

APPROXIMATE METHOD FOR OFF-LINE COMPUTATION OF DEM FROM SPOT STEREO PAIRS

Shue-Chia Wang
Institute of Photogrammetry
Cheng Kung University
Tainan, Taiwan, ROC
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Abstract

An approximate method, based on the two steps orientation of relative and absolute orientations, is derived for computing the DEM sample points from SPOT stereo pairs. The images should be measured stereo comparatively. The computation is off-line. Only familiar spatial resection programs and absolute orientation programs are needed, so that every one can do it by himself. Test results show that the accuracy is not much worse than rigorous solutions.

Introduction

Since the launch of spot satellite, many photogrammetrists see a new possibility for mapping. Because the spot scanner can take off nadir images, stereo pairs with very high B/H ratios (up to $B/H=1$) can be acquired. And also because of its high resolution (10 m for Panchromatic CCD Sensors), more details can be seen than any previous commercial satellite images. These two distinguished characters make spot stereo pairs be used for topographic mapping of small scales. In the Seminar on Photogrammetric Mapping from Spot Imagery held in Hannover F. R. Germany last September, some preliminary results were presented.

Although the CCD sensors produce digital images, which are naturally suitable for digital image processings, but at this moment it seems that analytical solutions using photographic films might be more successful.

Because the SPOT images are produced by CCD line scanner (push broom principle), conventional mathematical models can not be used directly for evaluating them. On-line measurement in analytical plotters could only be done either by the rigorous dynamic spatial resection, while the projection centers change steadily as the measuring marks moves from scan line to scale line, or by approximate interpolating of correction grids as proposed by Konecny /1/. Both need special programs for controlling the measuring marks of the analytical plotters.

But if only DEM is to be measured, the accuracy demand is not so high as for line mapping. In this case, approximate solution could be found, which off-line computes the DEM sample points from the stereo comparator coordinates. The DEM thus obtained will not be so accurate like those from on-line analytical measurements using special programs. But test shows that the accuracy can meet the requirement of 1/50000 maps.

Normally strip images with sidelap (overlap perpendicular to the flight direction) is very difficult to orient, because each image line has its own exterior orientation parameters. (See /2/ for detailed explanation). But for satellite strip images, the orientation is not too difficult, because the satellite orbit is much more stable than the airplane flight path so that some assumptions could be made about it. Usually simple functions of time (or scan line number) could be used for describing them. These functions not only drastically reduce the amount of unknowns at the orientation procedure but also stabilize the geometrical

conditions to make an orientation possible. Small variations in the orientation parameters will be treated like systematic errors, which could then be, for example, corrected by additional parameters. The aerial triangulation of spot images is usually based on such principle.

The method here proposed for off-line computation of DEM is based on the assumption of very stable orbits of SPOT, at least during the 9 second flying time, when one image of 6000 lines are scanned. Influence of the small deviations from the idea (or ideal) orbit will be treated as systematic errors.

The basic idea of this method is to try to orient the SPOT image pairs through the traditional two steps of relative orientation and absolute orientation. So that every photogrammetrist can do it without complicated computer programs. The only thing needed is stereo comparator coordinates of the image pairs. This method is only an approximate solution of the orientation problems of SPOT stereo pairs and is suitable only for computation of DEM sample points.

Concept of the Pseudo Images and the Pseudo Relative Orientation

We know that in the very special case, when the flight pathes of the two adjacent stereo strips are absolutely stable and parallel, the relative orientation of line scanned image pairs can easily be done by just eliminating the parallaxes at a few points. Fig. 1 shows such a case. When the two flight pathes are parallel, the two homologous scan lines of the left image (denoted by i') and the right image (denoted by i'') are parallel. Therefore by elimination of the X- and Y- parallaxes, these two lines can be relatively oriented. The relatively oriented "line model" is nothing but a forward resection of all the pixels in the overlapping area. The parallaxes can be simply eliminated through stereo comparator measurements.

