A Side-looking Airborne Radar Image For Scale Of 1:50,000 Map Revision

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Abstract

A side-looking airborne radar(SLAR) of synthetic aperture has a high resolution 3-meter, strong penetrating power, all weather and imaging capability day and night. The SLAR image, therefore, has wide application potentials. This paper reports the research on scale of 1:50,000 map revision using a SLAR image, including contents as follows:
1, the experiment and analysis for radar reflector.
2, two kind of methods for producing ortho-image map of a radar image: (a) the differential rectification of a SLAR image with auto-optical mosaic, using ortho-projector Z_S-1 made by China. (b) the digital ortho-rectification of a SLAR image with automatic mosaic and grey matching.
3, a rectified image map accuracy and the analysis of the effects of the office interpretation.

Introduction

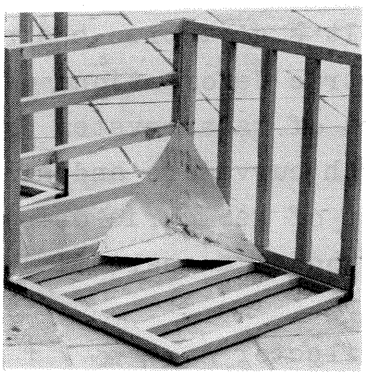
A radar transmits pulses of microwave energy and then imaging receiving reflection of the signal from target. It operates entirely independent of sunlight. This image is for a microwave image of reflecting characteristics of target. Because of imaging radar operates in microwave portion of the electromagnetic spectrum, it has strong penetrating power, all weather and imaging capability day and night. A side-looking airborne radar(SLAR) of synthetic aperture has many advantages of high resolution 3-meter, clear imaging, covering big areas, defferent side-looking angles and reflecting detailly ground surface. A SLAR image, therefore, has wide application potentials such as the military, geology, flood monitoring and imaging of cloudy and foggy and special areas, which is very poor condition for photography. The scientists, in the past, had researched on mapping scale of 1:200,000 and 1:100,000, using SLAR image, but we now research on producting a scale of 1:50,000 ortho-image map and map revision,

using the Goodyear Radar System of 3-meter.
The SLAR determinates the distance(r) and its change rate($\dot{r}$) between antenna and target by measuring the delay time and the Doppler shift. The SLAR image, therefore, is a dynamical one. It's geometric characteristics is not so good as air-photo. The geometric deformations of a SLAR image are generated by various of errors of radar system and environmental, such as topographic relief, earth curvature and atmospheric refraction. In order to remove the effect of geometric deformation, we choice a test region to research how to produce a scale of 1:50,000 ortho-image map and map revision.

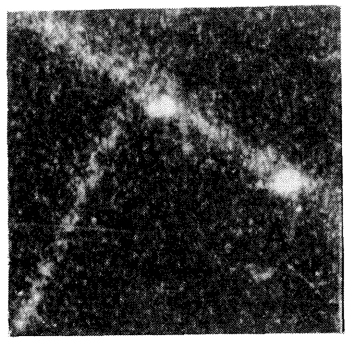
Experiment and analysis of the reflector

A man-made reflector is not only to be used determinating the performance and resolution of radar system, but also a signal of ground control point(GCP) of SLAR image. It is the same act with ground signal of air-photo. The reflector, however, is made up of metal plate.
If a reflector is used for ground control point, it's size must satify the requirement of mapping, at a time low cost, make easily, carry conveniently and mount simply. The reflector dimension is calculated with the relationship between image dot size and the maximum radar cross-section(ref. 1). A tri-hedral reflector is made of PS-plates that is out of use in the printing works, shown as fig. 1.
Experiment to separate in two groups: group A is a big reflector of edge length 65 cm and group B is a trinity of small reflector of edge length 35 cm, which is set in equal trilaterality in the range of 3X3 meter. An image of reflector is very clear-cut.
In order to analyse conveniently, the reflector image, first of all, is digitized in a densitometer PDS (P.E. Corp. of U.S.A.), a pixel size is 10 μm and then the density is transferred into intensity level and draw the response of central profile shown as fig. 2.
For group A, the response come only out single peak. Suppose the intensity below 80 level is the background, then the response width is of 260 μm at the intensity of 80 level. For group B , however, the response have obvious both peaks. Two white dots separated can be faintly seen in the enlarging image. The third response of reflector is not obvious. Because of the setting is not perfect, it overlay with the other one. This is a reason that left peak in fig. 2-b is higher obviously. Suppose now the small response is for single reflector, the response width is of 85 μm at the same intensity of 80 level. But our purpose is to test a whole response of a trinity. If fitting both peaks with dotline, the generalization width of 210 μm at the 80 level. It's effect

