similar approaches for exterior orientation of SPOT images.

The inverse computation for the exterior orientation elements, $X_s, Y_s, Z_s, \varphi, \omega, \kappa$ of a normal aerial (frame) photographic bundle of rays when the space coordinates of some ground points are known is a problem of single-image resection on space. The solution can be obtained after linearising Eq.(1).

4.1 Rigorous Formulas

It is necessary to introduce the following new parameters for the SPOT exterior orientation: the six $X_{So}, Y_{So}, Z_{So}, \varphi_o, \omega_o, \kappa_o$ exterior parameters of the centre line of a scanning line SPOT image, and $\Delta X_S, \Delta Y_S, \Delta Z_S, \Delta\varphi, \Delta\omega, \Delta\kappa$ are the six correction exterior parameters between two scanning lines, t is the scanning line number from the centre line.

Assume the flying path of the SPOT satellite platform is stable and can be fitted using a straight line during a period of time (scanning lines), then $\Delta X_S, \Delta Y_S, \Delta Z_S, \Delta\varphi, \Delta\omega, \Delta\kappa$ keep the same values between arbitrary two scanning lines during this period of time. So the collinearity equation for a SPOT image can be written as below:

$$
\begin{aligned}
x &= -f\frac{a_{11}(X - X_{So} - t\Delta X_S) + a_{21}(Y - Y_{So} - t\Delta Y_S) + a_{31}(Z - Z_{So} - t\Delta Z_S)}{a_{13}(X - X_{So} - t\Delta X_S) + a_{23}(Y - Y_{So} - t\Delta Y_S) + a_{33}(Z - Z_{So} - t\Delta Z_S)} \\
y &= -f\frac{a_{12}(X - X_{So} - t\Delta X_S) + a_{22}(Y - Y_{So} - t\Delta Y_S) + a_{32}(Z - Z_{So} - t\Delta Z_S)}{a_{13}(X - X_{So} - t\Delta X_S) + a_{23}(Y - Y_{So} - t\Delta Y_S) + a_{33}(Z - Z_{So} - t\Delta Z_S)}
\end{aligned}
\quad (3)
$$

where a_{ij} is the element of rotation matrix yielded by $\varphi_S + t\Delta\varphi, \omega_S + t\Delta\omega, \kappa_S + t\Delta\kappa$ at the scanning line t , and y keeps zero at any scanning line t .

The parameters $X_{So}, Y_{So}, Z_{So}, \varphi_o, \omega_o, \kappa_o$ and $\Delta X_S, \Delta Y_S, \Delta Z_S, \Delta\varphi, \Delta\omega, \Delta\kappa$ are to be determined. We may substitute their values by their approximate values plus their corresponding increments $\Delta X_{So}, \Delta Y_{So}, \Delta Z_{So}, \Delta\varphi_o, \Delta\omega_o, \Delta\kappa_o$ and $\Delta\Delta X_S, \Delta\Delta Y_S, \Delta\Delta Z_S, \Delta\Delta\varphi, \Delta\Delta\omega, \Delta\Delta\kappa$, thus the general forms of the error equations are:

$$
\begin{aligned}
v_x - \frac{\partial x}{\partial X}v_X - \frac{\partial x}{\partial Y}v_Y - \frac{\partial x}{\partial Z}v_Z &= \frac{\partial x}{\partial X_S}\Delta X_{So} + \frac{\partial x}{\partial Y_S}\Delta Y_{So} + \frac{\partial x}{\partial Z_S}\Delta Z_{So} \\
&+ \frac{\partial x}{\partial \varphi}\Delta\varphi_o + \frac{\partial x}{\partial \omega}\Delta\omega_o + \frac{\partial x}{\partial \kappa}\Delta\kappa_o + t\frac{\partial x}{\partial X_S}\Delta\Delta X_S + t\frac{\partial x}{\partial Y_S}\Delta\Delta Y_S + t\frac{\partial x}{\partial Z_S}\Delta\Delta Z_S \\
&+ t\frac{\partial x}{\partial \varphi}\Delta\Delta\varphi + t\frac{\partial x}{\partial \omega}\Delta\Delta\omega + t\frac{\partial x}{\partial \kappa}\Delta\Delta\kappa - (x - (x))
\end{aligned}
$$