By connecting all the line models of the image pairs, a relatively oriented model for the whole overlapping area can be obtained, which is exactly the same like a normal photogrammetric model from aerial photographs.

But for actual spot stereo pairs, such ideal case never occurs. Actual orbits are not stable and are usually not parallel. The non-parallelity of the orbits of stereo image pairs makes the relative orientation theoretically impossible. When the orbits of two images are not parallel, their ground tracks build a convergence. This convergence increases with the latitude. Fig. 2 shows this situation. When the orbits are not parallel, the scan lines from the left and from the right images are not parallel. In this case, the homologous pixels in both images will not lie in single scan lines simultaneously. For example, in Fig. 2, the pixels in the right image, which are homologous to the scan line i of the left image, lie in different scan lines. Since each scan line has its own exterior orientation parameters, these pixels do not belong to a single perspective projection. Therefore, they can not be relatively orientated to the corresponding scan line i in the left by simple parallaxe elimination.

But in this method, we will neglect this fact and perform a relative orientation. The relative orientatin will be done by simple forward intersection of homologous pixels, without considering the changing of the projection centers for each pixel.

In order to keep the error of the relative orientation, when neglect

the changing of projections, as small as possible, the image will be re-arranged before the stereo model is constructed.

For the re-arrangement of image, the idea of "pseudo line", "pseudo image" and "pseudo relative orientation" are introduced. The word "pseudo" is used to express that they are not real. The whole relative orientation will proceed as follows.

First, the two images will be measured stereo comparatively for the DEM points and enough control points. The comparator measurements give together with the image coordinates also the convergence of scan lines, because the y axis of image coordinate system is defined to run in the direction of scan line.

After the stereo comparator measurement of the two images, one of them will be chosen as the base image. In the base image, nothing is changed. Its original scan lines will serve as the basic line for the relative orientation of line model. The other image will be transformed into a pseudo image. A pseudo image is an imaginary image, which the SPOT would obtain, if the camera axis were vertical. We know that SPOT has a very narrow field of view (FOV) of only 4 degrees. In order to obtain a large B/H for stereo pairs from adjacent orbits, SPOT has to tilt its camera axis to the left or to the right. The purpose of pseudo image is to correct this tilting for later use. Since the correction is done line by line independently, it is very simple. Only a one dimensional transformation of the Y-coordinate of each pixel is needed.

$$y' = y + \tan \omega (-f + y \tan (\omega - y/f))$$

where

- y' is the pseudo image coordinate, referred to the nadir of scan line
- y is the original image coordinate, referred to the center of scan line (the 3000th pixel)
- f is the focal length of the imaging system
- ω is the tilting angle of the camera axis

Fig. 3 shows the meaning of the pseudo image. The focal length of the system remains unchanged after the transformation.

After the transformation, all the pixels of the pseudo image will be re-arranged into pseudo lines. A pseudo line is a line, which is homologous to one base line in the base image. Although the pixels in a pseudo line are homologous to those in the base line, they are not from one single center projection. But in the approximate solution, the pseudo line will be treated as a center perspective projected line and will be given a pseudo projection center. The pseudo line is only a re-arrangement of pixels in the pseudo image, no further calculation is needed. The pseudo projection center is defined as the intersection point of a vertical plane containing the pseudo line with the SPOT orbit. It can easily be found by a helmert transformation of the ground track of the orbit of the pseudo image into the base image. Since only relative orientation is concerned here, the actual stereo base length between the two adjacent orbits is not important.

Because the basic line and the pseudo line are parallel now, a relative orientation can be performed by forward intersection. Since the base line is the original CCD scan line, it forms together with its projection center a true center perspective projection. A forward intersection is permitted. But for the pseudo line it is not the case. The pixels in the pseudo line are actually from different scan lines. The forward intersection using pseudo perspective center is only an approximate relative orientation. We

shall call it the pseudo relative orientation. The pseudo relative orientation is deformed. How strong a model point is deformed, depends in the first stance on the degree of convergence of the orbits, and then on its height above the datum and the distance from this point to the (pseudo) nadir (ground track) of that image.

