Stereo Transfer Master——a new planimetric plotter for one-fourth enlarged photos of a stereopair

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ABSTRACT

The land use map of the status quo being a great need for the developing countries, such as China, is a planimetric map of the linear features and the outlines of the area features. The elevation figures are not needed in such maps. So long as the planimetric control points are enough, it is possible to transfer details from aerial photos to a map. Three basic approaches for transferring are reviewed. A new planimetric plotter has been developed in China. The one-fourth enlarged annotated photos of 23cm×23cm and 18cm×18cm can be directly used for continuous transferring on it. The characteristics of the instrument are discussed. The test and the transferring results are reported.

Introduction

For the developing countries, surveying and mapping of various thematic maps for construction and planning are the tasks which should be done in advance. Surveying and mapping of the land use map of the status quo is one of these tasks. In this important task, to transfer the linear features and the outlines of the area features(LFOAF) from the aerial photos to a map is an arduous task for the Land Administrative Department. However, this kind of map is actually a planimetric map of the LFOAF where the elevation figures are not needed. So long as the planimetric control points are enough, it is possible to transfer the LFOAF from the aerial photos to a map. Therefore, there is an urgent need of a transfer instrument which is cheap, practical and suitable for popularization in the Land Administrative Department at the county level of whole China. The new Stereo Transfer Master(STM) affords such possibilities.

Selection of transfer schemes

Transferring of the LFOAF from the aerial photos to a map is an old problem in Photogrammetry. Three basic approaches are possible for such a transferring:

(1) First approach

The principle of this approach is based on the rectification of a single photo according to the three dimentional ground data field(3-D GDF). Transferring of the rectified images of the LFOAF to a map by hand is called transferring. The orthophotos are actually made in the same principle. The orthophoto is almost the same as a part of a map in position but without the LFOAF and annotatations mapped by hand. Therefore, transferring is still needed for the orthophotos to be the land use map, and it can be

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done according to the images. Usually, the land use map should be extracted yet from the orthophoto transferred.

In the past decades, the single projector introduced by the Soviet Union in the late fifties was used mostly in China for transferring in zones according to the 3-D GDF such as at least six 3-D control points per photo on the manuscript and the contour lines on the aerial photos produced by a paper-print plotter --STD-2.

However, since the mid-seventies, the format of the aerial photos in China has been gradually changed from 18cm×18cm to the international format 23cm×23cm; the scale of the national base map has been changed from 1:50,000 to 1:10,000 and the scales of the aerial photos are equal to 1:30,000--1:36,000 accordingly. The annotated photos are usually enlarged 3--3.6 times for facilitating the field annotation, then the format of the enlarged photos will be of the size from 69cm×69cm to 83cm×83cm. In production, the photos of 23cm×23cm are usually divided into four parts in enlargement, the format of each part can reach the size of 49cm×49cm. Each part of the photos will be annotated and transferred seperately. However, the existing transfer instruments, such as the single projector and etc., are impossible or inconvenient to transfer such a big photo divided into four parts. In addition, it is necessary to have the 3-D GDF mentioned above, before the transferring can be started.

The orthophotos are possible for transferring, but it is still a problem of economy. It is difficult to imagine that the orthophotos can be popularized transferring in the developing countries, such as China in the near future.

In this approach, the land use map of the status quo should be extracted from the manuscript or from the orthophoto.

(2) Second approach

The principle of this approach is based on the radial-line method which needs only the 2-D control.

About four decades ago, two transfer instruments had been developed in Britain and USA. They were called the Radial Planimetric Plotter(RPP) and the Radial Line Plotter(RLP) respectively. They were almost the same. Ther were no market for these instruments in China so far. In addition, they are impossible to transfer the enlarged photos now. However, such instruments still have some outstanding advantages, such as the 3-D GDF, topograpgic maps, elevation figures and contour lines are not needed for transferring. On the other hand, the land use map of the status quo can be obtained directly in one operation.

(3) Third approach

The principle of this approach is based on the superimposition of a facet, if it is identifiable on the map and in the stereo model by an optical ZOOM and deformation system. Such an superimposition can solve perspective rectification of the facet on the photo and the affine rectification of the facet on the ground, then the transferring is followed facet by facet. However, the extraction of the LFOAF from the topographic map is needed. Such instruments have been developed in Italy and USA. They are called Stereo Facet Plotter(SFP) and Stereo ZOOM Transfer Scope(SZTS) respectively. However, the accuracy of the transfer depends on the accuracy of the superimposition of the facet, ie the amount of the outstanding points for the superimposition and roughness of the terrain. In addition, the enlarged photos are inconvenient or impossible for these instruments too, and the price is still much too high for popularization in the developing countries, such as China.