is better than group A.We can now come to the conclusion that small reflector group in the range of 3X3 meter can alternate a big one.



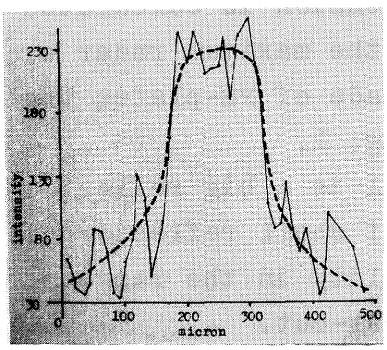
a) reflector



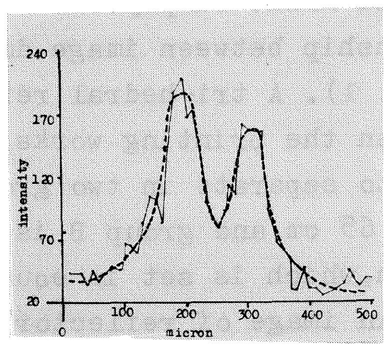
(enlarg. 18^x)

b) group A imaging
group B imaging

Figure 1



a) response of group A



b) response of group B

Figure 2

Geometric analysis of the SLAR imagery

A SLAR measures a slant-range along across-track direction and arranges a row image. The sequence row image are combined as two dimension radar image.This is not an ortho-image map of the ground,but a distant projection image.The geometric deformation of a SLAR image will be come out because a variety of error influences of aircraft and flying behavious and the operating errors of the radar system will be compensated.The environmental influences are now described as follows.The environmental consist of the terrain relief,the earth curvature and the atmospheric refraction.

(1) Radar imaging of the terrain relief

Suppose, first of all, the terrain surface is a flat one. Owing to distant projection, the scale of the slant-range image is not uniform, the farther off an antenna a target, the bigger a scale of image, and the nearer an antenna, the smaller a scale. This is called as the scale compression. The larger the depression angle, the more serious of compression. So the image quality of near nadar line is quite poor. If transforming the slant-range image to distant image, the scale error of an image near nadar line is the bigger, for instance, the distant image near antenna have remained a residual scale errors ± 1.5 percent. If the geometric deformation is forgotten transforming a range image into a distant image, the operation is very simple transforming the distant image into the ortho-image map and correcting the azimuth and uniforming the scale.

The terrain relief, however, is quite general case, and the displacement of the image point is always come into existence. Suppose a hill called as ABC shown as fig. 3. There are the foreslop surface AB and the foreslop angle α, the backslop surface BC and the backslop angle β as well as an elevation h above the mean sea surface. The ground point B of fig. 3-a, the first imaging at B_s and B_h with the same range will be imaged at the same point B_s. But the ortho-point B_o of a ground point B will go to the B_{os}.

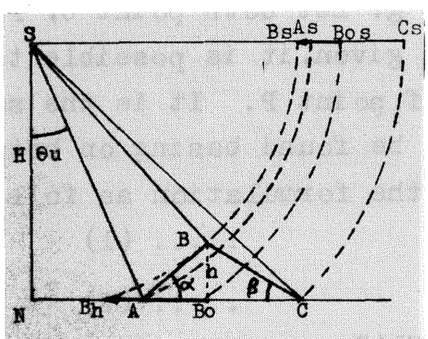


Figure 3-a

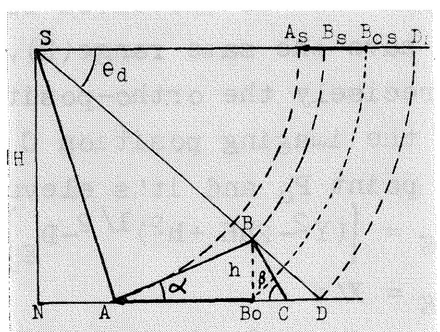


Figure 3-b

Figure 3

We can now say from figure 3 :

1) The topographic displacement direction points at the antenna or the nadar line, this is opposite to the aero-photo.