Fig. 4 shows the error in the pseudo line. The original scan direction is perpendicular to the orbit (X Axis in Fig. 4), but the relative orientation will be done in the direction of the pseudo line. For a point Pt on the ground, its image in the original scan line is P'. But in the pseudo line, P' is assumed to be the image of Pp. Thus, the relative orientation using pseudo lines will shift Pt to Pp. But the main shiftment is in the X direction of the model coordinates system, therefore a simple correction of the X coordinates of the model could be done using the following formula:

$$\Delta X = Z \cdot \frac{y'}{f} \cdot \sin \theta / 2$$

Where Δx is the correction, Z is the model height coordinate, θ is the convergence angle, f is the focal length and y' is the pseudo image coordinate. The first part, $Z \cdot y' / f$ in the formula is an approximate estimation of the relief displacement. The multiplication of $\sin \theta$ is to get its projection in the X direction (the shift from Pt to Pp). Since all X-shifts are already corrected by the amount of 1/2 during the relative orientation, only 1/2 of the shift remains to be corrected after the relative orientation. This correction is of course only an approximation. In the Y direction, no correction will be done, because its amount is too small for most practical cases.

There are also many other factors which cause further deformations of the relatively oriented model. For example, the earth curvature, the type of map projection for the national datum, the earth rotation during the scanning of the image, etc. But all their influences on the relatively oriented model are systematic, so we will also leave them until a later stage.

Absolute Orientation and Posterior Correction of Systematic Errors

In the second stage of this method, the relative oriented model will be absolutely oriented onto enough control points. The absolute orientation will be done exactly like in the conventional Photogrammetry, using only seven parameters. Since the model is strongly deformed, big discrepancies will occur on the control points after the absolute orientation. These discrepancies will serve as a base for correction of the systematic errors in the model. In order to obtain a better results, it is suggested to have control points uniformly distributed in the planimetry as well as in the height. According to the test, 9 points over the entire area are enough. The number of control point is not so important as their distribution, especially the distribution in the height is very important for a good correction effect.

Simple polynomials will be used to correct the systematic deformation. They are:

$$\begin{aligned} \Delta X &= a \cdot Y \cdot Z \\ \Delta Y &= b \cdot Y \cdot Z \\ \Delta Z &= c \cdot Y \cdot Z + d \cdot R^2 \end{aligned}$$

where R is the distance from model center to the object point. The correction polynomials are surprisingly simple. Although more complicated

forms might be better, but in the practice, when the control points are not signalized, complicated formulae bring no significant improvement. Because the control points themselves are not so accurate enough as to bring finer corrections.

When the above formulae are used, the coordinate system should be defined as follows: The X axis is north-south direction. The origin of the coordinate system should lie in the center nadir of the pseudo image (notice that the nadir is usually outside the image, when there is a tilt of the camera axis).

Test Results

Two SPOT images of center Taiwan with the number 298-302 and 299-302 are used for test of the approximate method. The former was taken on Dec. 15, 1986, the later on Jan. 16, 1987. Both are panchromatic with 10 m resolution. 298-302 has an inclination for $24^{\circ}04'$. 299-302 has an inclination of only $2^{\circ}25'$. The B/H is only 0.5. The DEM is sampled at a spacing of 200 m. The area covered extends from coast plain to center mountainous area, so that the elevation ranges from 8 m to more than 1500 m.

