Terrain Height Extraction by the Use of SPOT Data

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I .Introduction

French Satellite SPOT, launched in February, enables us to get Space borne stereoscopic images by offnadir viewing. By the use of SPOT data, topographic maps of scale 1/50,000 through 1/100,000 are expected. In order to extract terrain height from stereo pair images, the conventional photogrammetric approach may be applied. In this case, G.C.P.s (ground control points), whose plannimetric positions and heights are given, are needed, and much time and cost must be wasted to get G.C.P.s. On the other hand, there remain large area without complete coverage of 1/50,000 topographic maps. In such an area, it will be much less time and cost consuming to get height and plannimmetric data only from the position in the stereo pair images and wihout any use of G.C.P.s.

II. Ancillary Data of SPOT

Followings are the ancillary data of SPOT written in the C.C.T 's, which were used for this study.

① Satellite Position (x, y, z)
Satellite positions for Earth Center Rotation coordinates at each 60 sec.
9 data are given.

② Satellite Velocity ($\dot{x}$, $\dot{y}$, $\dot{z}$)
Satellite velocity for Earth Center Rotation coordinates at each 60 sec.
9 data are given.

③ Satellite Attitude Velocity ($\dot{\omega}$, $\dot{\Phi}$, $\dot{\kappa}$)
Satellite attitude velocities measured by gyroscope at certain lines of image.
72 or 73 data are given.

④ Observation time tc
Observation time for the image center.

⑤ Look angles of HRV θ_{PE}, θ_{PS}, θ_{RE}, θ_{RS}
These angles changes scene by scene because of the off-nadir viewing capability of HRV. Look directions of CCD Satellite's azimuth directtion (pitch) for the start (θ_{PS}), the end (θ_{PE}) and also towards scan (roll) direction for the start (θ_{RS}) , the end (θ_{RE}), are recorded in the CCT.

⑥ Distortion factors for level 1B
A(0)~A(3) and B(0)~B(3) are, respectively, line and pixel distortion factors to convert line and pixel numbers on the original image into those on level 1B image . On the other hand, C(0)~C(3) and D(0)~D(3) are, respectively, line and pixel resampling factors to convert line and pixel numbers on the level 1B image into those on the original image. And E(0)~E(3) are line shift model factors.

⑦ Direct positionning model factors (F(0)~F(9))×3

They are the factors to get the Earth Center Rotation coordinates (X, Y, Z) from the scanning time UT and pixel number. Each coordinate (X, Y, Z) has respectively 10 factors ; so there are 30 factors in total.

⑧ Inverse positionning model factors (G(0)~G(3))×2

Inversely to ⑦ they are the factors to get the line, and pixel on the image from the Earth Center Rotation coordinates (X, Y, Z) directions. There are respectively, 4 factors, so in total 8 factors.

Ⅲ. Image data of SPOT

The test site is located in Matsumoto area in Japan and the parameters are as follows:

column-row : 327-277
process-level : 1B
spatial resolution : 20m (multi spectral mode)
data acquisition
1) June 13, 1986, Observation Angle 21. 1°E
2) April 8, 1986, Observation Angle 23. 8° W
B/H = 1.0

Ⅳ Terrain height extraction based on the ancillary records (Position and attitude data of Satellite).

Following is the description of the present method; provided the two look directions (α_1, β_1, γ_1) and (α_2, β_2, γ_2) for the corresponding points P_1 and P_2 on the stereo pair images, and also provided the two corresponding pixel's positions O_1 (X_1, Y_2, Z_1) and O_2 (X_2, Y_2, Z_2) for the EarthCenter Rotation coordinates, the position of the target on the Earth Center Rotation coordinates must be obtained as the crossing point of 2 vectors, and thus, the terrain height can be calculated as the distance from the rotating ellipsoid of the Earth. The above-mentioned two directions towards the target (directional cosines) can be calculated from the multiplication of some rotation matrices whose inputs are attitude , position and look angle along the scanning direction at the data acquisition time of the corresponding pixels. In other word, the coordinates are rotated by application of rotation matrices, in order to get the look angle toward the target point on the ground by simulating sensor status at the moment of data acquisition. In this process, interpolation is needed to get position and attitude data, since these data are available only for limited instant. The above procedure can be expressed as:

$$\begin{pmatrix} \cos\Phi_x \\ \cos\Phi_y \\ \cos\Phi_z \end{pmatrix} = \Lambda_\lambda \Lambda_\psi \Lambda_\beta YPRML \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}$$

