

# Comparisons of Orientation Accuracy between types of Control Data for SPOT Imagery

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## Abstract

In this paper, we proposed a concept of suitable control data for the orientation problem of satellite imagery. Some results obtained through case study on orientation accuracy comparing between types of control data will be presented. The control data which were used in this paper are as follows :

- (1) Control points
- (2) Control points + Geodetic observations
- (3) Feature lines such as roads, rivers or shore lines etc.
- (4) Feature lines + Geodetic observations

## 1. Introduction

Nowadays, much world wide attention has been paid to the mapping from satellite imagery(SPOT imagery, LFC photo etc.). However, using spot images, as shown in Fig1,2,it is difficult to recognize any individual object on the earth surface from the image because of the small scale image. Moreover, in order to use the individual points on the image as control point, the coordinates of these points must be available in a geodetic coordinate system, that is very troublesome and expensive.

One of the solutions of this problem is to apply the simultaneous adjustment method in which geodetic observations (slant distances, elevation differences and horizontal angles etc.), observed in local coordinate system, as well as the coordinates of the individual control points are used as control data. Few years ago, this method was used in aerial triangulation, and good results had been obtained.(1,2,3) This method will become even more effective by using the Global Positioning System(GPS).

On the other hand, there are methods using feature lines instead of control points .(4,5,6) Using control points, the orientation of the images bared on point-to-point correspondence whereas in case of feature lines as control data it bared on point-to-line correspondence. Namely, as shown in Fig. 3, the orientation is carried out under the condition that the points which were observed on the image existed on the digitized feature lines. The advantages of this method are as follows :

(1) As shown Fig.1,2, satellite imagery usually contain a number of feature lines such as roads, freeways, coast lines etc. and can be clearly and accurately recognized.

(2) Individual control points supply few control data such as intersections or bending points of roads. But, in case of using feature lines a point can be utilized as control data if it exists on a feature line. Therefore, there are less restrictions in the selection of control data, and many of control data can be utilized.

Thus, a method of using feature lines as control data is very effective on the orientation of satellite imagery.

## 2. Mathematical Model

### 2.1 Observation equations by collinearity condition

The geometry of a linear array sensor mounted in SPOT satellite is considered as central projection of one scan type such as slit camera in photogrammetry. Therefore, the exterior orientation parameters of satellite are the same concept as conventional photogrammetry. However, as a linear array sensor is scanned in a very small time scale (1.5msec/line), the exterior orientation parameters are given as a function of scan line as shown below. The geometry of a linear array sensor is shown in Fig. 4.

$$\begin{array}{ll}
 \text{(position parameter)} & \text{(altitude parameter)} \\
 \bar{X} = X_0 + X_1 \cdot L & \kappa = \kappa_0 + \kappa_1 \cdot L + \kappa_2 \cdot L^2 + \kappa_3 \cdot L^3 \\
 \bar{Y} = Y_0 + Y_1 \cdot L & \phi = \phi_0 + \phi_1 \cdot L + \phi_2 \cdot L^2 + \phi_3 \cdot L^3 \\
 \bar{Z} = Z_0 + Z_1 \cdot L & \omega = \omega_0 + \omega_1 \cdot L + \omega_2 \cdot L^2 + \omega_3 \cdot L^3
 \end{array} \quad (1)$$

By using collinearity condition, the following equations are obtained.

$$\begin{aligned}
 F_x &= -x - f \frac{a_{11} \cdot (X-\bar{X}) + a_{12} \cdot (Y-\bar{Y}) + a_{13} \cdot (Z-\bar{Z})}{a_{31} \cdot (X-\bar{X}) + a_{32} \cdot (Y-\bar{Y}) + a_{33} \cdot (Z-\bar{Z})} = 0 \\
 F_y &= -y - f \frac{a_{21} \cdot (X-\bar{X}) + a_{22} \cdot (Y-\bar{Y}) + a_{23} \cdot (Z-\bar{Z})}{a_{31} \cdot (X-\bar{X}) + a_{32} \cdot (Y-\bar{Y}) + a_{33} \cdot (Z-\bar{Z})} = 0
 \end{aligned} \quad (2)$$