Control points and check points are chosen from topographic maps of 1/25000 scale. Totally 85 points were identified both for height and planimetry. Another 168 points are identified only in the height. Their planimetry was too poor to be identified in the maps or in the images. Most of them are mountain peaks, small openings in the valley with good definable height but very little ground features for identifying planimetry position. From the 85 points, 10 are used for full control. Their heights range from 20 m to 650 m. From the 168 height points, 7 are used as height control, so that there are totally 10 planimetric and 17 height control points. All the remaining points are used for checking purposes. But since the 1/25000 maps are strongly generalized, the accuracy of most points are not very high, especially those in the mountains. Very often the highest mountain peak should be chosen as full control, but it is very difficult to define in the planimetry, where (or which) is exactly the highest peak. Considering this, we can not expect a very high accuracy. Even the rigorous solution would not help much.

Since the test area has a very low latitude (less than 25° N), the convergence correction is very small, the systematic model deformation should also be small.

The accuracy in planimetry (μ_{xy} of the 75 check points) is 16 m, the maximum position error is 28 m. The accuracy in height (μ_z of 236 height check points) is 11 m, the maximum error in height is -33 m. The accuracy in planimetry seems to be not better than in the height. The reason is very simple. Very few control points or check points can really be identified very accurately in planimetry in the mountain area. But the heights of mountain peaks or the heights in the bottom of the valley can usually be more accurately measured from the maps and from the SPOT images, even without good identification of their planimetric positions. This indicate also that the actual achievable accuracy of this method might be higher than the values given above. This can only be proven when using better identifiable control points and check points.

Fig. 5 is the contour line made by the SCOP program package from part of test area of 8 km by 10 km in the scale 1/50000. Fig. 6 is the topographic map of the same area.

Conclusion

The method introduced in this paper is very simple, no need to pay special consideration to the moving projection centers between scan lines. The relative and absolute orientations are very familiar to photogrammetrists. The computation of the pseudo image and the posterior correction of absolute oriented model is very simple too.

The accuracy here obtained is not so high like Rivereau /3/ announced for rigorous solutions done by IGN France. But at a B/H ratio of 0.5, the approximate method can give an accuracy of about 11 m (about one pixel size) in the height, is surprisingly good enough. Don't forget that the quality of control points and check points are not very good.

This method is suitable for computing large amount of DEM sample points, while only stereo comparator coordinates of the SPOT stereo pairs are available and the computation can be done scan line wise. It is not suitable for computing line informations, because for the line information, the sequence of the measured object points is very important, which is very difficult to take care of by scan line wise computation.

The result here is only a preliminary test. Simulated data has shown, that more complicated correction polynomials could bring better accuracy. But this improvement can only be seen in the practice, if the control and check points have very high accuracy. But it is not very easy for practical cases.

The systematic deformation of the pseudo relative orientation becomes more complicated with increasing latitude. Simulated data shows that more higher order terms are needed to correct them. But which terms are necessary, still need to be investigated by more computer simulations.

Although some reports give very optimistic prognosis about the topographic usage of SPOT images in the middle scale, but from the very limited experience here, it is found that without existing maps or aerial photographs, many line features are very difficult to identify in the SPOT images. Also good control points with high accuracy are not very easily to find in the images, especially for mountaineous area. All these will limit the SPOT usage in obtaining line information. But the test here shows that the high B/H value of SPOT stereo pairs makes its usage in DEM very excellent. For national DEM data base, SPOT stereo pairs might be the most economic way for data collection.

Literature

- /1/ Konecny, G., Lohmann P., Engel H., Kruck E., 1987. Evaluation of SPOT imagery on analytical photogrammetric instruments. PE&RS Vol. 53, No. 9 Sep. pp. 1223-1230.
- /2/ Derenyi, E.E., 1971: An exploratory investigation concerning the relative orientation of continuous strip imagery. Tech. Report No. 8, University of New Brunswick, Canada.
- /3/ Rivereau, J.C., 1987: SPOT 1 current status and first application results. Seminar on Photogrammetric Mapping from SPOT imagery. Instiute of Photogrammetry and Engineering Surveys, University of Hannover, F.R. Germany, September 1987.

