A STUDY ON SIMULATION OF THREE DIMENSIONAL MEASUREMENT WITH USE OF STEREO LINEAR ARRAY SENSOR

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ABSTRACT

The objectives of this study are

1) to develop an algorithm to determine exterior orientation paprameters of linear array sensor given as the function of time or scan line number, by using both of control points and satellite data (orbit and attitude), and
2) to develop an algorithm to perform three dimensional measurement by applying auto-correlation to the stereo images produced by linear array sensor.

In order to fulfill the objectives, a computer simulated stereo imagery in side looking mode were produced by using the national digital terrain model (DTM) and corresponding precision corrected LANDSAT MSS data in the central Japan.

Preliminary study has been already done by the authors in 1982 (1), when the method of exterior orientation was developed for fore & aft looking stereo mode and the accuracies of three dimensional measurement were compared between parameters of stereo angle, number of control points, widow size for stereo matching and so on.

In this study, the method of exterior orientation and automated three dimensional measurement for side looking stereo mode as proposed in French SPOT has been developed by the authors.

In order to improve the accuracy of stereo mapping by computer, a combination of two window patches, that is, 3x3 and 9x9 was adopted to the simulated stereo images.

From the results of this study, it can be said that contour map with 20 to 30 meters interval can be automatically generated under the assumption that 10 meters IFOV stereo imagery with B/H (base to height ratio) of 0.5 or 1.0 and 10 m accuracy of satellite orbit and 0.01° of satellite attitude are available.

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COMPUTER SIMULATED STEREO IMAGES

Computer simulated stereo images were produced with use of the national DTM and LANDSAT MSS data in the mountaneous area in the central Japan as shown in Figure 1.

The following parameters were input for simulation.

a. IFOV on the ground ; 10 meters
b. B/H ratio ; 0.5 and 1.0
c. Accuracy of satellite orbit; $\sigma_x = \sigma_y = \sigma_z =$ 10 meters
d. Accuracy of satellite attitude; $\sigma_\omega = \sigma_\phi = \sigma_\kappa =$ 0.01°
e. Image data ; LANDSAT MSS 5

Figure 2 shows a stereo pair in side looking stereo mode with B/H ratio of 1.0. Figure 3 shows the side looking stereo mode.

Figure 1 Topomap of Study Area (figures show elevation; rectangular shows the test area for DTM generation)

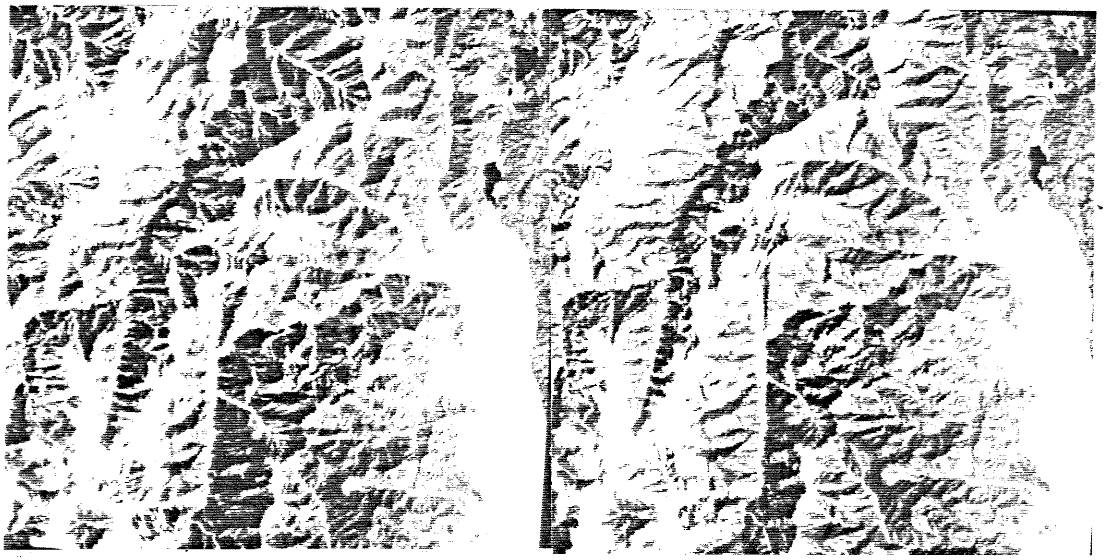

Figure 2 Computer Generated Stereo Pair (B/H = 1.0)