Therefore, the one-fourth enlarged photos are inconvenient or impossible to be processed directly by all existing transfer instruments so far.

The new STM belongs to the second approach. Transferring from the one-fourth enlarged annotated photos, format up to 49cmx49cm , the planimetric map of scale 1:10,000, can be done continuously and directly, without the requirement of the 3-D GDF, such as topograpgic maps, elevation figures and contour lines, for transferring in zones, slits, patches or facets.

The outstanding advantages of the STM are simple in structure , easy in operation, low in price, needless to have the 3-D GDF and to extract the LFOAF from the topograpgic map transferred.

<u>Principles of the STM</u>

The STM has been developed on the basis of the RPP. The principle of the STM is also based on the radial-line method./1/,/2/

As is known, the forward intersection has a dead area near the photo base. According to the analyses, if the relief is larger than ±5m, the method used in RPP for transferring of the dead area is not allowed /2/. The errors of intersecting points from the false photo-centers will exceed the tolerance due to the enlarged photos used. A graphic-analytical transfer method for the dead area(GATMDA) is introduced /3/. The 3-D GDF are also not necessary for the GATMDA. The accuracy of the GATMDA depends on the size of the dead area which are rather small in the STM, such as 22mm×B for the principle points to be the radial centers and 14mm×B for the nadir points to be the radial centers, where B is the model base, and is equal to the distance between the two sliding linkages on the ends of the parallel bar minus the distance between the two radial centers. Therefore, the GATMDA is specially suited for cooperating with the STM for transferring of the dead areas.

The corrections of the GATMDA can be calculated as follows;

$$\left.\begin{aligned} r_{R_i} &= r_{R_i} - \frac{r_{R_i}}{r_{L_i} \times \mathrm{Cos}\theta_{L_i} + r_{R_i} \times \mathrm{Cos}\theta_{R_i}} \cdot B \\ r_{L_i} &= r_{E_i} - \frac{r_{L_i}}{r_{L_i} \times \mathrm{Cos}\ _{L_i} + r_{R_i} \times \mathrm{Cos}\ _{R_i}} \cdot B \end{aligned}\right\} \qquad (1)$$

where r_{L_i}, r_{R_i} --- the distance between the ith pair of the homologues and the radial centers in the left and right photos respectively

θ_{L_i}, θ_{R_i} --- the angles between the two radials r_{L_i}, r_{R_i} and the photo base respectively

B--- model base

Δr_{L_i}, Δr_{R_i} --- the corrections of the radials r_{L_i}, r_{R_i} respectively and "+" stands for the correction towards the center,"-" stands for the correction away from the center.

After correction, the position of the ith pair of the homologues are determined twice. The mean position is taken as the most probable position. However, if the discrepancy of the two homologues is less than the tolerance, one of these two positions which is nearer to the radial center can be taken as the final intersecting point, ie only one correction is enough.

Composition of the STM and its features

The STM is composed of the same four parts as in the RPP: the base plate; the parallel-motion linkages(double parallelogram) (PML or DP); the parallel bar(PB) and the drawing head(DH); the photo-tables(PT) and their supporting plates; the optical stereo observation system(OSOS). Moreover, the STM has been brought forward some new ideas and improvements in the format of the photo-tables; the way of intersection; the structure of the radial arm;the four movable pillars for supporting the horizontal moving parts; the OSOS; the GATMDA and etc. The main structures and the features will be explained in the following sections.

(1) Photo-tables for one-fourth enlarged annotated photos

Each photo-table of such a big format should be cut off by three-fourths of it. The design of the photo-tables is shown in Fig.1.