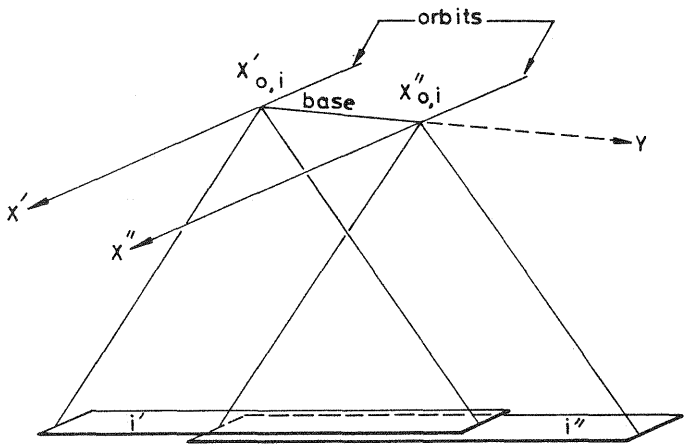


Fig. 1 Homologous scan lines of parallel orbits.

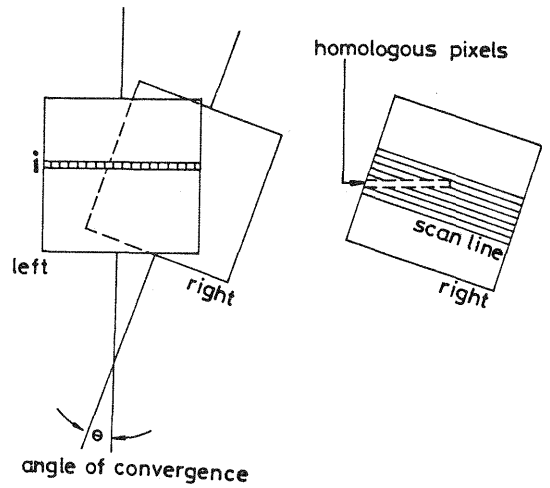


Fig. 2 Scan lines in the image pairs when orbits are not parallel

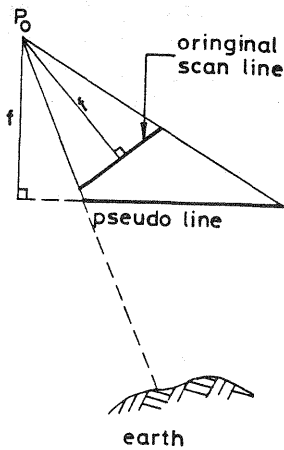


