Terrain height estimation using a HRV stereo pair

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Abstract:

One of the advantage of the SPOT system is a terrain height estimation using the off-nadir viewing stereo pair of HRV data. A method for estimation of terrain height is proposed. In this method, the stereo pair images are superimposed on a base plane using GCPs. In this process, view points on the reference map are previously estimated through the computation of satellite position and attitude taking into account the earth's model and the map projection. Three different methods have been attempted for the GCP matching. The first one is searching of GCPs on CRT with human perception. The second one is the automatic searching with computer process while the last one is visual searching with a stereo plotter(mapper).

Some experiments have been conducted to assess accuracy on the terrain height estimation. The results show that the best accuracy has been realized for the manual searching with mapper followed by the automatic searching and visual searching on CRT. Mean and RMS errors have been computed to asses the accuracy of terrain height estimation . These were within a range between 24.2-26.6m, while that of the case using Landsat TM data was around 98.0m. The factors influencing the accuracy such as errors on the satellite position and attitude estimations have been evaluated.

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1.Introduction:

SPOT has a capability of off-nadir viewing with High Resolution Visible Imaging System (Ref.1). This implies that it can observe the same area from the different directions. Some studies have been conducted to extract 3D information (terrain height) from stereo pair images. Regarding evaluation of terrain height estimation using stereo pair of SPOT HRV data, several papers have been published(Ref. 2, 3, 4).

First, the proposed methods will be explained in detail, followed by assessment of estimated accuracy in terms of mean and RMS error. Finally, an error analysis concerning estimation accuracy of satellite altitude and attitude, and miss identification of the corresponding points on the stereo pair, on the terrain height estimation will be described.

2. Intensive study area and data used.

Test sight is shown in Fig. 1 and 2. The date used are also indicated below.

	SPOT GRS	DATE	VIEW ANGLE
IMAGE 1	327-278	86'12/8	13.6W
IMAGE 2	327-278	86'12/12	20.2E

This study area of Kiso mountain ranges is in Nagano prefecture Japan. Although majority of the area is covered by high mountain ranges, agriculture land and a small city of Iida. Further villages are also included.

3. A Method for estimation and evaluation of terrain height.

Terrain height estimation and its evaluation has been performed in the following procedures.

(1)Geometric correction

Geometric distortion in each image of the SPOT HRV stereo pair were precisely corrected based on auxiliary data derived from SPOT CCT and SPOT data base.

(2)Create stereograph image

One of the stereo pair images is superimposed to the other by the first order Affine transformation with 3 GCPs on the approximately same base plane. We can get 3D information from this image.

(3)Search of corresponding points

The corresponding points in the stereo pair are searched. The aforementioned three methods are attempted. 62 points were selected for evaluation of height estimation accuracy. The estimated altitude was evaluated in comparison with a reference topographic map.

(4)Algorithm for the terrain height estimation

The geometric relationship between satellite positions and ground target is shown in Fig. 3. In this figure, terrain height Hp is calculated by the following equation.

$$Hp = \frac{Ll + Lr - Lb}{Ll/Hl + Lr/Hr} \qquad (1)$$

Hl,Hr : satellite altitude
Ll,Lr : base line length (see Fig.3)
Lb : parallax

For more details, Hp is obtained from the position data(Pl,Pr), corresponding to those on the stereo pair images and the satellite position data (Sl,Sr) obtained from SPOT data. These data are translated to the geocentric coordinate system. It,however, is not always that there exists the crossing point. For instance, if the viewing vectors from the different satellite positions do not crossed at a time as is indicated in Fig. 4 , a crossing point is determined from minimum X (see Fig. 4)

$$X = f(Z)$$
$$df/dz=0$$

4. Terrain height estimation accuracy

Estimation errors were evaluated with Mean and RMS values in unit of meter. Table 1 shows estimation errors on the check points for the different methods for the searching of the corresponding points. An example shows the correlation between the estimated value using stereo pair of SPOT HRV data and the height obtained from the topographic map as is illustrated in Fig. 5.

For comparison, estimation error using Landsat TM data is also indicated in the Table 1. As is shown in Table 2 , theoretical accuracy on the terrain height estimation for both data of SPOT HRV and Landsat TM are obviously different. The dominant factors of these errors are as follows;

(1) Miss identification of the corresponding points,
(2) Estimation error on the satellite positions,
(3) Over-lapping error on the base surface.

Table 3 shows the effect of magnitude with each factor to the error.