The linearization of equation (2) by Taylor expansion around the approximated values of unknowns yields the following equation.

$$\begin{matrix}
 \ddot{V} & + & \dot{B} & \cdot & \dot{\Delta} & + & \ddot{B} & \cdot & \ddot{\Delta} & = & \epsilon \\
 (2p,1) & & (2p,18n) & & (18n,1) & & (2p,3m) & & (3m,1) & & (2p,1)
 \end{matrix} \quad (3)$$

where,  
 $\ddot{V}$  - is the residual vector of photo coordinates  
 $\dot{\Delta}$  - is the vector of the unknown corrections of approximate values of the exterior orientation parameters of satellite imagery.  
 $\ddot{\Delta}$  - is the vector of unknown corrections of approximate values of the ground coordinates.  
 $\dot{B}$  - is a matrix whose coefficients are partial derivates of the collinearity equation with respect to the exterior orientation parameters.  
 $\ddot{B}$  - is a matrix composed of partial derivates of the collinearity equation with respect to the ground coordinates.  
 $\epsilon$  - is the vector of the differences between the observed image coordinates and the computed ones.  
 $p$  - is the total number of image points.  
 $n$  - is the total number of satellite images.  
 $m$  - is the total number of object points.

According to equation (3), the following observation equations can be set up if the unknowns are observed.

$$\begin{array}{l}
 \text{exterior orientation parameters : } \ddot{V} - \dot{\Delta} = \epsilon \\
 \text{ground coordinates : } \ddot{V} - \ddot{\Delta} = \ddot{\epsilon}
 \end{array} \quad (4)$$

where,  $\hat{v}$  - is the residual vector of the exterior orientation parameters.

$\hat{\epsilon}$  - is the vector of the differences between the refined exterior orientation parameters and observed ones.

$\hat{v}$  - is the residual vector of ground coordinates.

$\hat{\epsilon}$  - is the vector of the differences between refined ground coordinates and observed ones.

## 2.2 Observation equations of geodetic data

### (1) in case of slant distance

An exact slant distance  $S_{ij}$  from point i to point j can be expressed directly in terms of a rectangular coordinate system as follows :

$$S_{ij} = [ (x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2 ]^{1/2} \quad (5)$$

The true quantity  $S_{ij}$  can be expressed in terms of the observed quantity  $S_{ij}^0$  and an approximation  $S_{ij}^0$  which correspond to corrections  $(v_s)_{ij}$  and  $S_{ij}$ , respectively. Thus,

$$(v_s)_{ij} + \delta S_{ij} = S_{ij}^0 - S_{ij}^{00} \quad (6)$$

where :

$$\begin{aligned} \delta S_{ij} &= \partial S_{ij} / \partial X_i \cdot \Delta X_i + \partial S_{ij} / \partial Y_i \cdot \Delta Y_i + \partial S_{ij} / \partial Z_i \cdot \Delta Z_i \\ &\quad + \partial S_{ij} / \partial X_j \cdot \Delta X_j + \partial S_{ij} / \partial Y_j \cdot \Delta Y_j + \partial S_{ij} / \partial Z_j \cdot \Delta Z_j \end{aligned}$$

Let d be the number of observed slant distances, then the complete set of observation equations of slant distance is expressed in matrix notation as follows :

$$\begin{matrix} v_s \\ (d,1) \end{matrix} + \begin{matrix} G_s \\ (d,3g) \end{matrix} \cdot \begin{matrix} \Delta_g \\ (3g,1) \end{matrix} = \begin{matrix} \epsilon_g \\ (d,1) \end{matrix} \quad (7)$$