2) If $\alpha > \theta_u$, the imaging of the slop surface AB and BC will generate the layover each other.

3) If $\beta > \theta_d$, the radar beam does not illuminate the backslop surface. So the shadow B_sD_s is generated for the backslop surface BC and the flat surface CD. If $\beta = \theta_d$, the radar beam just grazes the backslop surface BC and if $\beta < \theta_d$, the backslop surface BC is fully illuminated with the radar beam and non-shadow to happen shown as fig. 3-b.

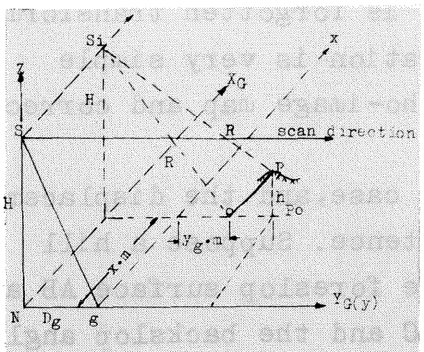


Figure 4 Radar imaging principle

Figure 4

Generally speaking, the SLAR produces displacement as a function of the terrain relief and topographic displacement and shadow come only out in the side looking plane. Except the nadar line in which nothing to happen for topographic displacement and the shadow, the other position always have the displacement and the higher the elevation h, the larger the displacement. The imaging geometry of a SLAR from above is more complicated. To perform fine geometric rectification, it is in need a digital terrain model(DTM). Fig. 4 is an imaging principle of the SLAR.

Let $D_g = N_g$, it is called as the delay distance in which nothing is imaged. A row on the film is initiated from point g. Let both point C, P and the arc CP have the same range(R), if h is given, it is possible to work out precisely the ortho-position P_o of point P. It is the same thing that the imaging position C can also be found basing on both the ortho-grid point P_o and it's elevation h, the formulation as follows

$$y_g = \left[(Y^2 - 2hH + h^2)^{1/2} - D_g\right]/m \qquad \ldots\ldots (1)$$

$$x_g = X/m \qquad \ldots\ldots (2)$$

where m ------ scale denominator of the SLAR imagery

X, Y ------- the coordinates of the ortho-grid point

(2) The earth curvature influence

Because of the radar scanning and having big coverage, it is neccessary to consider the earth curvature influence of each scan line. There are two kind of different methods:

(a) For ortho-projector Z_s-1, shown as fig. 5-a, the difference between the elevation Z_p of the earth surface point P and the elevation h above the surface E is generated by the earth curvature.So the influence of the earth curvature can be brought in a DTM. The formulation as follows:

$$h=Z_p.\cos(\theta)-Z$$

$$=Z_p.\cos\left(\frac{Y}{2.R}\right)-Y.tg\left(\frac{Y}{2.R}\right) \quad \ldots\ldots (3)$$

(b) For digital differential rectification as fig. 5-b, if a range r is responded to a ground point P, it is possible to transform a P into P' after the slant-range plus the correction value ΔS_e, and then the ortho-projection transform can be performed,the formulation as follows:

$$\Delta S_e=\left[(H-Z_p)^2+T^2\right]^{1/2}-r \quad \ldots\ldots (4)$$

$$T^2=R^2.\frac{r^2-(H-Z_p)^2}{(R+Z_p).(R+H)} \quad \ldots\ldots (5)$$

where R..... the earth radius

(3) Atmospheric refraction influence

The path of the microwave transmission is bent for atmospheric refraction influence,which is the same thing with the other electromagnetic waves. The path radius is calculated following Laurila's formulation:

$$\frac{1}{r}=A-\frac{b\cdot s^2}{6}.\left(\frac{1}{R}+A\right) \quad \ldots\ldots (6)$$

$$A=a+b\cdot(H+Z_p)$$

where r .... the path radius, a ..... $-3.7X10^{-5}$,

b .... $1.4X10^{-6}$, s .... the slant-range,

R .... the earth radius.