5. Assessment of the factors' sensitivities on the terrain height estimation.

Sensitivities of the following factors are considered

(1) Estimation error of the satellite positions,
(2) Estimation error of the satellite attitude.

A geometric relationship between satellite positions and ground target is illustrated in Fig. 6. The highest point (the top of Mt. Komagatake, 2956m) was selected for the case study.

In the figure, UTM-coordinate of (Sl,Pl,Sr,Rr) is known while H_r and Ro are assumed. The other parameters are calculated by taking into account the geometric relationship.

Equation (1) was partialiy differentiated about Hl, Hr, Ll, Lr.

$$\frac{\partial Hp}{\partial Hl} = \frac{(Ll+Lr-Lb)*Hr^2*Ll}{(Hl*Lr+Hr*Ll)^2} = Ld*0.0012 \qquad (2)$$

$$\frac{\partial Hp}{\partial Hr} = \frac{(Ll+Lr-Lb)*Hr^2*Lr}{(Hl*Lr+Hr*Ll)^2} = Ld*0.0007 \qquad (3)$$

$$\frac{\partial Hp}{\partial Lr} = \frac{Hp}{Ll} = \frac{Hl*Hr^2*(1-Ld*Hr)}{(Hl*Lr+Hr*Ll)^2} = -Ld*0.0007 \qquad (4)$$

where Hr=Hl and Ld=Ll+Lr-Lb , (parallax of the object and 1689m at the Komagatake point).

(1) Sensitivity has been calculated by substituting the nominal values into the above equations. Then it is found that the effects of these factors are 1.0-2.0m.

(2) The effect of the estimation error of the satellite attitude on the estimation of H_p corresponds to that of estimation error of L_l or L_r. The sensitivity of ground range dLl to rolling angle dθ, in this case, is indicated by the following equation.

$$dLl=933*d\theta \qquad (5)$$

6. Conclusions

Through the aforementioned analyses, the followings are concluded.

(1) RMS error decreases by taking into account the earth's ellipsoid for the coordinate transformation from longitude-latitude to geocentric.

(2) The most dominant factor on the terrain height estimation is miss-identification of GCPs in the process of automatic corresponding points searching with stereo pair.

7. References

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(3)R.K. Vincent Automatic extraction of high resolution elevation data from SPOT stereo images, ibid.

(4) Begni, G., SPOT Image Quality, The 3rd GOSS Meeting, 1987.