EXTERIOR ORIENTATION

Exterior orientation parameters are given as the function of time or line number as follows.

satellite orbit :

$$X_0 = X_{00} + X_1 * L$$

$$Y_0 = Y_{00} + Y_1 * L$$

$$Z_0 = Z_{00} + Y_1 * L$$

satellite attitude :

$$\omega_0 = \omega_0 + \omega_1 * L + \omega_2 * L^2 + \omega_3 * L^3$$

$$\phi_0 = \phi_0 + \phi_1 * L + \phi_2 * L^2 + \phi_3 * L^3$$

$$\kappa_0 = \kappa_0 + \kappa_1 * L + \kappa_2 * L^2 + \kappa_3 * L^3$$

where L : line number

(X_0, Y_0 , Z_0) : projection center

(ω , ϕ , κ) : attitude (roll, pitch and yaw)

Total number of unknown parameters are eighteen. These unknown parameters are determined by applying the following colinearity equation with use of known control points and observed orbit and attitude data with the weight of $1/\sigma$. Figure 4 shows the location of ground control points.

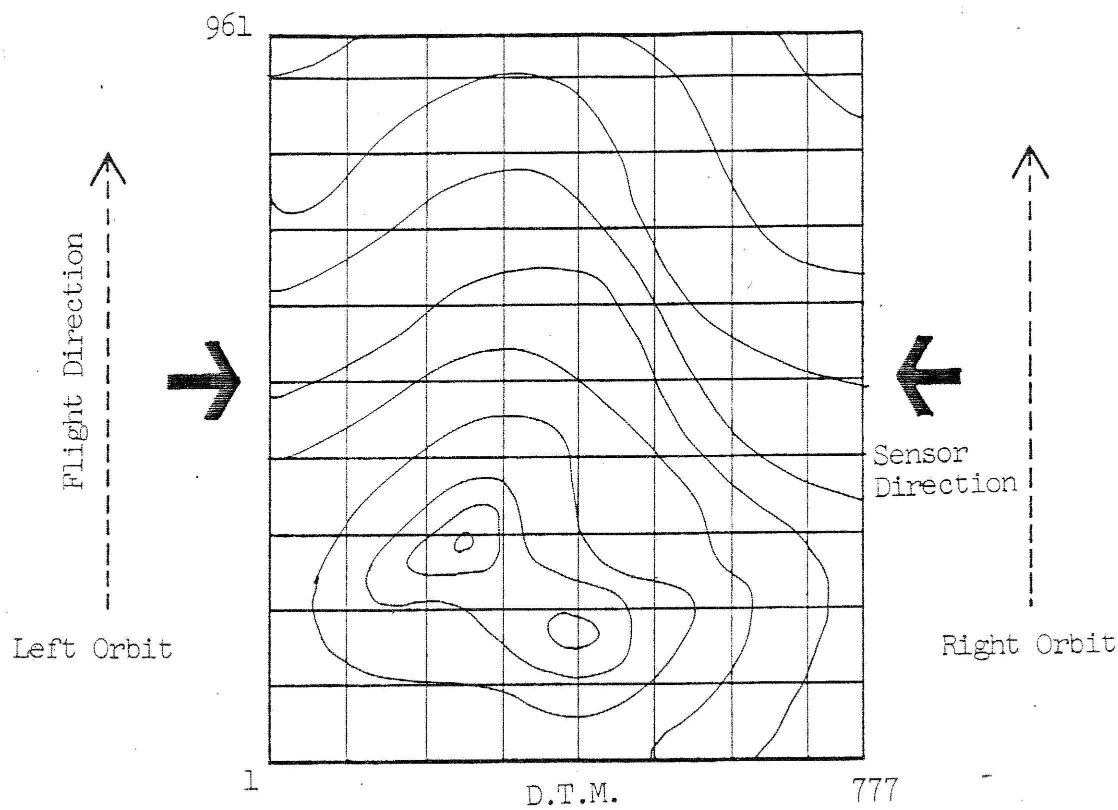

Figure 3 Stereo Photography in Side Looking Mode

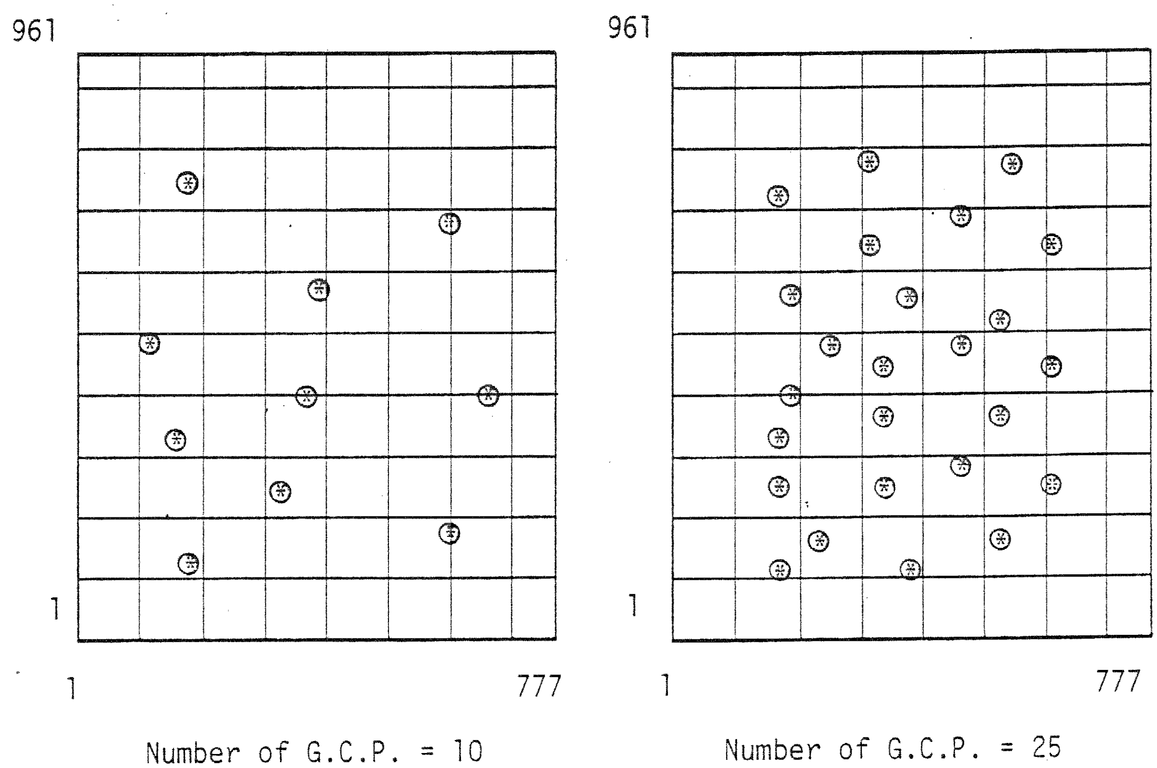

Figure 4 Selection of Ground Control Points

Colinearity equation :

$$\frac{a_{11}(X - X_0) + a_{12}(Y - Y_0) + a_{13}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} + \frac{x}{f} = 0$$

$$\frac{a_{21}(X - X_0) + a_{22}(Y - Y_0) + a_{23}(Z - Z_0)}{a_{31}(X - X_0) + a_{32}(Y - Y_0) + a_{33}(Z - Z_0)} + \frac{y}{f} = 0$$

where

(X, Y, Z) : coordinates of object

(X_0, Y_0, Z_0) : projection center