(4)

$$
\begin{aligned}
v_y - \frac{\partial y}{\partial X}v_X - \frac{\partial y}{\partial Y}v_Y - \frac{\partial y}{\partial Z}v_Z &= \frac{\partial y}{\partial X_S}\Delta X_{So} + \frac{\partial y}{\partial Y_S}\Delta Y_{So} + \frac{\partial y}{\partial Z_S}\Delta Z_{So} \\
&+ \frac{\partial y}{\partial \varphi}\Delta\varphi_o + \frac{\partial y}{\partial \omega}\Delta\omega_o + \frac{\partial y}{\partial \kappa}\Delta\kappa_o + t\frac{\partial y}{\partial X_S}\Delta\Delta X_S + t\frac{\partial y}{\partial Y_S}\Delta\Delta Y_S + t\frac{\partial y}{\partial Z_S}\Delta\Delta Z_S \\
&+ t\frac{\partial y}{\partial \varphi}\Delta\Delta\varphi + t\frac{\partial y}{\partial \omega}\Delta\Delta\omega + t\frac{\partial y}{\partial \kappa}\Delta\Delta\kappa - (y - (y))
\end{aligned}
$$

When it is necessary to introduce values such as v_X, v_Y, v_Z, their corresponding weights should be added in the least squares operation to reflect the accuracy features if the control points. All the observed values of the image coordinates are generally regarded as of equal weight. In the above equations, $(x),(y)$ are the computed values of x, y when the approximate values of the values to be determined have been substituted into Eq.(3). To express Eq.(4) in matrix form, we obtain:

$$Av = Bx - l \tag{5}$$

$$A = \begin{bmatrix} 1 & 0 & a_{11} & a_{12} & a_{13} \\ 0 & 1 & a_{21} & a_{22} & a_{23} \end{bmatrix} \quad v = \begin{bmatrix} v_x \\ v_y \\ v_X \\ v_Y \\ v_Z \end{bmatrix} \quad l = \begin{bmatrix} l_x \\ l_y \end{bmatrix}$$

where $l_x = x - (x), l_y = y - (y)$.

$$B = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} & ta_{11} & ta_{12} & ta_{13} & ta_{14} & ta_{15} & ta_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} & ta_{21} & ta_{22} & ta_{23} & ta_{24} & ta_{25} & ta_{26} \end{bmatrix}$$

$$x^T = \begin{bmatrix} \Delta X_{So} & \Delta Y_{So} & \Delta Z_{So} & \Delta\varphi_o & \Delta\omega_o & \Delta\kappa_o & \Delta\Delta X_S & \Delta\Delta Y_S & \Delta\Delta Z_S & \Delta\Delta\varphi & \Delta\Delta\omega & \Delta\Delta\kappa \end{bmatrix}$$

Based on these error equations, normal equations can be formed through conventional methods. The solution of the normal equations would give the elements of exterior orientation.

Since the coefficients a_{ij} in Eq.(5) are taken from the first derivative term of Tayor's formula and the approximation values of the unknowns are usually coarse, the method of successive approximation should be applied in computation. In each approximation, the constant term should be recalculated, and when there are substantial changes in the corrections of the unknowns, recalculation should be performed also for the values of coefficients. The final value of an unknown is the sum of its initial value and the corrections obtained in the approximations. When the corrections are smaller than a limit value, the approximation procedure may be stopped.

5. Image matching for SPOT Epipolar images

Image matching is a common topic whatever kinds of images are used, therefore we only describe the normal image matching our DPW used and lit's also suitable for SPOT image matching.

It is well known that photogrammetry and remote sensing provide two types of information: geometric and thematic information. In any mapping procedure, these two types of information are involved, but generally saying photogrammetry emphasises on geometry which is mainly based on image coordinate measurements, while remote sensing emphasises interpretation. Therefore, the measurement is the most important and fundamental task in photogrammetry. In classical photogrammetry, either analog or analytical, this problem is solved manually with a human operator. Actually, the problem which identifies the correspondence points between two or multiple images is an image matching problem. In order to realise automatic matching and obtain 3D geometric information which is reliable and high accurate effectively, photogrammetrists have worked for a long time to get many effective research results. For examples, according to the geometric concept of photogrammetry, epipolar image matching was proposed, VLL image matching and converting 2D image matching to 1D image matching were also put forth. Even more, based on image spectrum analysis, the strategy of matching from coarse to fine was proposed. Using least squares theory, image matching was cast as least squares results and high precise image matching algorithm was proposed. Then, It was developed to multi-point least squares matching algorithm.

At meantime, researchers working on computer science have also worked on the image matching problem. They cast image matching problem as a kind of pattern recognition problem. It is particular interest to see how photogrammetry and remote sensing apply methods from computer vision. Since 1990, we have applied relaxation technique of pattern recognition in grey-based correlation system and the reliability and efficiency has been improved greatly.