### (2) in case of elevation difference

Let's consider the elevation difference  $\Delta h_{ij}$  from point i to point j. the elevation difference  $\Delta h_{ij}$  can be expressed as the following equation ;

$$\Delta h_{ij} = h_j - h_i = F_{h_j}(x_j, y_j, z_j) - F_{h_i}(x_i, y_i, z_i) \quad (8)$$

The following observation equation was derived from observed elevation difference between point j and point i :

$$(v_{\Delta h})_{ij} + \delta h_j - \delta h_i = (h_j^0 - h_i^0) - \Delta h_{ij}^{00} \quad (9)$$

where  $\Delta h_{ij}^{00}$  is observed elevation difference,  $(v_{\Delta h})_{ij}$  is the residual of the observation,  $h_i^0$  and  $h_j^0$  are the approximate elevation of point i and j,  $\delta h_i$  and  $\delta h_j$  are the corrections which correspond to the approximate values.

Decomposing  $\delta h_i$  and  $\delta h_j$  into X-, Y-, Z-components in the rectangular coordinates system, then equation (9) will be as follows :

$$(V_{\Delta h})_{ij} + \partial F_{h_i}/\partial X_i \cdot \Delta X_i + \partial F_{h_i}/\partial Y_i \cdot \Delta Y_i + \partial F_{h_i}/\partial Z_i \cdot \Delta Z_i - \partial F_{h_j}/\partial X_j \cdot \Delta X_j - \partial F_{h_j}/\partial Y_j \cdot \Delta Y_j - \partial F_{h_j}/\partial Z_j \cdot \Delta Z_j = (h_j^0 - h_i^0) - \Delta h_{ij}^{00}$$
 (10)

Let  $t$  be the number of observed elevation differences, then the complete set of  $t$  observation equation is expressed in matrix notation as follows :

$$\begin{matrix} V_{\Delta h} & + & G_{\Delta h} \cdot \ddot{\Delta}_g & = & \epsilon_{\Delta h} \\ (t,1) & & (t,3g) & & (t,1) \end{matrix} \quad (11)$$

the subscript  $g$  in equation (7) (11) means the geodetic observation points.

Collecting all the observation equations for the geodetic data will be as follows :

$$\begin{array}{lll} \text{slant distance} & \cdots & \begin{bmatrix} V_s \\ V_{\Delta h} \end{bmatrix} + \begin{bmatrix} G_s \\ G_{\Delta h} \end{bmatrix} \ddot{\Delta}_g = \begin{bmatrix} \epsilon_s \\ \epsilon_{\Delta h} \end{bmatrix} \\ \text{elevation difference} & \cdots & \end{array} \quad (12)$$

Thus, the equation (12) may be represented in matrix as follows :

$$\begin{matrix} V_g & + & G_g \cdot \ddot{\Delta}_g & = & \epsilon_g \\ (d+t,1) & & (d+t,3g) & & (d+t,1) \end{matrix} \quad (13)$$

To include all the non-geodetic points in a scene, this equation can further be generalized as follows :

$$V_g + [G_g \ 0] \begin{bmatrix} \ddot{\Delta}_g \\ \ddot{\Delta}_1 \end{bmatrix} = \epsilon_g \quad (14)$$

i.e.,

$$V_g + \dot{G} \cdot \ddot{\Delta} = \epsilon_g \quad (15)$$

where,  $\ddot{\Delta}$  is a vector of all the points involved in the adjustment, and  $\ddot{\Delta}_1$  is a vector of all the non-geodetic points.

### 2.3 Observation equations by the collinearity condition of using the feature line as control data

As shown in Fig. 5, the digitized feature line  $F$  is obviously defined in the three dimensional space. Then, suppose that it is possible to describe a feature line mathematically by a parametric function, viz ;

$$\begin{bmatrix} F_x \\ F_y \\ F_z \end{bmatrix} = \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} F_X(s) \\ F_Y(s) \\ F_Z(s) \end{bmatrix} = \begin{bmatrix} A_0 + A_1 \cdot s + A_2 \cdot s^2 + A_3 \cdot s^3 \\ B_0 + B_1 \cdot s + B_2 \cdot s^2 + B_3 \cdot s^3 \\ C_0 + C_1 \cdot s + C_2 \cdot s^2 + C_3 \cdot s^3 \end{bmatrix} \quad (16)$$

where,  $s$  is a curve length on the feature line, and  $A_i$ ,  $B_i$ ,  $C_i$  ( $i=0,1,2,3$ ) are the coefficients of the cubic spline function. These coefficients generally vary from one section to another

where each section is described by two point of a feature line.

