

# SPOT IMAGERY ORIENTATION WITH AUXILIARY SATELLITE POSITION AND ATTITUDE DATA

Ryosuke Shibasaki  
Public Works Research Institute  
Ministry of Construction  
1, Asahi, Tsukuba City, Ibaraki, Japan

Shunji Murai  
Institute of Industrial Science  
University of Tokyo  
7-22, Roppongi, Minatoku, Tokyo, Japan

Tsutomu Okuda  
Softopia Company  
8082, Shinkai, Kisofukushimacho, Nagano, Japan

Commission III/1

## ABSTRACT

Accurate estimation of exterior orientation parameters of SPOT imagery have required large number of ground control points because the swath width of SPOT HRV is very small compared with the satellite altitude. Authors proposed a method of SPOT imagery orientation where observed data of satellite position and attitude rate, provided in SPOT CCT, are employed for new constraint conditions in addition to colinearity equations for ground control points. The experiment using 'Mt. Fuji' images of SPOT HRV shows improvement of orientation accuracy when small number of G.C.P.s are used.

## INTRODUCTION

Exterior orientation parameters of SPOT HRV are given as functions (polynomials etc.) of time or scan line number, because the position and the attitude of SPOT HRV change smoothly with time or scan line number. In case polynomials are employed, coefficients of the polynomials are exterior orientation parameters to be estimated.

Preliminary studies [1], [2] by authors on simulated linear array sensor imagery showed that accurate estimation of the orientation parameters require large number of ground control points without using auxiliary satellite position and attitude data. The first reason is that larger number of orientation parameters are to be estimated than those of conventional metric cameras. The second reason is that the swath width of SPOT HRV is very small compared with the altitude of SPOT satellite.

As shown in Figure 1, in case swath width/ altitude ratio is small, G.C.P. errors may cause gross errors in estimating orientation parameters, while in case swath width/ altitude ratio is large the influence of G.C.P. errors is relatively small. And this kind of orientation errors may not be able to be detected through checking residuals. In SPOT case, swath width/ altitude ratio is about 0.074, which is much smaller than those of conventional metric cameras ( 0.86 - 1.50 ).

Auxiliary use of satellite position and attitude rate data for additional constraint conditions is expected to have direct effect on decreasing gross errors in estimating the orientation parameters. In order to estimate the orientation parameters more accurately with less ground control points, authors proposed to use auxiliary satellite position and attitude rate data.

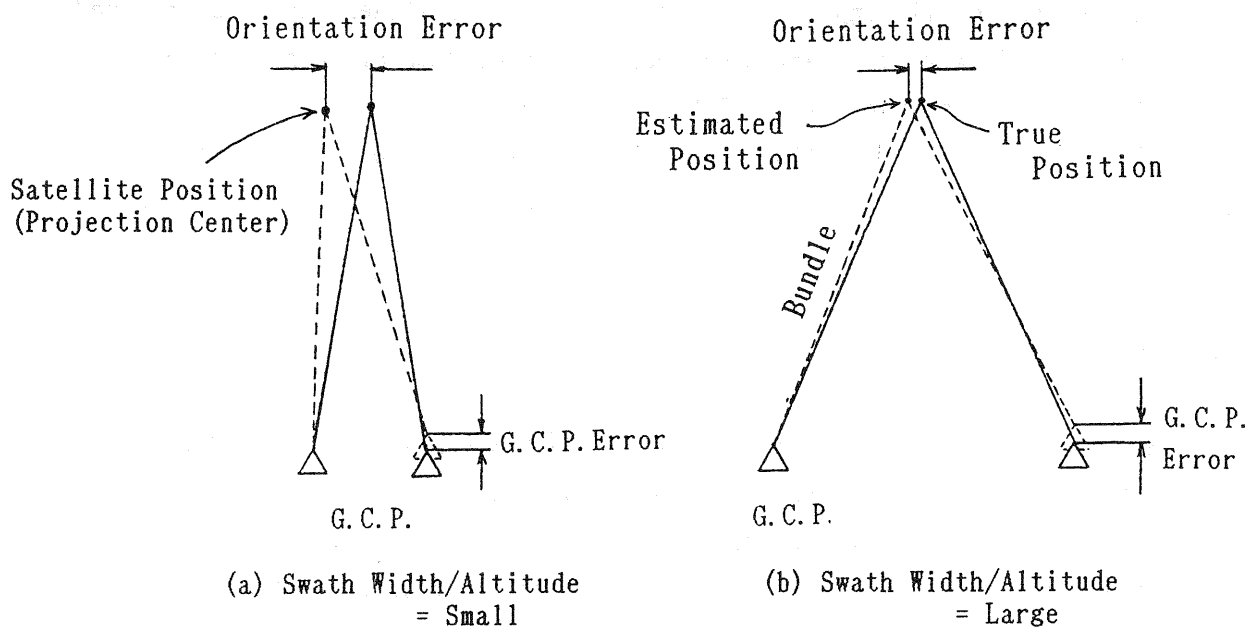


Fig. 1 Comparison of Stability in Estimating Orientation Parameters

## ORIENTATION WITH SATELLITE POSITION AND ATTITUDE RATE DATA

The position and attitude of SPOT satellite can be approximated well enough with polynomials of line number. Appropriate order of polynomials depends on length of an orbit, the stability of attitude change and so on. In the following case, the position and attitude are expressed with first order polynomials.