Fig. 3 Transformation of original scan line into pseudo line

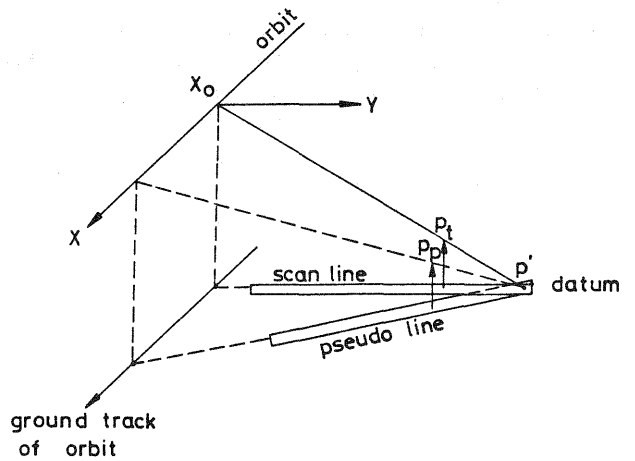


Fig. 4 Spatial resection error of the pseudo line

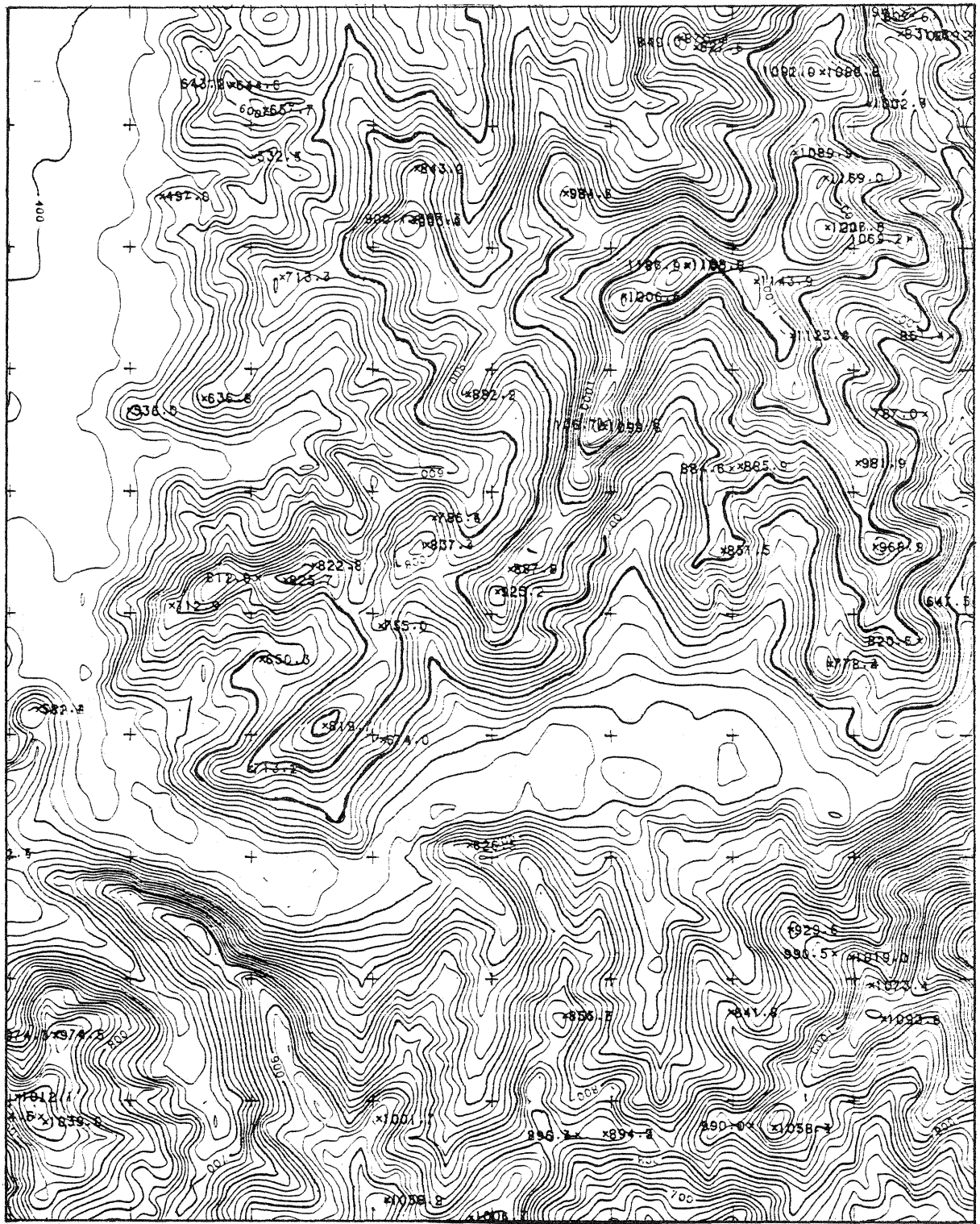


Fig. 5 Contour lines from SPOT DEM (1/50000 scale)