Defining the feature line F by equation (16) that will reduce the number of unknown of ground coordinates from three ( $\Delta X, \Delta Y, \Delta Z$ ) to one ( $\Delta s$ ). Therefore, the observation equation expressed as equation (3) may be described as the following equation.

$$\begin{array}{l} V_f + \dot{B}_f \cdot \dot{\Delta} \\ (2p', 1) \quad (2p', 18n) \end{array} \quad \ddot{B}_f \cdot \ddot{\Delta}_f = \epsilon_f \quad (17)$$

$$(18n, 1) \quad (2p', f) \quad (f, 1) \quad (2p', 1)$$

where  $\ddot{B}_f$  - is a matrix whose coefficients are partial derivative of the collinearity equation with respect to the curve length

$\ddot{\Delta}_f$  - is the vector of the unknown correction to approximate value of the curve length.

the subscript f means a point on the feature line.

#### 2.4 The Complete Mathematical Model

The complete mathematical model is obtained by combining equation (3), (4), (15), (17). Using matrix notation, the model may be written as follows :

$$\begin{bmatrix} V \\ \dot{V} \\ \ddot{V} \\ V_g \\ V_f \end{bmatrix} + \begin{bmatrix} \dot{B} & \ddot{B} & 0 \\ -I & 0 & 0 \\ 0 & -I & 0 \\ 0 & G_g & 0 \\ \dot{B}_f & 0 & \ddot{B}_f \end{bmatrix} \begin{bmatrix} \dot{\Delta} \\ \ddot{\Delta} \\ \ddot{\Delta}_f \end{bmatrix} = \begin{bmatrix} \epsilon \\ \dot{\epsilon} \\ \ddot{\epsilon} \\ \epsilon_g \\ \epsilon_f \end{bmatrix} \quad (18)$$

i.e.,

$$\bar{V} + \bar{B} \cdot \Delta = \bar{\epsilon} \quad (19)$$

The normal equation is

$$(\bar{B}^T W \bar{B}) \Delta = \bar{B}^T W \bar{\epsilon} \quad (20)$$

where W is the weight matrix associated with the observed quantities.

$$\therefore \Delta = (\bar{B}^T W \bar{B})^{-1} (\bar{B}^T W \bar{\epsilon}) \quad (21)$$

#### 3. Study area and Materials

This study is based on the Fuji test field (60km x 60km) as shown in Fig. 6. The materials are three SPOT stereo images with column-row no. 329-279 which were acquired on March 7, 8, and 17, 1986 in panchromatic mode with 10 meters resolution.

In the study of orientation precision, different types of control data pattern were used.(shown in Fig. 7) And also geodetic observations (slant distances and elevation differences) were applied.(shown in Fig. 8) In computation of adjustment, weight matrix(W) was estimated under the assumption that a measurement was done with typical geodetic instruments.

Table 1. weight matrix value

type of control data	accuracy
- image coordinates (one pixel)	0.013( $\mu\text{m}$ )
- slant distance	0.10 (m)
- elevation difference	0.50 (m)
- ground coordinate in X-Y plane	10.0 (m)
in Z	5.0 (m)

Both control points and feature lines were taken by digitizing from the existing topographic map of the scale 1 : 25,000. the study has been done under the following condition;

- (a) Earth curvature is neglected.
- (b) Additional observations on positions and altitudes of the satellite are not used.
- (c) Only the constant terms ( $\kappa_0$ ,  $\phi_0$ ,  $\omega_0$ ) are regarded as unknown for altitude parameters ( $\kappa$ ,  $\phi$ ,  $\omega$ ), because the altitude of the satellite is thought to be stable.
- (d) The inner orientation is neglected.