Here we areonly in consideration of the influence for the difference refractive indexes as follows:

$$\Delta_n S=-\frac{s}{r}\cdot n \quad \ldots\ldots (7)$$

where Δn......the difference between actual refractive index.

Geometric rectification for SLAR imagery

There are two kind of ways to rectify the SLAR image.They have been programmed: the ortho-projector Z_s-1 method and computer digital differential rectification method. Through a Z_s-1 is specially designed for the ortho-rectification of aero-photo.But it can also rectify the radar image using the special programme modula which is mounted in microcomputer TP-86. The both rectifying schemes are based on the geometric principel of the radar imaging. However, it must be pointed out that the discrepancies between calculated image coordinates and measured image coordinates are still existed after correcting topograph relief, the earth curvature and the atmospheric refraction. It is thought that there are the other disturbing resources, such as the attitude and the imaging parameters errors and the optical correlator errors, ... They are considered as the systematic errors. So the discrepancies can be fitted with the bi-variete polynomial function and then the polynomial coefficiences are worked out with the least squares method. The fitting polynomial as follows:

$$x - x_g = \Delta x = a_0 + a_1 \cdot x_g + a_2 \cdot y_g + a_3 \cdot x_g y_g + a_4 \cdot x_g^2 + a_5 \cdot y_g^2$$

$$y - y_g = \Delta y = b_0 + b_1 \cdot x_g + b_2 \cdot y_g + b_3 \cdot x_g y_g + b_4 \cdot x_g^2 \qquad \ldots(8)$$

where the relationship between image point error y and Δy in the scan direction is considered as the linearity.

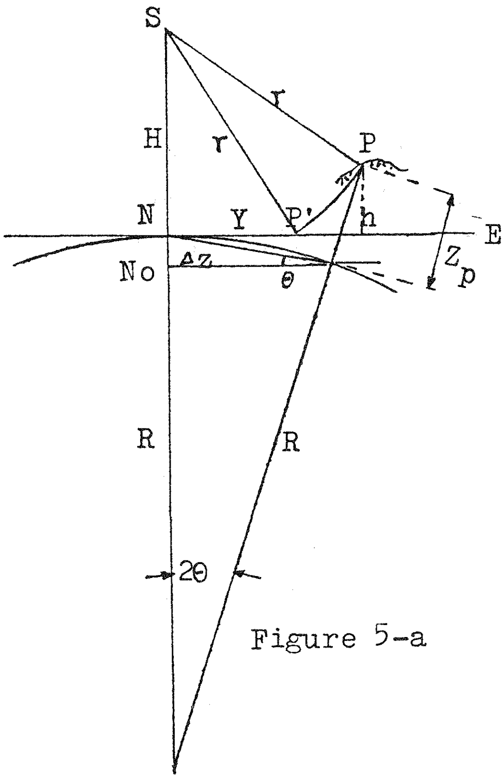


Figure 5-a

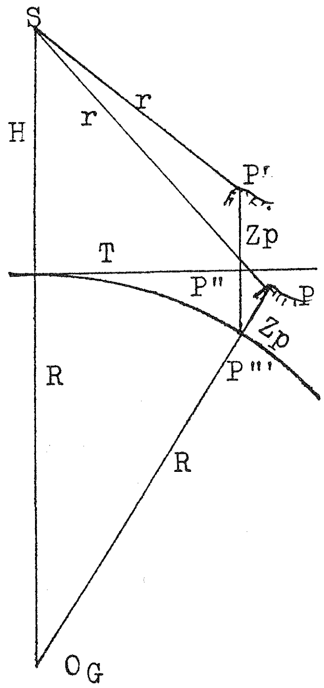


Figure 5 - b

(1) The ortho-projector Z_s-1 is also called as the digital control projector, including two parts: the data collector and the ortho-projector. Each part has a single board microcomputer TP-86 to perform a real time control and calculate. In beginning of the work, we must observe and calculate a radar image coordinates and then get the scan data and using it to control the principal part of the ortho-projector for scan and output ortho-image. The scan data is that the irregular grid coordinates of the radar image is worked out from correspondent the regular grid coordinates and set up in order of the scan data,