f : focal length

(x, y) : photographic coordinates of element

$$x = x_i$$

$$y = \{i - (n-1)/2\}\delta + y_i$$

i : element number

(x, y): corrections for inner distortion

n : total number of elements

δ : spacing of elements

$$\begin{bmatrix} a_{11} a_{12} a_{13} \\ a_{21} a_{22} a_{23} \\ a_{31} a_{32} a_{33} \end{bmatrix} = \begin{bmatrix} \cos\phi & 0 & -\sin\phi \\ 0 & 1 & 0 \\ \sin\phi & 0 & \cos\phi \end{bmatrix} \begin{bmatrix} \cos\kappa & \sin\kappa & 0 \\ -\sin\kappa & \cos\kappa & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & \sin\omega \\ 0 & -\sin\omega & \cos\omega \end{bmatrix}$$

$a_{11} = \cos\phi \cos\kappa$

$a_{12} = \cos\phi \sin\kappa \cos\omega$

$a_{13} = \cos\phi \sin\kappa \sin\omega - \sin\phi \cos\omega$

$a_{21} = -\sin\kappa$

$a_{22} = \cos\kappa \cos\omega$

$a_{23} = \cos\kappa \sin\omega$

$a_{31} = \sin\phi \cos\kappa$

$a_{32} = \sin\phi \sin\kappa \cos\omega - \cos\phi \sin\omega$

$a_{33} = \sin\phi \sin\kappa \sin\omega + \cos\phi \cos\omega$

In this study, the exterior orientation was carried out by using 10 and 25 control points for comparison. Table 1 shows the accuracy of exterior orientation in the term of residuals on the image plane with unit of pixel. There was not so much differences between two cases, because the weight of orbit and attitude data played a lot of role to the total accuracy as compared with control points.