#### 4. Results

The purpose of this study is to propose the suitable orientation method for satellite imagery by comparing the orientation accuracy on types of control data. Some results are shown in Table 2.

Table 2. RMSE in check points in some precision test

Case no.	Control data for orientation			RMSE in C.P.(m)			$\sigma_0$ ( $\mu\text{m}$ )
	C.P.P.	F.L.P.	G.O.P.	X	Y	Z	
1	1	-----	-----	14.3	9.8	13.9	10.3
2	2	-----	-----	13.2	12.0	14.4	9.7
3	3	-----	-----	12.3	17.5	16.5	6.6
4	4	-----	-----	19.1	17.1	14.5	5.7
5	-----	1	-----	14.0	11.2	13.3	10.4
6	-----	2	-----	16.6	13.4	14.4	9.4
7	-----	3	-----	14.7	25.1	16.1	7.1
8	-----	4	-----	orientation impossible			
9	4	-----	1	10.5	16.9	14.2	9.2
10	4	-----	2	18.8	18.0	12.7	5.8
11	4	-----	1+2	10.7	17.1	12.8	9.0
12	-----	3	1	11.1	17.9	13.9	9.2
13	-----	3	2	14.7	26.5	12.8	7.4
14	-----	3	1+2	11.1	17.9	13.6	8.9
15	-----	4	1+2	10.8	20.0	12.5	9.0

C.P.P. : Control points pattern

F.L.P. : Feature lines pattern

G.O.P. : Geodetic observation pattern

C.P. : Check points

From these results, the following points should be obtained.

1) the fewer the control data (both control points and feature lines) were used, the more the planimetric precision decreased. But the height precision hardly decreased. In view of the precision, the orientation would necessitate at least 12 control data if the control data was not accurate enough.

2) Comparing using control points with using feature lines, they showed an equivalent precision in height. However, feature lines decreased the precision about 10 percent in planimetry.

3) Introducing a slant distance data, the X-directional precision increased 1.5-2.0 times than before in both control points and feature lines. But the Y-directional precision is not good.

4) With respect to an elevation difference data, it is hard to observe the effectiveness by itself.

5) In case of introducing both slant distance data and elevation difference data, the precision improve up to nearly one rank of control pattern, in both control points and feature lines.

## 5 Conclusion

It has been proved that the orientation using feature lines was effective on satellite imagery, on which it's easier to identify lines than points. And the orientation method by including geodetic observations such as slant distances, elevation difference is very effective in case that there are a few control data. Therefore in future, by use of GPS this method will be effective.

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Fig. 1 Town area in SPOT image