Where

L : Look direction matrix (azimuth direction)
M : Look direction matrix (scan direction)
R : Roll matrix
P : Pitch matrix
Y : Yaw matrix
Λ_β : Heading matrix
Λ_ψ : Latitude matrix
Λ_λ : Longitude matrix

However, the two vectors calculated by the above method don't cross in general. So, we suppose, in this study, that the cross point is located at the mid-point of the straight line along which the distance between two lines is minimized (Fig.1)

(a) Calculation of directional cosine

Scanning direction angle θ and azimuth direction angle δ are given by.

$$\theta = (LO - 1) \cdot (\theta_{RE} - \theta_{RS}) / (NP - 1) + \theta_{RS}$$
$$\delta = (LO - 1) \cdot (\theta_{PE} - \theta_{PS}) / (NP - 1) + \theta_{PS}$$

where

LO : pixel number on the original image

NP : total pixel number for one scan on the original image (3000 for XS mode) (6000 for panchromatic mode)

After application of scanning direction rotation matrix M, the original direction vector q_0 is rotated to q :

$$q = Mq_0 = \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} -1 \\ 0 \\ 0 \end{pmatrix}$$

And azimuth direction rotation matrix L is :

$$L \equiv \begin{pmatrix} \cos\delta & 0 & \sin\delta \\ 0 & 1 & 0 \\ -\sin\delta & 0 & \cos\delta \end{pmatrix}$$

Since attitude data is given only as time derivatives, on the CCT the attitiude at certain moment is obtained by the integration with the initial condition at the moment for the image center . Supposing that this hypothesis, yaw (η), pitch (α) and roll (ρ) angles are given, the corresponding rotation matrices Y, P, and R are expressed as follows :

$$Y \equiv \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\eta & -\sin\eta \\ 0 & \sin\eta & \cos\eta \end{pmatrix}$$

$$P \equiv \begin{pmatrix} \cos\alpha & 0 & \sin\alpha \\ 0 & 1 & 0 \\ -\sin\alpha & 0 & \cos\alpha \end{pmatrix}$$

$$R \equiv \begin{pmatrix} \cos\rho & -\sin\rho & 0 \\ \sin\rho & \cos\rho & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Similarly, the rotation matrices to relate the satellite-fixed coordinates to the Earth Center Rotation coordinates are given as follows :

$$\Lambda\beta = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\beta & -\sin\beta \\ 0 & \sin\beta & \cos\beta \end{pmatrix}$$

$$\Lambda\lambda = \begin{pmatrix} \cos\lambda & -\sin\lambda & 0 \\ \sin\lambda & \cos\lambda & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\Lambda\psi = \begin{pmatrix} \cos\psi & 0 & \sin\psi \\ 0 & 1 & 0 \\ -\sin\psi & 0 & \cos\psi \end{pmatrix}$$

where β, λ and ψ represent heading, latitude and longitude of geodetic coordinate. These values can be calculated from the satellite position and velocity vectors, using spline function.

(b)Conversion of corrected data (level 1B) to uncorrected data (level 1A)

Conversion of level 1B data to level 1A (original) data can be done by the following formula :

$$J = E(0) + E(1) \cdot I + E(2) \cdot I^2 + E(3) \cdot I^3$$
$$L = C(0) + C(1) \cdot I + C(2) \cdot I^2 + C(3) \cdot I^3$$
$$P = D(0) + D(1) \cdot J + D(2) \cdot J^2 + D(3) \cdot J^3$$

Where

L : line number on the original image
P : pixel number on the central line of the original image
I : line number on the level 1B image
J : pixel number on the resampling line
$\triangle$J : moving distance of the line number I