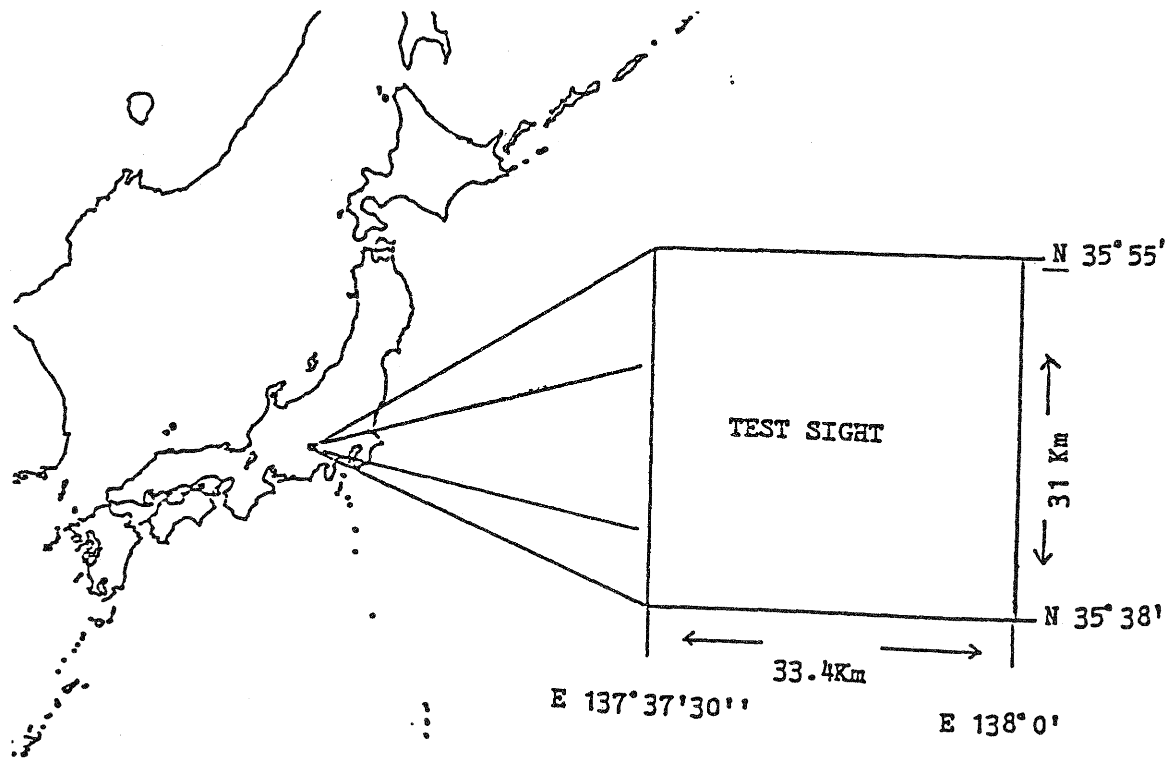

Fig. 1 Location of the intensive study area in Japan.

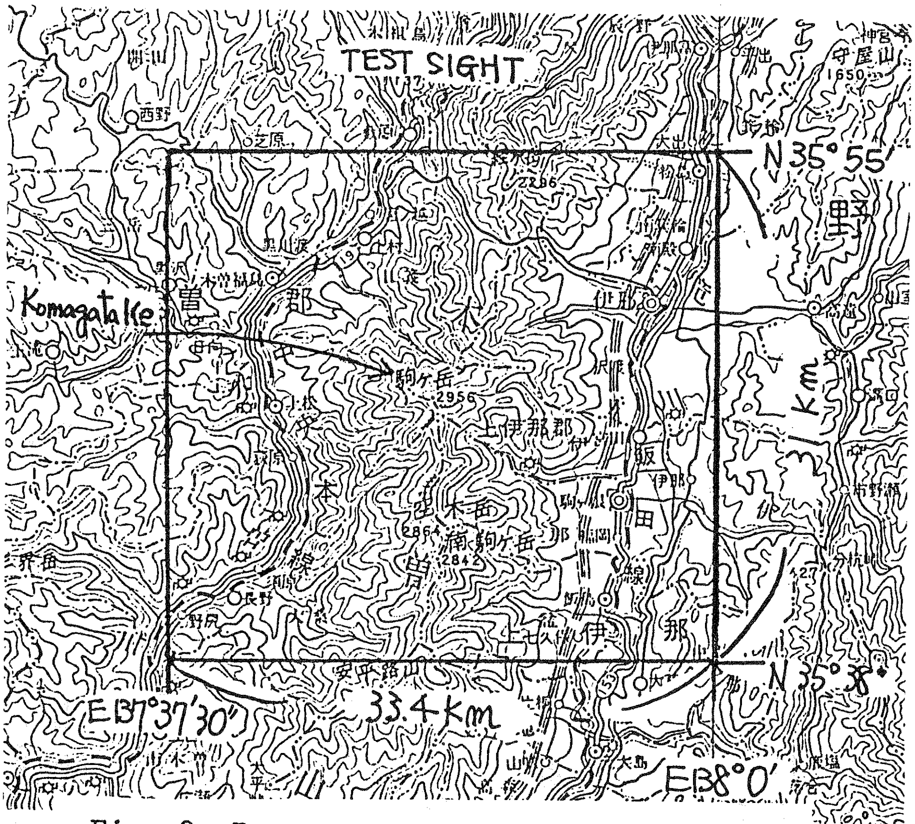

Fig. 2 Intensive study area for terrain height estimation.
(contour distance is 200m.)