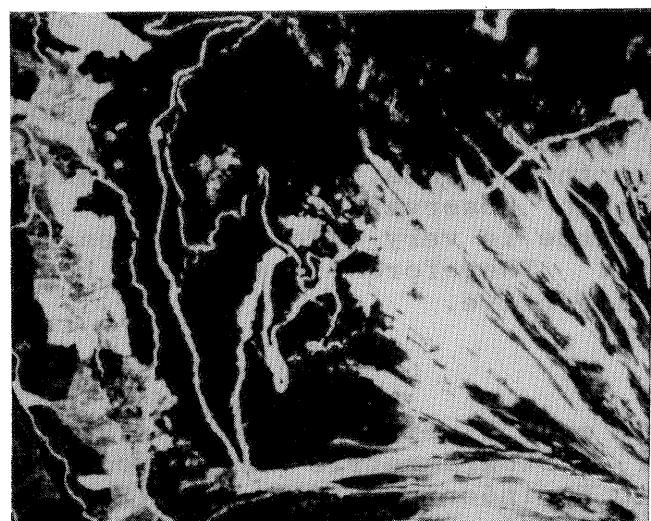


Fig. 2 mountain area in SPOT image

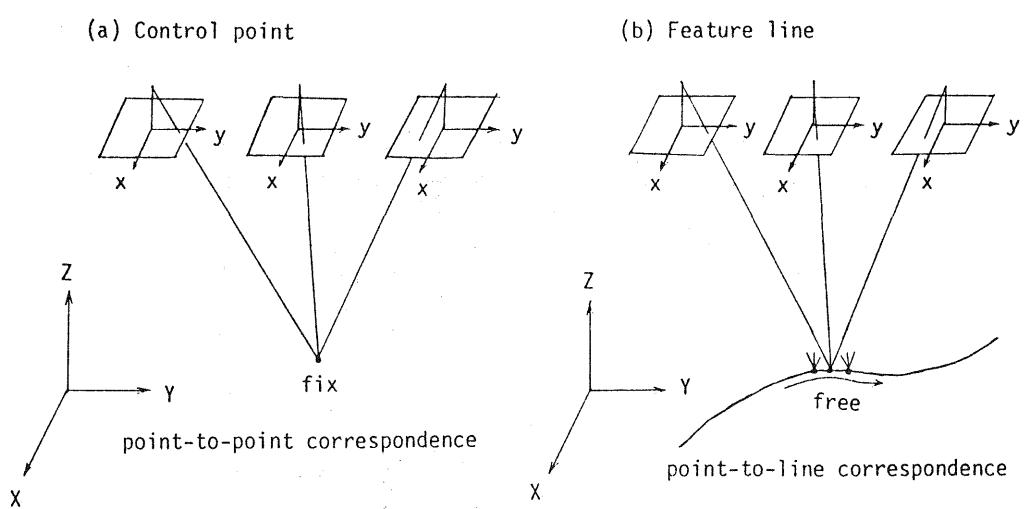


Fig. 3 a concept of orientation

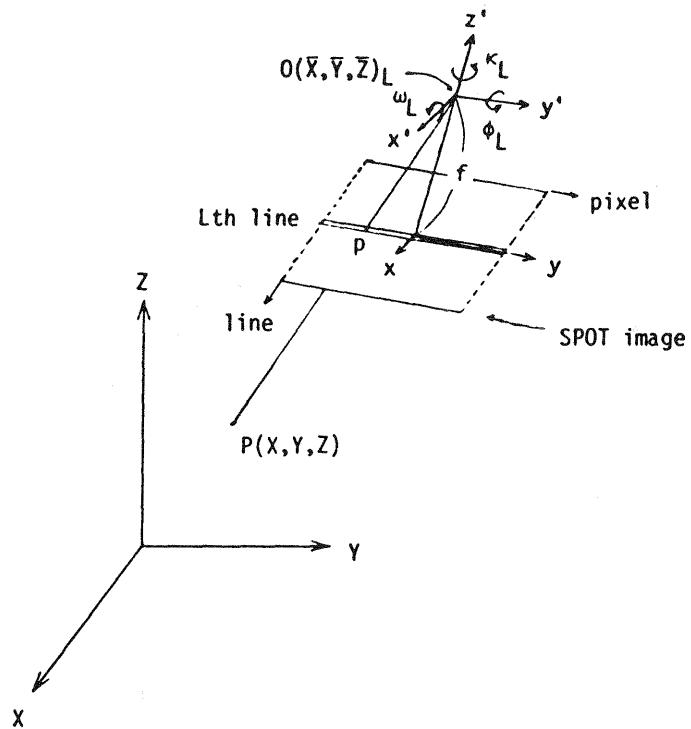


Fig. 4 The geometry of a linear array sensor