Using contextual information, relaxation method can reduce local ambiguity and improve global consistency. It has been applied on image segmentation, shape matching, line and curve enhancement, handwritten character recognition, sequential image analysis and correspondence problem, etc..

Relaxation technique has been used for a long time. In 1980, Barnard and Thompson (1980) used relaxation technique to recognise spatial physical points, that is the correspondence problem. Lee and Lei (1994) used relaxation to solve region matching problem, etc.

Relaxation was classified by Rosenfeld and Kak (1982) into three kinds: discrete relaxation, probabilistic relaxation and fuzzy relaxation. Probabilistic relaxation is the commonly used one. Assume there are n objects, $A_1, A_2, \ldots, A_n$, and m classes, $C_1, C_2, \ldots, C_m$. In relaxation, we also suppose that there exists an compatibility measure, $c(i,j;h,k)$, between each classification: $A_i \in C_j$ and $A_h \in C_k$. Suppose that the probability of $A_i \in C_j$ is $P_{i,j}^0$, $1 \le i \le n, 1 \le j \le m$. For each object, $0 \le P_{i,j}^0 \le 1$ and $\sum_{j=1}^{m} P_{i,j}^0 = 1$. The main goal of relaxation is to use initial probabilities $P_{i,j}^0, P_{h,k}^0$ and compatibility measure $c(i,j;h,k)$ to update the probability of $A_i \in C_j$, and to classify the n objects into classes so that $A_i \in C_j$ and $A_h \in C_k$ are most compatible. Therefore global consistency will be reached.

Relaxation is a parallel iterative procedure. The iteration is the processing of updating probability $P_{i,j}$ for each object i that belongs to classification j, $A_i \in C_j$. The key problem is to update $P_{i,j}$ so that optimal global consistency can be reached. Viewing from physical point, if $P_{h,k}$ is very big and $c(i,j;h,k)$ is positive, then $P_{i,j}$ should increase otherwise $P_{i,j}$ should decrease. Therefore the simplest probabilistic updating is the direct ratio of the product of $P_{h,k}$ and $c(i,j;h,k)$, $c(i,j;h,k) \cdot P_{h,k}$. Normally, we can consider the contribution of all $A_h (h = 1,2,\ldots,i-1,i+1,\ldots,n)$ and all classes $C_k (k = 1,2,\ldots,m)$ except A_i, that is $q_{i,j}$, the increment of $P_{i,j}$.

$$q_{i,j} = \frac{1}{n-1} \sum_{h=1,h \neq i}^{n} \left(\sum_{k=1}^{m} c(i,j;h,k) \cdot P_{h,k} \right) \tag{6}$$

According to the increment $q_{i,j}^r$ of probability $P_{i,j}^r$, we can calculate the $(r+1)^{TH}$ probability of $A_i \in C_j$.

$$P_{i,j}^{r+1} = \frac{P_{i,j}^r (1 + q_{i,j}^r)}{\sum_{j=1}^{m} P_{i,j}^r (1 + q_{i,j}^r)} \tag{7}$$

Through several iterations, the probability of $A_i \in C_j$ which is compatible will increase while the probability of $A_i \in C_j$ which is incompatible will decrease. In the end, we can get the matching results that global consistency is the most optimal.

We have applied the relaxation technique in area-based correlation successfully. Compared with feature-based correlation, though area-based correlation has some weakness, it can avoid the maladies of image segmentation in feature-based systems. Especially, it can use bridging mode method to calculate the compatibility measure $c(i, j; h, k)$ and the result is more reliable.

The basic concept of bridging mode method is: that connecting a pair of correspondent points $A_i \in C_j$ and $A_h \in C_k$ on left and right images. Calculate the correlation coefficient of this pair of image segment $\overline{ih}$ and $\overline{jk}$. If the probability of $A_h \in C_k$ is big and segment $\overline{ih}$ is similar to segment $\overline{jk}$, then the increment of probability $P_{i,j}$ should be positive. Actually, it is the compatibility measure $c(i, j; h, k)$ in relaxation :

$$c(i, j; h, k) \propto \rho(\overline{ih}, \overline{jk}). \tag{8}$$

where $\rho(\overline{ih}, \overline{jk})$ is the bridging mode correlation coefficient of segments $\overline{ih}$ and $\overline{jk}$ on left and right images.

Based on bridging mode, the relaxation method takes the contextual information into account so that the global consistency can be improved greatly. It has been applied in the matching of terrain successfully. Even in the very steep area, the matching results are also very satisfied.