(c)Observation time

On the CCT, no data are available to determine the data acquisition time for certain pixel except tc (observation time for the image center). (In the case of level 1A, scanning time is available). For the level 1B data, scanning time (U. T) can be calculated from the factors specified in II, ⑦, ⑧ in the following manner : Using these factors, the Earth Center Rotation coordinates (X, Y, Z) can be calculated from the scanning time (U.T) and the pixel number in this scanning line, and on the contrary, the line and pixel numbers on the original image can be calculated from the Earth Center Rotation coordinates (X, Y, Z). Followings are explicit expressions :

$$\begin{aligned} X \text{ (or } Y \text{ or } Z) = {} & F(0) + F(1)\,T + F(2)\,P + F(3)\,T^2 \\ & + F(4)\,T\,P + F(5)\,P^2 + F(6)\,T^3 \\ & + F(7)\,T^2\,P + F(8)\,T\,P^2 + F(9)\,T^4 \quad \cdots\cdots(1) \end{aligned}$$

$$l \text{ (or.p)} = G(0) + G(1)\,X + G(2)\,Y + G(3)\,Z \quad \cdots\cdots(2)$$

where

X, Y, Z : the EarthCenter Rotation coordinates (unit : m)
l : line number on the original image
p : pixel number on the original image

Then, letting (l_A, P_A) the image coordinates of the pixel for which the scanning time must be obtained,

$$p = p_A$$

(X, Y, Z) can be calculated using the eq. (1) with the initial condition T = tc. Then, from the eq. (2) l can be calculated ; In such a way, the iteration continues until $\triangle = | l - l_A |$ becomes sufficiently small, and finally T is obtained. Thus, the data acquisition time of any pixel can be available.

(d)Results

The 106 test points on the stereo pair image are selected (Fig. 3), and the results calculated by the above mentioned procedure are converted to the latitude, longitude and height and compared to those obtained from the existing topographic map. Plannimetric errors of latitude and longitude are converted to UTM projection and NS and EW errors in meter are calculated. The means and standard deviations of the errors are shown in Tab. 1, with the results obtained from the adjacent Landsat 4 stereo pair (path/row 108-35, 109-35)

V. Contour map generation

Contour map is tentatively generated from the above results. The area located approximately 5km South-East of Matsumoto city, contains the neighbourhood of Mt. Takato and is nearly 6km for North-South and 7km for East-West. In order to get accurate contour map, not only the accuracy of position and height data are necessary but also uniform and dense data are requested. On the other hand, the search of tie points is usually done by spatial correlation method, in case of computer processing. In other word, tie point is found by maximizing the correlation by changing the relative position. However, because of the seasonal difference, it was difficult to find sufficiently many tie pionts. So, we should say that the generated contour is based on limited data. The contour map with such tie points is shown in Fig. 4. For comparison, the contour map is also generated from the topographic map (Fig. 5). In this case, height data are selected only for the points used for Fig.4, for the direct comparison. So, this contour map could be slightly different from the actual topographic map.

VI. Conclusion

By the height data extraction from SPOT stereo pair data without any use of GCP, the accuracy for this method is estimated .