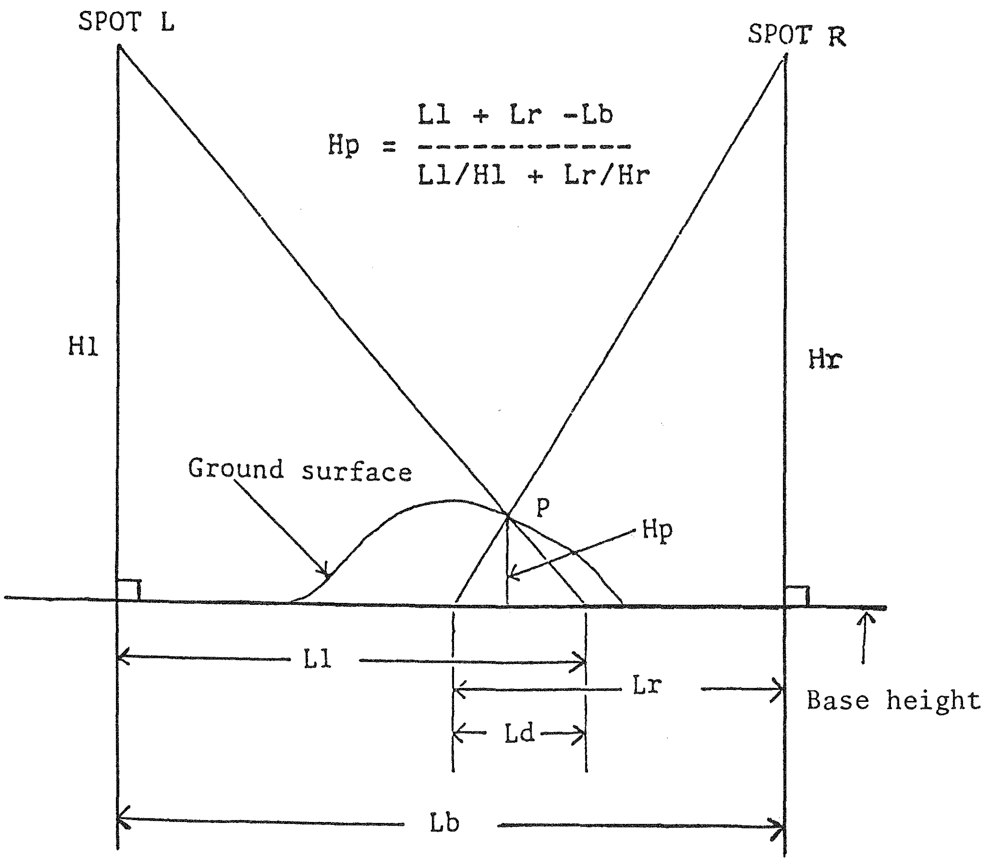

Fig. 3 A explanatory illustration showing principle of the terrain height estimation using stereo pair of SPOT HRV data.