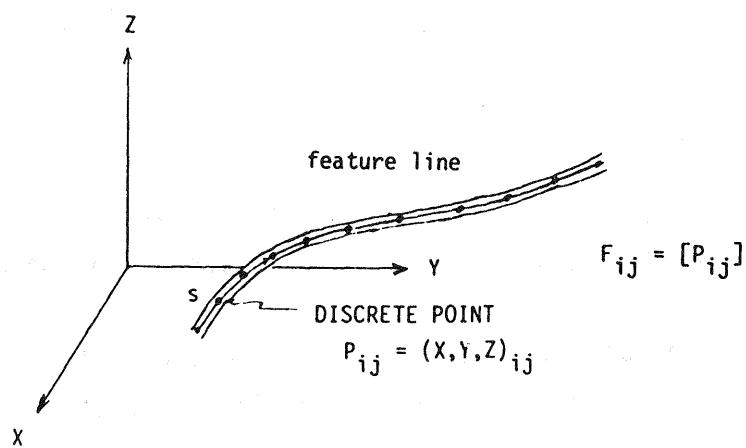


Fig. 5 Mathematical definition of a feature line

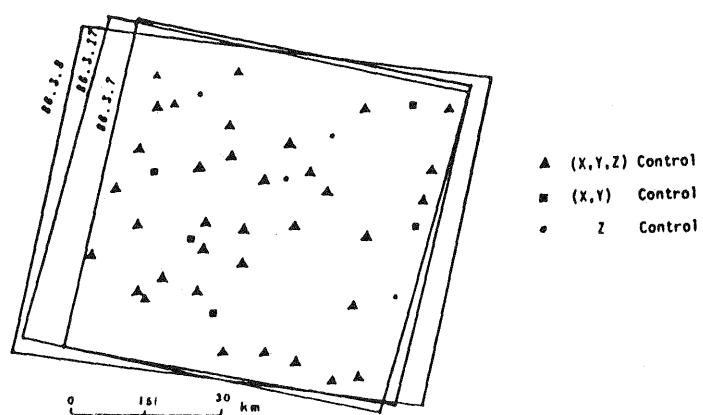


Fig. 6 The control net of Mt Fuji area and the SPOT images