satellite orbit :

$$\left. \begin{aligned} X_s &= X_{s0} + X_1 * L \\ Y_s &= Y_{s0} + Y_1 * L \\ Z_s &= Z_{s0} + Y_1 * L \end{aligned} \right\} (1)$$

satellite attitude :

$$\left. \begin{aligned} \omega &= \omega_0 + \omega_1 * L \\ \phi &= \phi_0 + \phi_1 * L \\ \kappa &= \kappa_0 + \kappa_1 * L \end{aligned} \right\} (2)$$

where L : line number

(  $X_s$  ,  $Y_s$  ,  $Z_s$  ) : sensor position ( projection center )  
 (  $\omega$  ,  $\phi$  ,  $\kappa$  ) : sensor attitude ( roll, pitch and yaw )

The unknown twelve orientation parameters in (1) and (2) satisfy colinearity equations (3) for ground control points.

$$\left. \begin{aligned} \frac{a_{11}(x-x_s) + a_{21}(y-y_s) + a_{31}(z-z_s)}{a_{13}(x-x_s) + a_{23}(y-y_s) + a_{33}(z-z_s)} + \frac{x_g}{f} &= 0 \\ \frac{a_{12}(x-x_s) + a_{22}(y-y_s) + a_{32}(z-z_s)}{a_{13}(x-x_s) + a_{23}(y-y_s) + a_{33}(z-z_s)} + \frac{y_g}{f} &= 0 \end{aligned} \right\} (3)$$

$$a_{ij} = R_{\omega \cdot \kappa \cdot \phi}$$

( Rotation Matrix of roll, pitch and yaw )

f : focal length

( $x_g, y_g$ ): image coordinates of G.C.P.s

( $X, Y, Z$ ): ground coordinates of G.C.P.s

Observed satellite position and attitude rate data and the unknown orientation parameters satisfy the following additional equations (4), (5), which authors call 'satellite data equations'.

satellite orbit :

$$\left. \begin{aligned} X &= X_{00} + X_1 * L \\ Y &= Y_{00} + Y_1 * L \\ Z &= Z_{00} + Y_1 * L \end{aligned} \right\} (4)$$

satellite attitude :

$$\left. \begin{aligned} \dot{\omega} &= \omega_1 \\ \dot{\phi} &= \phi_1 \\ \dot{\kappa} &= \kappa_1 \end{aligned} \right\} (5)$$

where L : line number

( X , Y , Z ) : observed satellite position

(  $\dot{\omega}$  ,  $\dot{\phi}$  ,  $\dot{\kappa}$  ) : observed attitude rate ( roll, pitch and yaw )

The unknown parameters are obtained through solving these colinearity equations and satellite data equations simultaneously with weighted nonlinear least square method. Weight values for the colinearity equations and for the satellite data equations are proportional to expected variance of residuals of colinearity equations and to expected variance of satellite data error respectively.

#### TEST PROCEDURE

Test of exterior orientation was carried out for three SPOT HRV images of a mountainous area around Mt. Fuji. Figure 2 and Figure 3 show the topomap of test area and distribution of G.C.P.s and check points respectively. The number of G.C.P.s is different among test cases, while same eighteen check points and forty nine pass points are used in all cases. Their ground coordinates were measured on 1:25,000 scale topomap with 10m interval contour lines, while the image coordinates were measured on photo copies of SPOT images. Figure 4 shows the dates and the sensor angles of SPOT HRV images.

The accuracy of orientation are evaluated in terms of residuals at G.C.P.s and pointing error at the check points.