Table 1 Accuracy of Exterior Orientation

B/H ratio		B/H = 0.5		B/H = 1.0	
Image		Left	Right	Left	Right
Error (RMS)	G.C.P.= 10	0.27	0.27	0.36	0.32
	G.C.P.= 25	0.35	0.35	0.38	0.39

Since in the former study (1), the minimum absolute sum method was selected as the best method from the engineering view point such as CPU time and accuracy, as compared with Fourier adjustment method and maximum correlation coefficient method, an improved algorithm has been developed for the minimum absolute sum method.

A combination of two window patches, that is, small window and large window has been tested in order to improve the accuracy for searching conjugate points in the stereo amages. The reason why a combination of small window and large window was selected is that very few but big errors occur in the case of small window while standard deviation is rather big in the case of large window. Therefore, if a combination of small window and large window is selected, the error distribution will be improved.

After trial and error for many combinations of two different window patches, a combination of 3x3 and 9x9 was selected as the best one.

Table 2 compares the errors of height for three cases, that is, 3x3 window alone, 9x9 window alone and a combination of 3x3 and 9x9 windows, in the term of root mean square of differences between observed height (DTM) and computed height for 260x260 pixels in the study area. Figure 5 shows the error distributions for B/H=1.0.

Table 2 Root Mean Square of Height Error

no. of G.C.P.= 25, unit: meter

Window types	B/H = 0.5	B/H = 1.0
3 x 3 window alone	18.2	15.2
9 x 9 window alone	10.5	9.6
3 x 3 and 9 x 9 windows	8.2	6.6

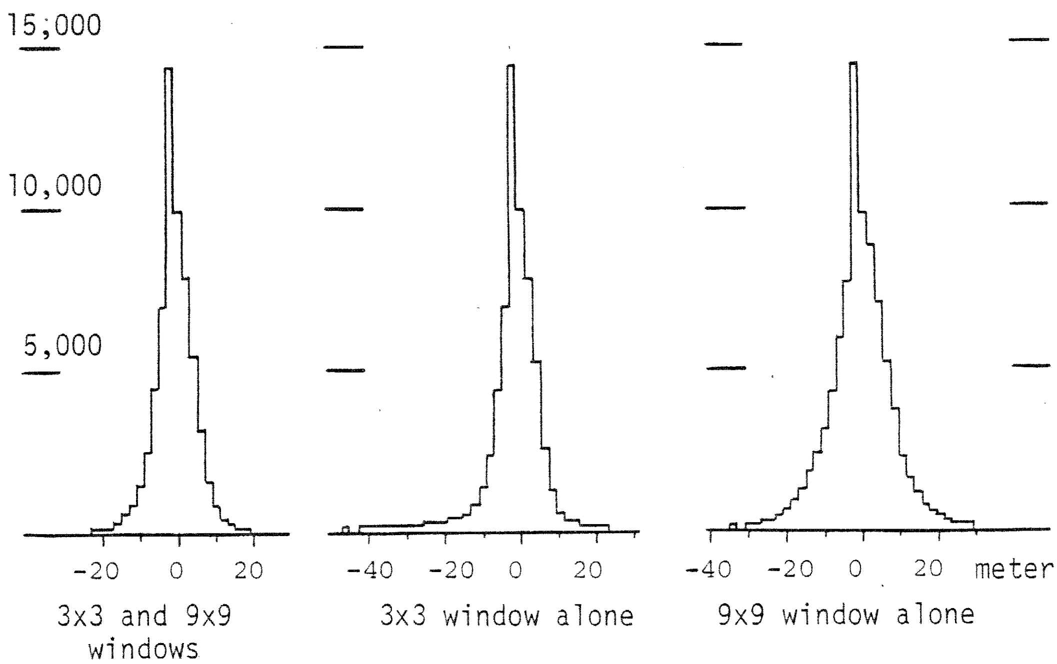

Figure 5 Error Distribution of Height Data (B/H=1.0)

COMPUTER GENERATED DTM

When all of points in one of stereo pair are searched for their conjugate points in the other stereo pair point by point, irregularly spaced net data will be obtained as shown in Figure 6 . For convenience of utilization of DTM, regularly spaced DTM should be generated from irregularly spaced DTM. The authors have developed a high speed interpolation algorithm to convert from irregularly spaced DTM to regularly spaced DTM.