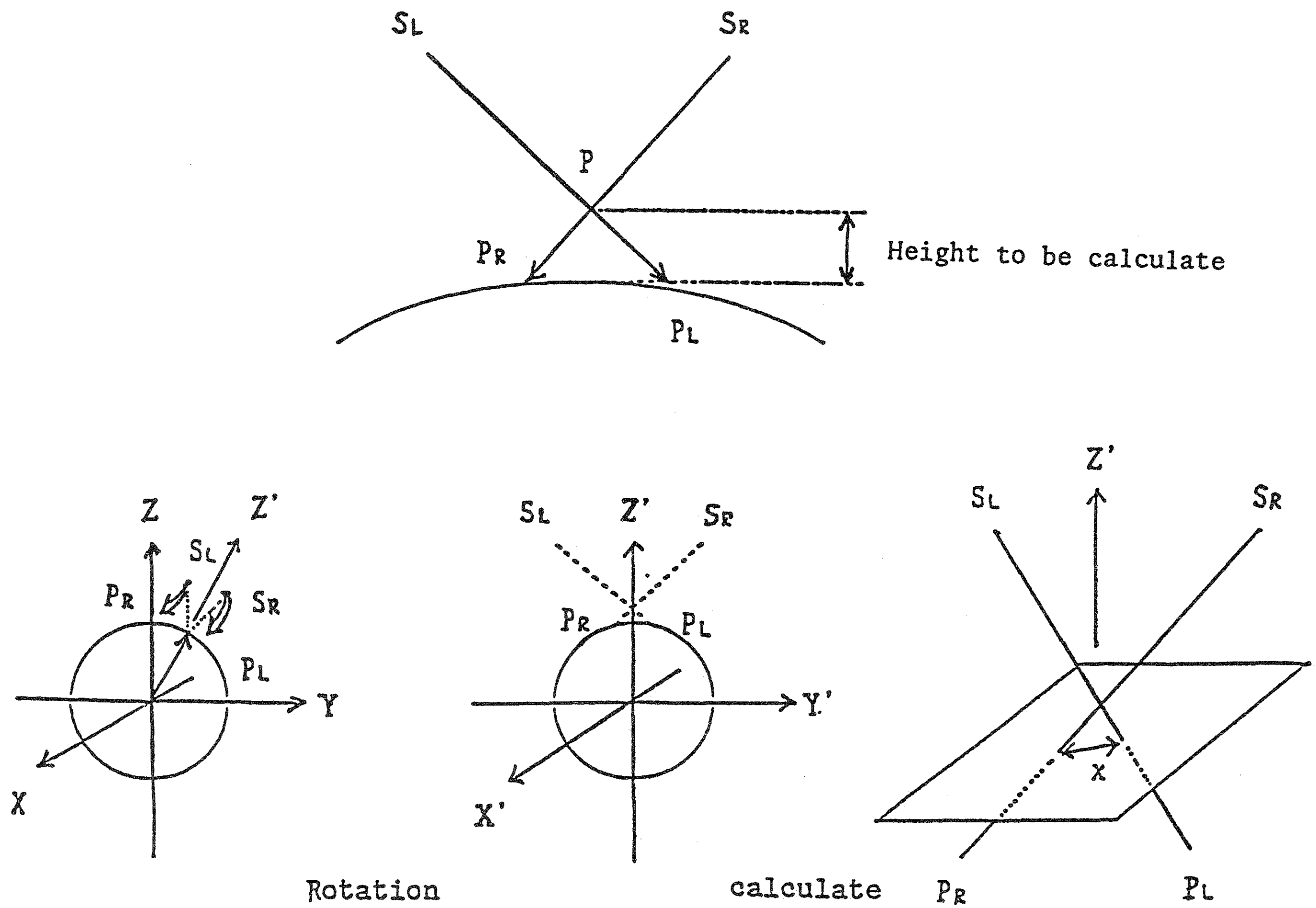

Fig.4 Schematic illustration for the terrain height estimation cross points between two different viewing vectors which show the minimum distance are determined on the corresponding the terrain height plane.