the calculation follows the formulation (1),(2) and (3),put the programming module into the microcomputer TP-86. Fig. 6 is a flow chart rectifing the radar image by Z_S-1. In practical production,it is the best to have 30 GCP's of even distribution and 2 orientation points for rectifing single strip image. If rectifing whole frame,the tie points can be selected in the overlay image. In such a case,the number of GCP's each strip can reduce to a half. A DTM is generated in large scale topographic map by human,a DTM's mesh size is coincide with the slit length of Z_S-1, the shifting direction of the slit in Z_S-1 should be the radar side-looking direction.

(2) The digital rectification is in fact a rectification point by point.The rectifing princinel is as above.But there are some characteristics in digital rectifing as follows: (a) First of all the digitization of the radar image. In order to keep the geometric precision of original image,digitizing space takes a 25 μm,correspond to ground about 2.5 meter.An image in PDS must orienlate with azimuthal line before digitization. (b) Calculating scales of both direction. (c) Mosaicing the adjacent canal image as a whole strip image. (d) Selecting and measuring about 30 GCP's and tie points on display scene of the Image System PC-2000 and measuring accuracy as 0.5 pixels,the GCP's coordinates are producted using aerotriangulation or from scale of 1:10,000 map. (e) Read out DTM grid elevation on the scale of 1:10,000 map,the mesh size is 100x100 meter and extensing of 20x20 meter. (f) The earth curvature and atmospheric refraction are corrected in the slant-range. (g) Using partition of rectifing and the corners of earth partition seriously calculated. The size of partiting is automatically calculated depending on the terrain relief. (h) Histogram matching both strip image and apply enhancment technique. Figur 7 is a flow chart of the digital rectification a SLAR image.

A rectified image map accuracy and the generatizied assessment of the effects of the office interpretation

The test region is located in the suburbs of a city,including terrain relief and flat,the imaging by Goodyear Radar System with a revolution 3-meter. The whole test region is covered by two strips and there are four canal strips image each strip. .The first strip is for the north frame taking in the Fall of 1985,Set.and the other is taken in the winter of 1986 Mar..Owing to the exitence scale of 1:50,000 map is made by 1971 Nov.,the features of the test region is changed so much. The scale of 1:50,000 ortho-image map is generated after the rectified SLAR image. The assessment of the geometric accuracy for the

ortho-image map of a SLAR is described with two ways as follows:
(a) The 32 points of obvious feature is evenly chosen in the ortho-image map generated by Z_s-1. The image map overlay seriously in a exitence topographic map basing on three GCP's and then the discrepancy between the ortho-image and the topographic map is measured. The root-mean-square, $m_x = \pm 13.5$ meter and $m_y = \pm 13.5$ meter, is calculated following as $m = \pm\sqrt{\frac{[vv]}{n-1}}$. Fig. 8 is a vector chart of discrepancy.
(b) For the digital rectification, the ortho-image map is stored in dice of a computer. The man-machine assessment system is formed with a Benson Digital Table, display system PC-2000 and the programmes. The topographic map is the first fixed on Benson table, the rectified image is display in a scene. The relationship between the rectified image and the map is established with some GCP's and then selecting any feature on a map and transforming it into the image, displaying with a lightmark. We can now find and measure the discrepancy between a rectified image and the map. The 41 obvious features is evenly selected from the scene. After a calculation the rms, $m_x = \pm 11.0$ meter, $m_y = \pm 12.8$ meter. Figure 9 is a vector chart of the discrepancy.