Just as mentioned above, due to there are no strict epipolar lines in stereo SPOT images but approximate epipolar lines, we should consider the y-parallax, which is 2~3 pixels normally. We have applied the bridging mode based relaxation in the automatic measuring of SPOT images. The speed of image matching using an *Indigo*^{2} workstation is 400 points per second. Therefore we have realised the automatic measuring for stereo SPOT images.

8. Test Results and Conclusions

One stereo SPOT images pair was used to investigate how accurately it is possible to model the geometry of a SPOT scene, and what is the effectiveness and practicality of our DPW in automatic extracting the DEM from the stereo SPOT images.

115 tie corresponding points were automatic found for epipolar lines' determination using Eq.(2), the average residual in y-direction is 0.7 pixel. Use of 20 control points in the exterior orientation adjustment resulted in the following r.m.s. residual errors:

error in latitude direction	= 14.415 m
error in longitude direction	= 11.487 m
error in height direction	= 7.353 m

The area imaged in this scene is moderately hilly with heights varying from 0 m to 640 m.

We resampled the original images into the approximate epipolar images using the algorithm we mentioned above. then image matching algorithms were performed, the image matching can result in less 6 meters accuracy in heights or corresponding 0.4 pixel in images. Fig.1 shows the landscape of this test area.

The stereo SPOT images' exterior orientation and epipolar resampling algorithms have been derived. The control data test results verify the equations and algorithms for the computation, which thus supply a theoretically exact and readily accessible solution to the substantial problem of stereo SPOT images. And the relaxation image matching method is also much suitable for the SPOT epipolar images. We believe our DPW will give the whole solution for DEM automatic extracting from stereo SPOT images.

References:

Barnard,S.T. and Thompson,W.B., 1980: Disparity Analysis of Images. IEEE PAMI, No.4, 333--340.

Case,J.B. 1982: The Digital Comparator/Compiler(DSCC), International Archives of Photogrammetry, 24 23--29.

Dowman,I.J. (Editor), 1991: Test of Triangulation of SPOT data. OEEPE Official Publication 26. Institut für Angewandte Geodäsie, Frankfurt am Main

Dowman,I.J., Gugan,D.J. Muller,J.P. O'Neill,M. and Paramananda,V. 1987, Digital Processing of SPOT Data, Intercomm. Conference on Fast Processing of Photogrammetric Data, Interlaken, Switzerland

Gugan,D.J., 1991: Strip Orientation of SPOT Imagery with an Orbital Model. OEEPE Official Publication 26: 129-134

Heleva,U.V. 1992: State of the Art in Digital Photogrammetric Workstation, ASPRS/ACSM/RT 92, Technical Papers, Vol.2

Konercny,G., Lohmann,P., Engel,H. and Kruck,E., 1987: Elaluation of SPOT Imagery on Analytical Photogrammetric Instruments. Photogrammetric Engineering and Remote Sensing, 53(9): 1223-1230

Lee,H.J. and Lei,W.L., 1994: Region Matching and Depth Finding for 3D Object in Stereo Aerial Photographs, Pattern Recognition, Vol.23, No.1/2

Neto,F. and Dowman,I.J., 1991: Triangulation of SPOT data at University College London. OEEPE Official Publication 26

Rosenfeld A. and Kak A.C., 1982: Digital Picture Processing. Academic Press, INC. (London)

San,I.C. and Man,L.A., 1993: Digital Photogrammetry on the Move, GIM, Vol.7, No.8

Sarjakoski,T. 1981: Concept of a Completely Digital Stereoplotter, The Photogrammetric Journal of Finland, 2:95--100

Sharp,J.V. et al, 1965: Automatic Map Compilation(DMAC), Photogrammetry Engineering, Vol. 21, No.2

Shiaw-Shian Yu and Wen-Hsiang Tsai, 1992: Relaxation by the Hopfield Neural Network, Pattern Recognition, Vol.25, No.2, 197--209

Torlegard,K., 1992: Sensors for Photogrammetric Mapping: review and prospects, ISPRS Journal of Photogrammetry and Remote Sensing 47, 241--262

Trinder,J.C., Donnelly,B.E. and Kwoh Leong Kelong, 1988: SPOT Mapping software for Wild Aviolyt BC2 Analytical Plotter. Proceedings of IGARSS'88 Symposium on Remote Sensing: Moving Towards the 21st Century, ESA SP-284

Zhang Z. and Zhou,Y., 1989: A New Approach to Arrange the Approximate Epipolar lines for SPOT Images, ACTA Geodetica et Cartographica Sinica 1989/1.(English Version)