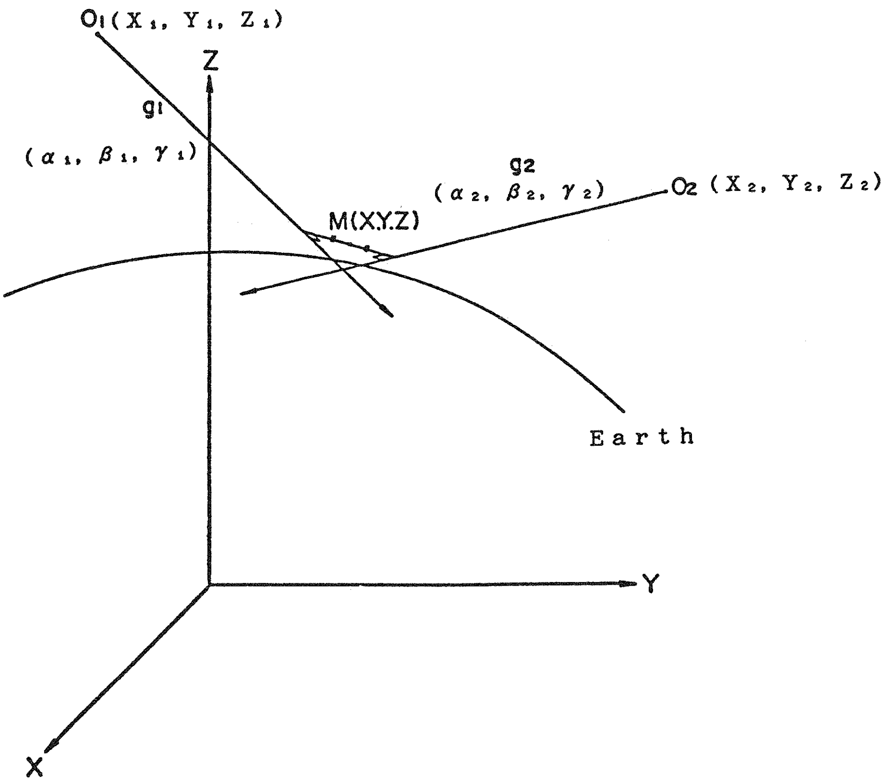

Fig. 1 Determination of the ground surface point as the middle point

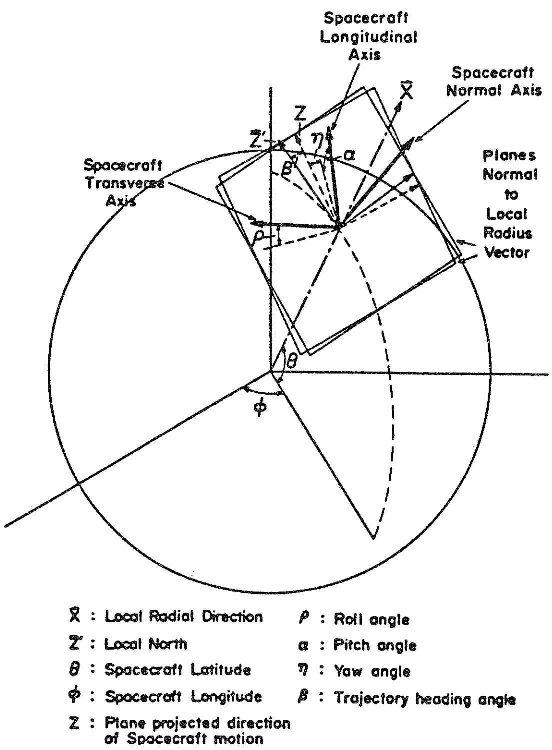

Fig. 2 Transformation geometry

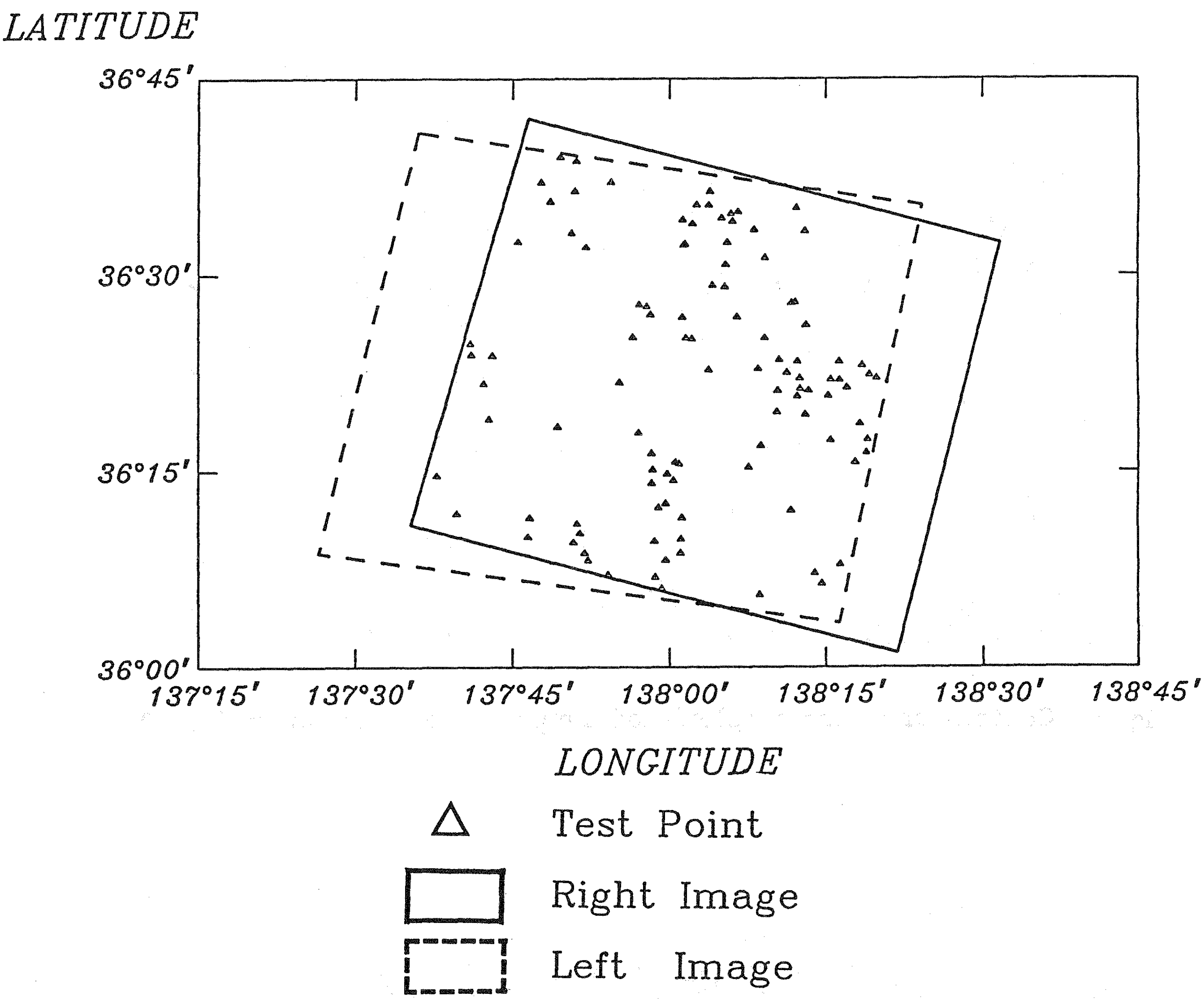

Fig. 3 Distribution of 106 test points

Table 1 Error of calculated positions and height(elevation)

SATELLITE : SPOT

	AVERAGE (meter)	S. D. (meter)
NORTHING	839.39	36.00
EASTING	-322.50	33.49
ELEVATION	440.29	25.89

SATELLITE : LANDSAT 4

	AVERAGE (meter)	S. D. (meter)
NORTHING	-2072.09	105.21
EASTING	208.88	74.56
ELEVATION	627.28	439.16