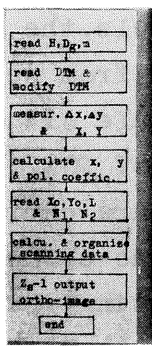


Fig. 6

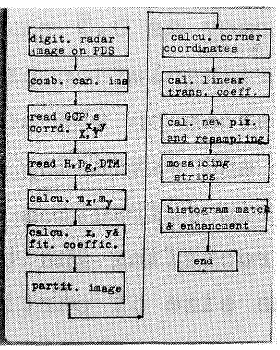


Fig. 7

Table 1

NAME	interpretation accuracy (%) in WS	interpretation accuracy(%) in FS
agro-town & village	92	90
rail road	97	96
pool & reservoir	90	90
major road	80	92
rural road	70	50
canal & bank	70	70
fruit & tree pattern		70-80
electric-wire	no-imaging	imaging

Figure 6 flow chart of Z_s-1 rect.
Figure 7 flow chart of digital
rectifing SLAR image

Table 1

The generatizied interpretation effect for a SLAR image is discribed as follows. The north of frame is scanned in Fall(FS), and the south of frame is scanned in Winter(WS). After rectifing and enhancing, the SLAR image is enlarged to scale of 1:35,000 for the interpretation. Two experienced operators are responsible for the office interpretation and the verification of the field work, and the statisticing the accuracy of the interpretation. The operator at first, must understand the principel of SLAR imaging and the image characteristics ,and then the office interpretation is performed and drawn in SLAR image combining exitence scale of 1:50,000 map.Finally,the verification and accuracy statistic of the interpreted feature are conducted in the field work of test region. Table 1 is a list of the accuracy statistic percent for major features of the office interpretation. The percent in table is a statistic value in range of 0.5 to 1.0 mm on map. The interpretation of the village,water body,bank and line features are successful as above table 1. in addition,the electric power wire can be seen in WS image and the fruit and tree pattern can be found in FS image.

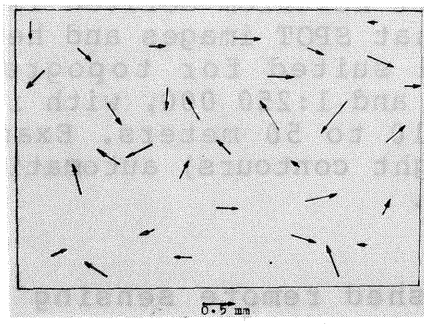


Figure 8 discrepant vertor of rectifing result image using Z_S-1

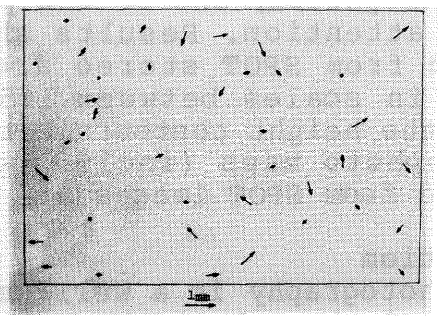


Figure 9 discrepant vertor of rectified image using digital rectification

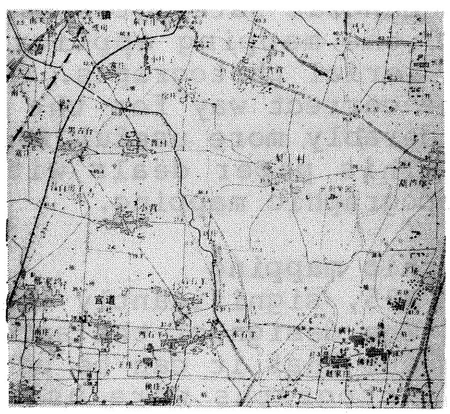


Fig.10 a oart of old map

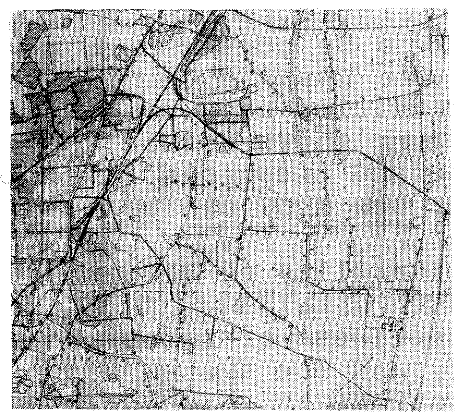


Fig.11 a part of revised map

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