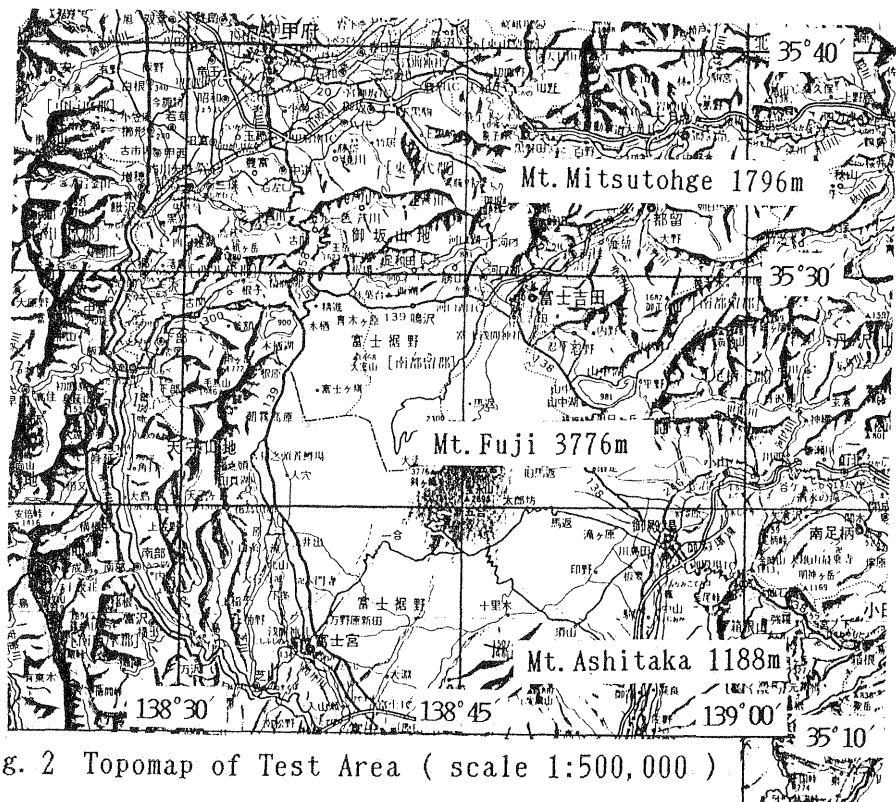


Fig. 2 Topomap of Test Area ( scale 1:500,000 )

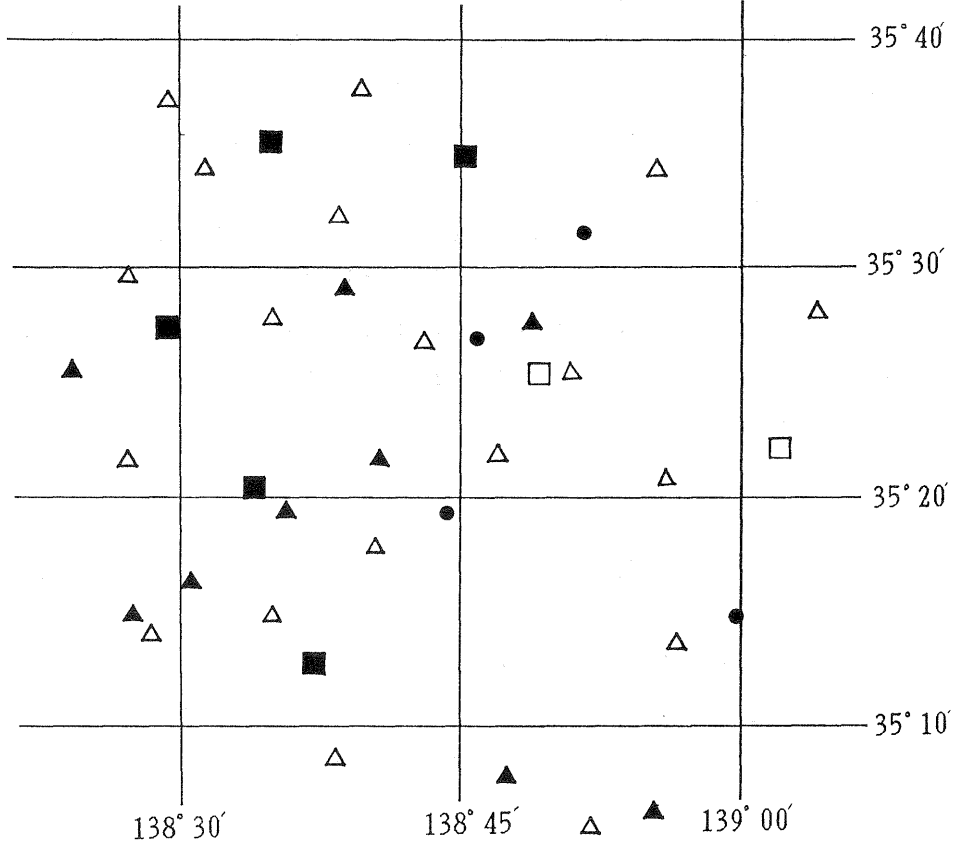


Fig. 3 Distribution of G.C.P.s and Check Points

- ▲ : Check Points with X, Y, Z coordinates
- : Check Points with X, Y coordinates
- : Check Points with Z coordinate
- △ : G.C.P. with X, Y, Z coordinates
- : G.C.P. with X, Y coordinates
- : G.C.P. with Z coordinate