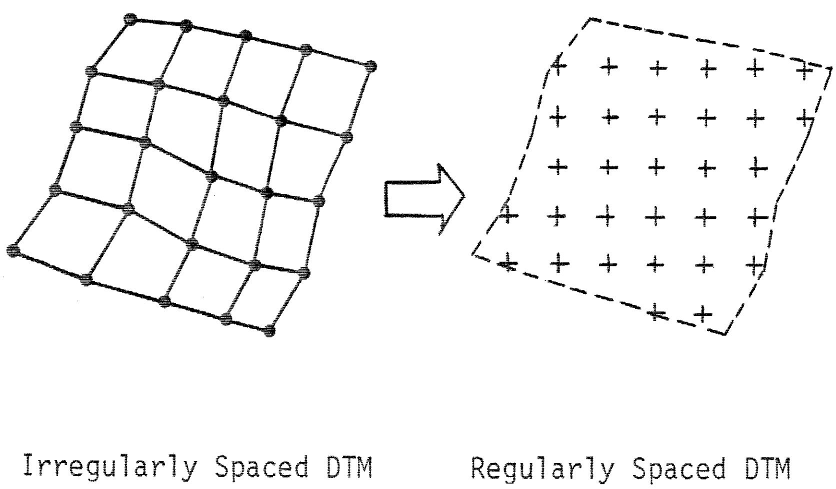

Figure 6 Interpolation of Regularly Spaced DTM

Figure 7 shows the observed DTM with 25 meters contour which is selected in the study area, shown in Figure 1 (a frame of bold line).

Figure 8a and 8b show the conputed DTM with 25 meters contour for the case of a combination of 3x3 and 9x9 windows for B/H= 0.5 and 1.0 respectively.

Figure 9a and 9b show the computed DTM with 25 meters contour for the case of 3x3 window alone and 9x9 window alone respectively for B/H=1.0.

The contour images are displayed by two cycles of gray scale from white (low altitude) to black (high altitude) in order to identify the detail of topography.

As realized in the figures, the computer generated DTM shows relatively good accuracy though dot shape errors are seen in the figures because of mismatching of conjugate points in the stereo pair.

Table 3 shows the computing time for stereo matching per point in msec.

Table 3 Computing Time per Point

Window types	B/H = 0.5	B/H = 1.0
3x3 window	2.53	2.01
9x9 window	6.74	6.24
3x3 and 9x9 windows	12.82	24.58

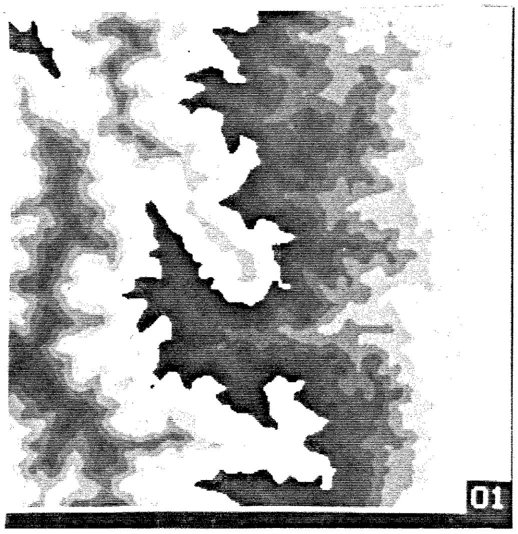

Figure 7 Observed DTM

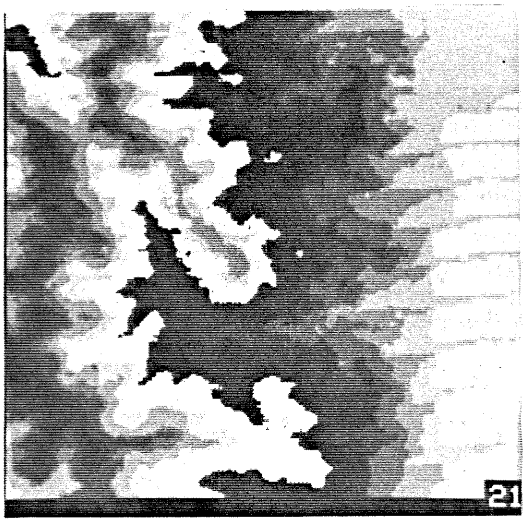

Figure 8a 3x3 and 9x9 (B/H=0.5)