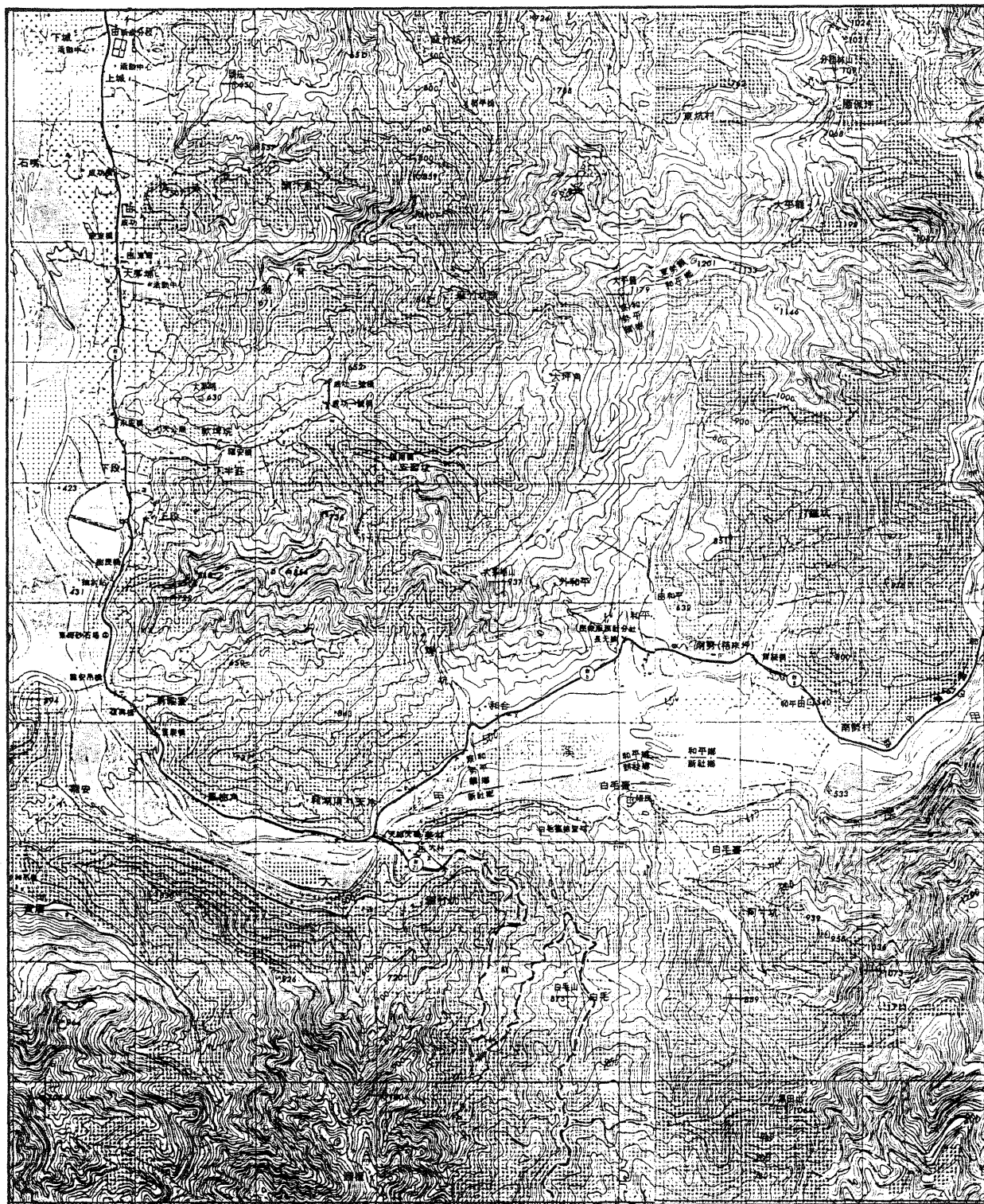


Fig. 6 Topographic map of the same area like in Fig. 5.