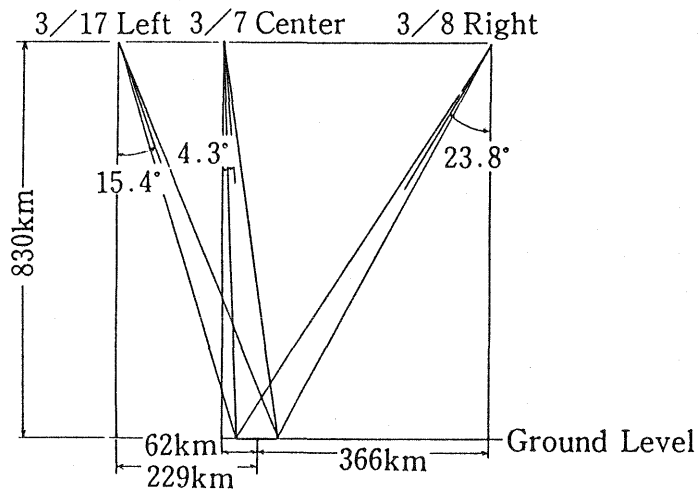


Fig. 4 Dates and Angles of the three SPOT Images

Nine SPOT satellite position data are provided in SPOT CCT. Observation interval between these position data, which is about 450km along orbit, is much larger than SPOT image size on the ground. For the test of orientation, authors obtained ten position data (X,Y,Z) within the test area through linear interpolation of height, longitude and latitude data of two original position data ( the fourth and fifth data in CCT ) which are nearest to the test area. As for attitude rate data, ten data (roll,pitch and yaw) within the test area were chosen for the test out of seventy two data provided in CCT.

In deciding weight values for the colinearity equations and the satellite data equations, authors assumed variance of residuals for the colinearity equations to be 0.3 pixel and variance of satellite data errors to be 8000m for position data and 0.01 rad/line for attitude rate data through some trials.

## RESULTS

Table 1 and table 2 show residuals at G.C.P.s and pointing error at check points. The residuals of the cases with satellite data are slightly smaller than those of the cases without satellite data are small. As for pointing accuracy, the cases with satellite data give better altimetric accuracy, while in terms of planimetric accuracy, there are little differences.

Improvement of altimetric accuracy obtained by use of satellite data is 1.7m - 7.9m in R.M.S.E.. The improvement effect tends to increase in the cases where smaller number of G.C.P.s are used. This fact implies that use of satellite data would be recommended especially when large number of G.C.P.s are

not available.

Tab. 1 Residuals at Ground Control Points

Number of G. C. P. s	Without Satellite Data			With Satellite Data		
	Residuals (m)			Residuals (m)		
	X	Y	Z	X	Y	Z
8	4.78	7.18	20.33	5.67	6.85	6.78
10	6.81	7.58	6.52	3.56	6.31	4.14
16	6.26	7.41	13.79	5.80	7.44	11.48
21	7.64	7.86	11.46	7.29	7.95	10.85

Tab. 2 Pointing Error at Check Points

Number of G. C. P. s	Without Satellite Data			With Satellite Data			Improvement Effect (Without-With) Z (m)
	R. M. S. E. (m)			R. M. S. E. (m)			
	X	Y	Z	X	Y	Z	
8	11.24	12.56	21.39	9.42	11.67	13.47	7.92
10	11.34	11.88	21.36	11.15	11.16	15.41	5.95
16	9.49	9.55	14.45	10.56	9.94	12.73	1.72
21	10.18	8.35	18.26	10.18	8.47	14.54	3.72

Number of Check Points is 18.

## CONCLUSIONS

- (1) Accuracy of SPOT image orientation is improved by auxiliary use of satellite position and attitude rate data which are provided in SPOT CCT.
- (2) Improvement effect by use of satellite data tends to increase in cases where smaller number of G. C. P. s are used.
- (3) The results of the experiment imply that auxiliary use of satellite data

would be recommended when large number of G.C.P.s are not available.

#### REFERENCES

- [1] Murai, S., Shibasaki, R. ; Geometric Correction of Linear Array Sensor, Proceedings of International Symposium on Advances in the Quality of Image Data, Com. III, Camberra, Australia, 1982
- [2] Murai, S., Shibasaki, R. ; A Study on Simulation of Three Dimensional Measurement with Use of Stereo Linear Array Sensor, I. S. P. R. S. Congress, Com. III, Rio de Janeiro, 1984, pp.759-767
- [3] Shibasaki, R., Murai, S. ; Accuracy of Terrain Measurement Using SPOT HRV Data, Asian Conference on Remote Sensing, Indonesia, 1987