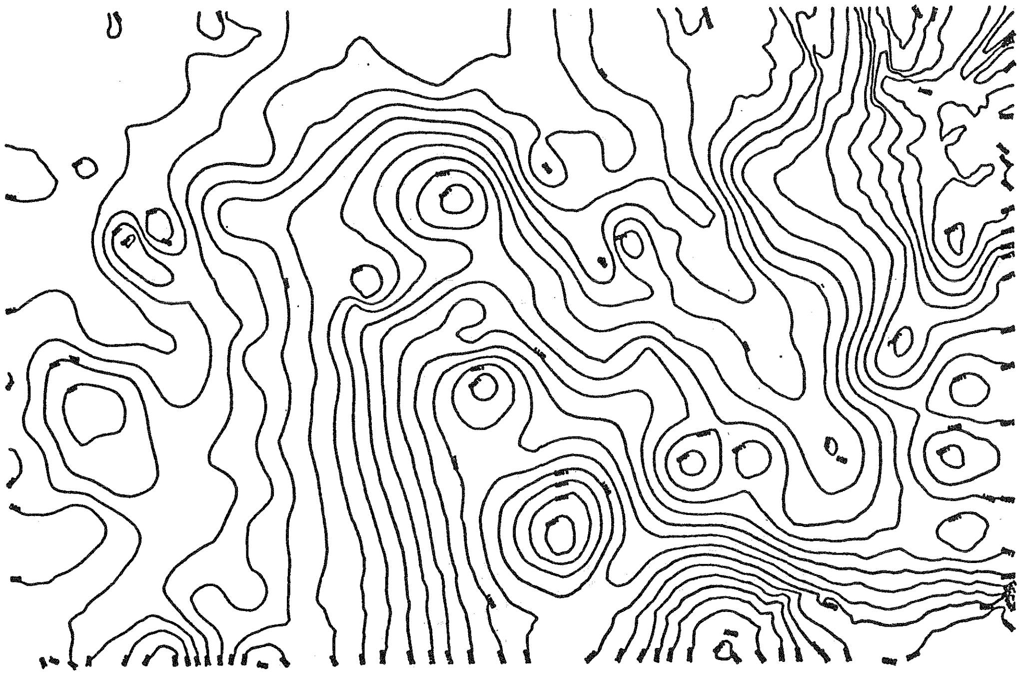

Fig. 4 Contour map from calculated height (contour interval : 50 m)

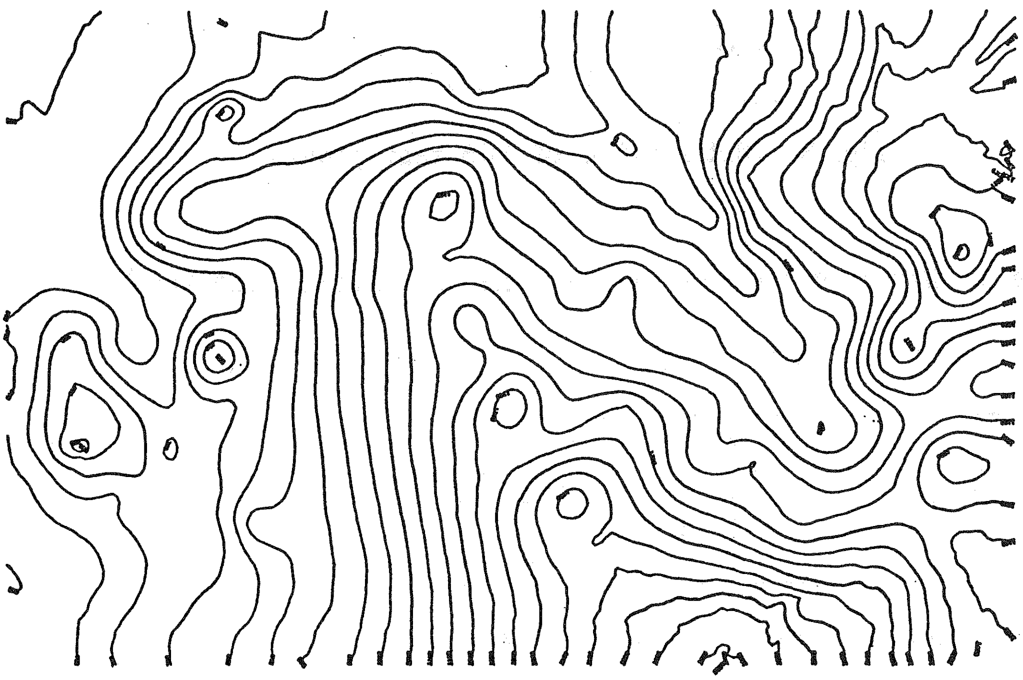

Fig. 5 Contour map from existing topogrphic map
(contour interval : 50 m)