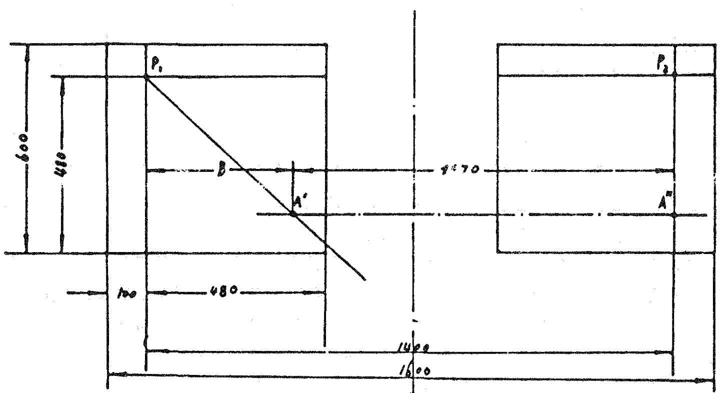


Fig.1 The photo-tables of one-fourth enlarged photos

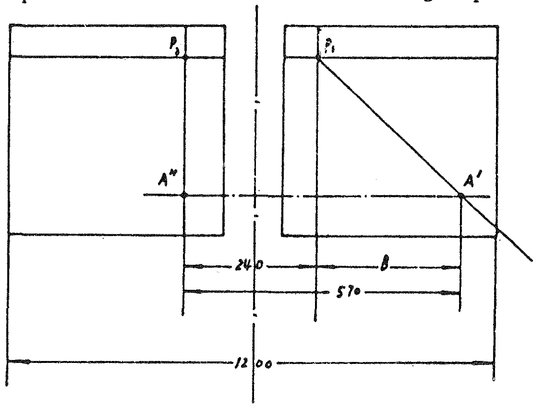


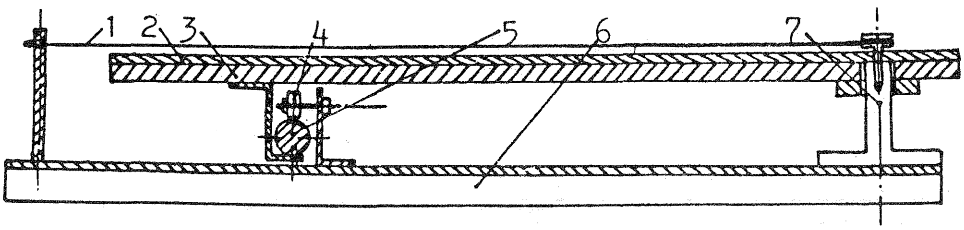
Fig.2 A special parallelogram with base outside and the two photo-tables interchanged

(2) Way of intersection

The width of the two radial centers will be at least equal to two times of the radial arm plus two halves of the photos,ie 2360 mm. A special parallelogram with base outside and photo-tables interchanged are adopted for intersection. Therefore, the dimension of the STM is reduced from 2360 to 1200mm as shown in Fig.2.

(3) Structure of the radial arm(RA)

The structure for supporting the cantilever radial arm (CRA) and the weight of the CRA itself are two thorny problems in the STM. The bending moment of the CRA at its pivot is proportional to its length and weight. In order to simplify the structure of the pivot of the CRA, a hooked ball bearing is mounted on the CRA near its gravity center. The ball bearing runs on a hanged cylindrical bearing rod under the supporting plate of the photo-table as shown in Fig.3.



1-radial index line
2-photo-table
3-supporting plate of the photo-table
4-hooked ball bearing
5-hanged cylindric bearing rod
6-radial arm
7-pivot of the radial center

Fig.3 The structure of the RA

The bearing rod supports the most weight of the CRA. Thus, bending moment of the CRA is eliminated. An optimum gravity equilibrium of the RA is reached. Therefore, the silk thread or any other thread with the brightest colors which you feel best can be used as the radial index line (RIL),because it does not suffer the pulling force any more now. To pull it to be a straight line is enough. Therfore, the intersecting point of the RIL observed under the stereoscopic vision is quite clear and confortable. Hence the accuracy of observation and the operational efficiency can be raised obviously. In addition, a light metal is adopted for reducing the weight of the RA itself. When the parallel bar moves near the pivots, the operational force will increase, if the direction of movement is perpendicular to one of the RA.

(4) Four movable pillars supporting the PML or DP, PB and DH

The four movable pillars are well distributed under the PML, PB and DH. The height of each movable pillars can be adjusted in order to make the loci of the PML, PB and the DH to be in their own horizontal planes respectively, and to avoid the twisting of these thin and long arms which will influence the parallelism of the PB during operation.

(5) Optical Stereo Observation System(OSOS)

There are some shortcomings in the RPP and the RLP, such as the long sight line of observation causing fatigue in observation and inconvenience in adjusting the optical parts of the RPP a n d the RLP. A new OSOS has been designed for the STM. A microscopic system with the enlargement of one time is adopted . The field of view of the OSOS can have four movements: x, y, p_x, p_y relative t o the two photo-tables. Any pair of the homologues in the photos of the stereo pair can be moved to the centers of the fields of view of the OSOS by the four movements combined. The sight line of the OSOS can be deflected from the optical axis at the focal plane of the objective up to 4.7 degrees in x-direction. Thus the optimum stereo observation condition can be reached and the uneven model deformation can be eliminated during interpretation /4/. Therefore , the clear, comfortable, convenient and optimum stereo vision can be realized. The schematic drawing of the OSOS is shown in Fig.4.