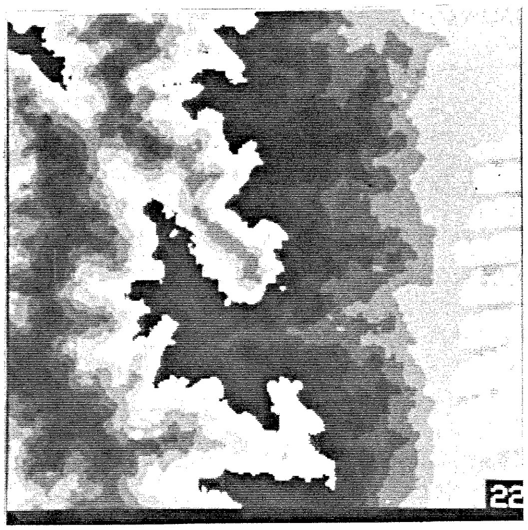

Figure 8b 3x3 and 9x9 (B/H=1.0)

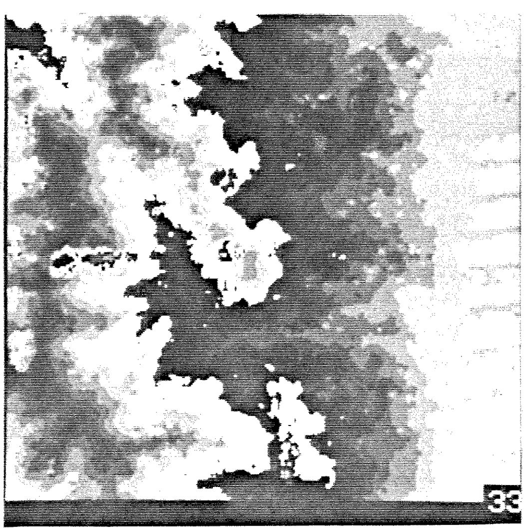

Figure 9a 3x3 alone (B/H=1.0)

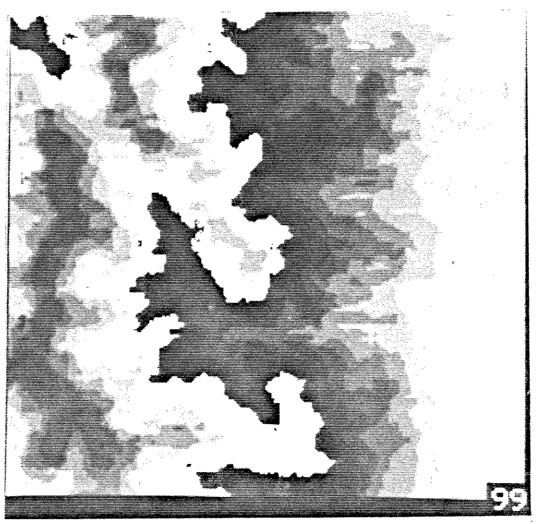

Figure 9b 9x9 alone (B/H=1.0)

CONCLUSION

1) An algorithm to determine orientation parameters given as the function of time or scan line number, has been developed by the authors. In this algorithm, control points as well as observed satellite data with respect to orbit and attitude can be input with specific weight for solving those parameters.

2) When B/H ratio is 1.0, the total accuracy of three dimensional measurement was better than in the case of where B/H ratio is 0.5, while the accuracy of stereo matching or auto-correlation becomes a little less.

3) The number of control points did not affect the accuracy of exterior orientation less than expectation. This was because the assumed accuracy of observed satellite data was excellent as expected in G.P.S. (Global Positioning System) and Star Tracking System.

   In this study, 10 control points were good enough to determine the exterior orientation parameters.

4) Contour map with 25 meters interval as equivqlent as 1: 50,000 or 1: 10,000 scale topomap could be generated by computer under the assumption of 10 meters IFOV. Total accuracy of height ranged 6.6 meters in average in the case of 1.0 B/H ratio to 8.2 meters in average in the case of 0.5 B/H ratio.

REFERENCES

1) S.Murai and R.Shibasaki ; " Geometric Correction of Linear Array Sensor " ; Proceedings of International Symposium on Advances in the Quality of Image Data, Commission I, ISPRS, Canberra, Australia, April, 1982