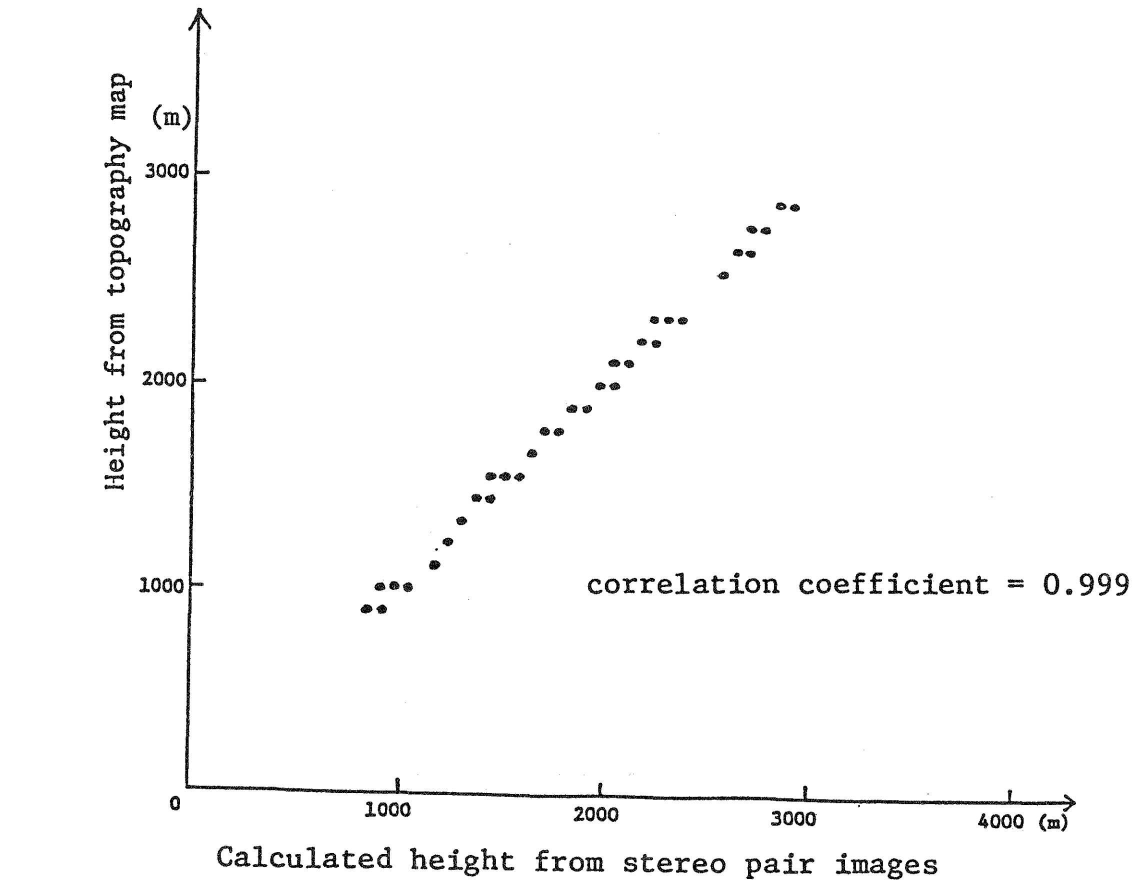

Fig. 5 Relationship between true height and calculated height

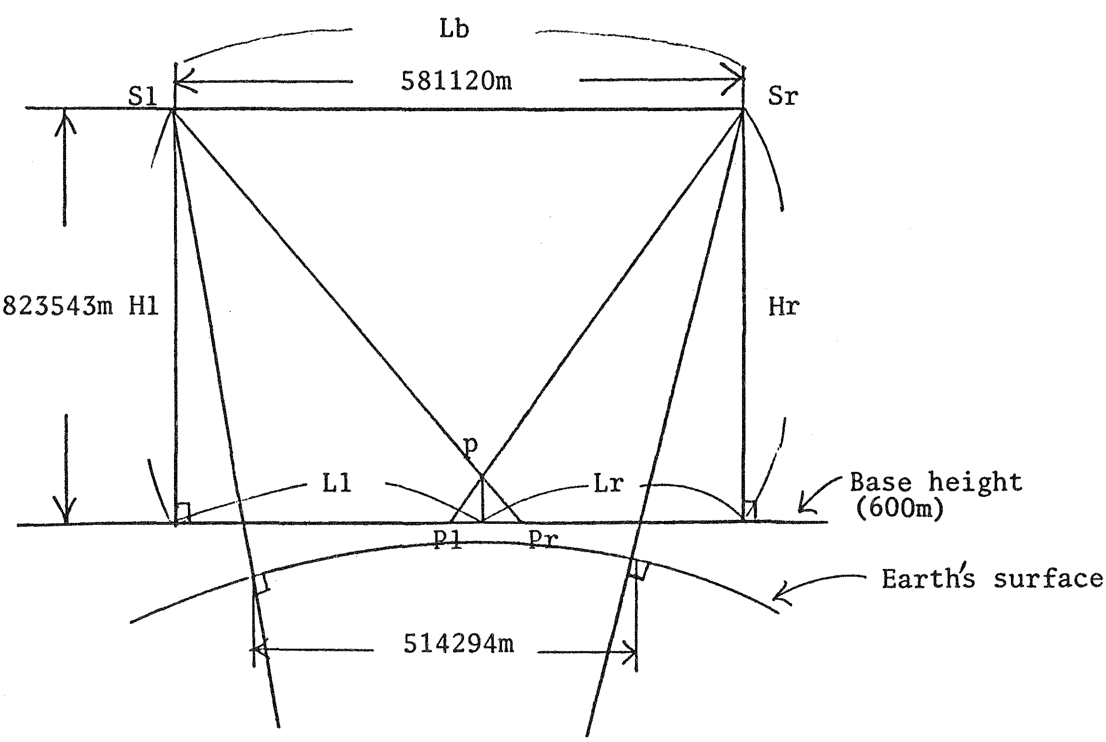

Fig. 6 Geometric relationship among satellite positions and target.

Table 1 Statistics of Terrain Estimation Errors

Case	RMS Error (m)	Mean of Absolute Error(m)	Corre-lation	No. of GCPs
Searching GCPs on CRT	26.6	22.0	0.999	58
Automatic GCP Matching	25.1	21.5	0.999	51
Manual Matching with Mapper	24.2	20.2	0.999	56
Landsat TM(Searching GCPs on CRT)	98.0	82.9	0.989	43

Table 2 Terrain estimation accuracy

	SPOT(HRV)	LANDSAT(TM)
B/H ratio	0.509	0.130
σ :Geound resolution	10 m	30 m
(resolution·H/B)	19.63 m	231 m
H :Satellite altitude	822 Km	712.5 Km
B :Base line length	418.8 Km	92.5 Km

$$\sigma_H = \frac{H}{B} \cdot \frac{H}{f} \cdot \sigma_P \simeq \text{(resolution} \cdot \text{H/B)}$$

σ_H: Standard deviation of terrain estimation error(19.38m SPOT)
σ_P: Standard deviation of parallax
f : Focal length

Table 3 Error factors and their effects

Error factor	Assumed error	Influence on the terrain height estimation
Miss-GCP identification	1 pixel	15 m
Estimation of satellite position	1000 m	8.8 m
Gradient of the base surface	1 deg	6.3 m