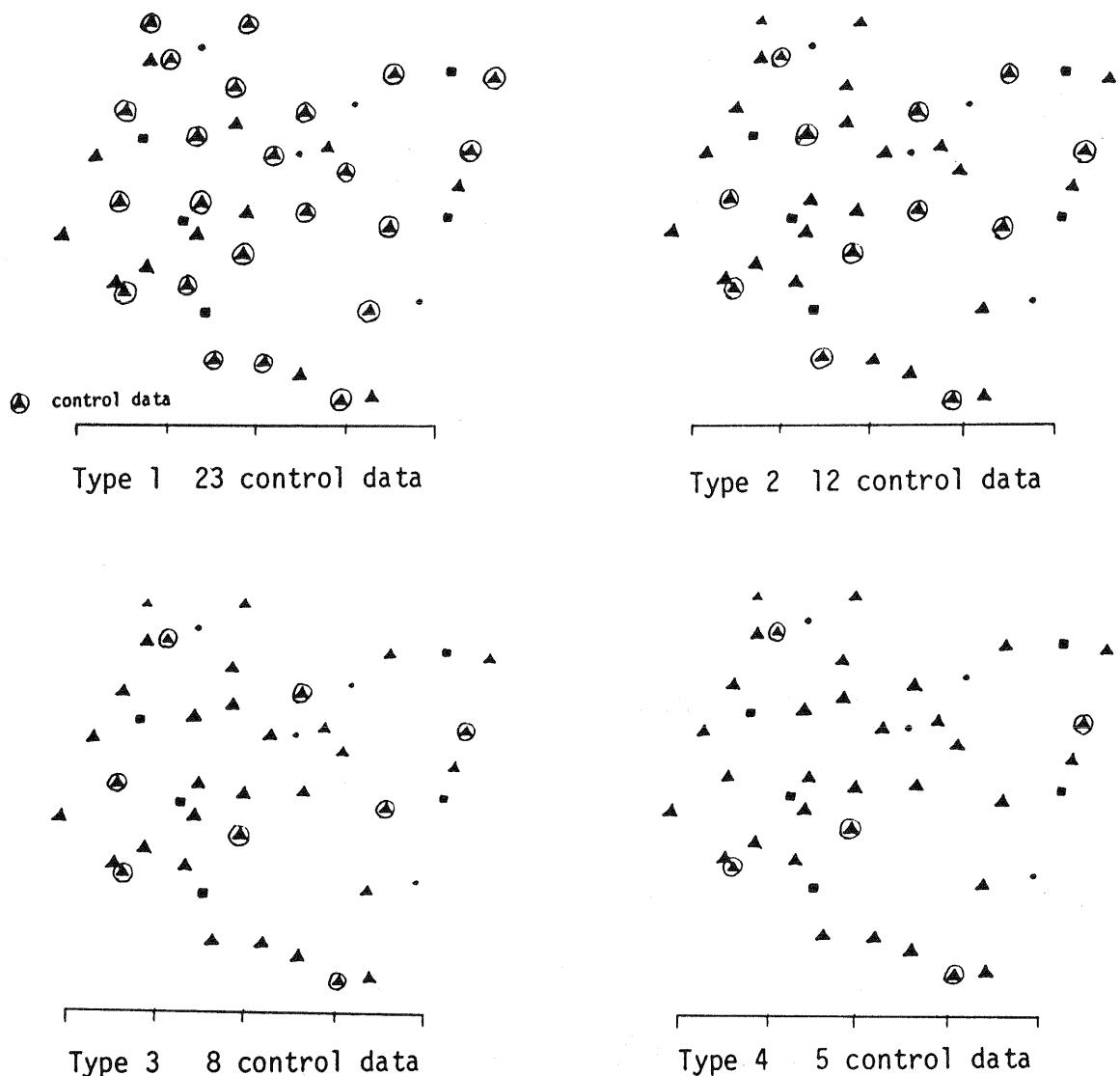


Fig. 7 The control points patterns and the feature lines patterns where were used in test area

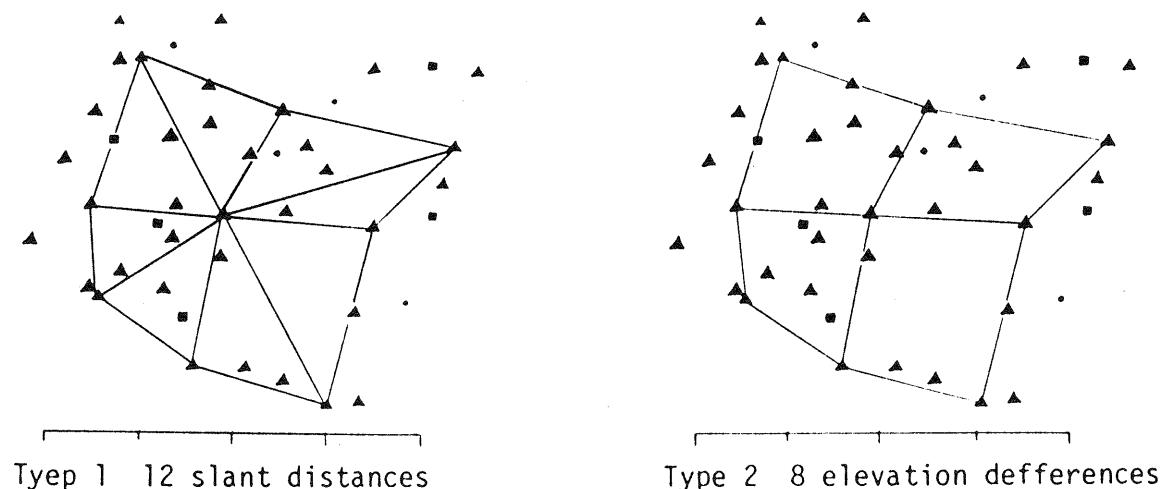


Fig. 8 The geodetic observation used in the test area