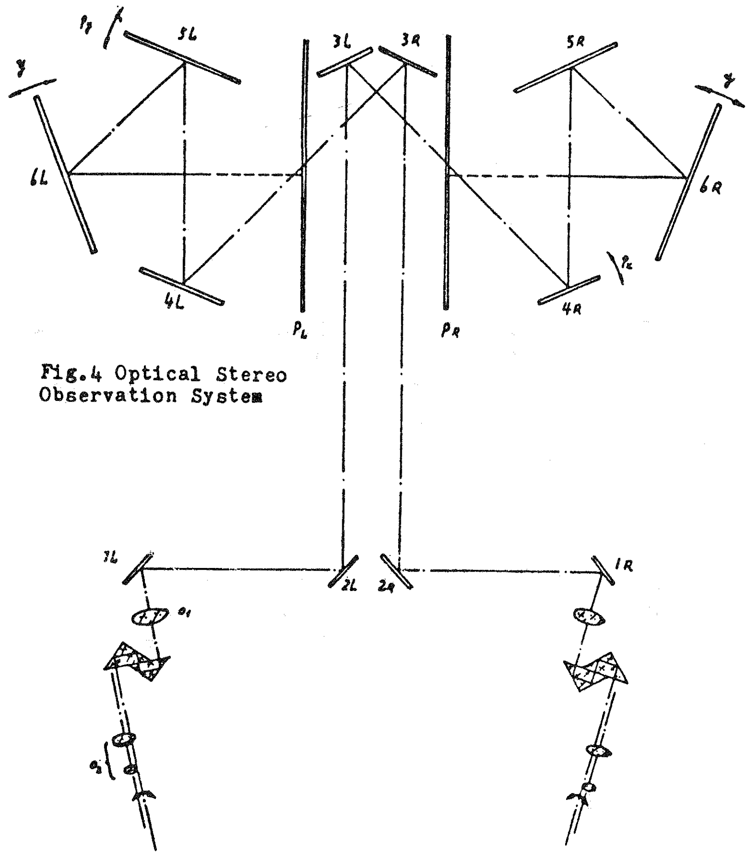


Fig.4 Optical Stereo Observation System

The following features of the OSOS may be mentioned:

--the two optical trains are interchanged for satisfying the base outside and the two photos interchanged in order to obtain the correct view

--the enlargement of the OSOS is equal to $1^{\times}$, the enlargement of the photos is equal to $3 - 3.6^{\times}$. Therefore, the total enlargement of the OSOS relative to the original photos is equal to $3 - 3.6^{\times}$

--the diameter of the field of view is equal to 150mm, the ranges of the four movements: x, y, p_x, p_y are: ± 240mm, ± 240mm, ± 112mm and ± 40mm respectively

--the whole OSOS is mounted on a carriage which can be moved along the x-direction, ie the fields of view can be moved in the x-direction relative to the photo-tables

--the other three movements y, p_x, p_y are realized by the deflection of the mirrors in the $OS^x OS^y$ respectively. Thus the precision guides for linear movements are saved

--an eccentric eyepiece tube(EET) is designed for the optimum stereo vision condition. The sight line is deflected from the optical axis at the focal plane of the objective up to 4.7 degrees . Each of the EET can be rotated round its optical axis of the objective

--all the four movements:x,y,p_x,p_y can be controlled by the left hand. It is necessary for the field of view to follow the intersecting point , while the intersecting point is controlled by the right hand in operation.

(6) Considerations of human engineering in designing

The sight line of the OSOS is equal to 20 degrees of depression angle which is approximately the optimum angle, because it makes one in a more natural relaxing state with less fatigue in operation.

A tracking ball is attached by the drawing head for tracking of the intersecting point by the free hand control with the right hand. It makes the tracking more natural and smooth.On the other hand, the intersecting point can be tracked by the fields of view of the OSOS with the left hand so that the intersecting can always be in the centers of the fields of view by the four movements:x,y,p_x,p_y combined. Usually, p_y should be removed at all times and p_x can be removed when it is larger than a certain amount, eg 5mm.

The direction of the free hand movement of the right hand should be coincident with the direction of the visual movement of the intersecting point image in the OSOS. Therefore, the OSOS should be designed such that the image in the OSOS should be upright.

(7) Transferring of the dead area

When the relief of the terrain exceeds the tolerance, ie ±5m, , then the GATMDA should be used for transferring/3/. Provisions for displacing a fixed distance in the y-direction on both sides of the photo-tables have been made for transferring of the dead area in the area of smooth terrain only in this STM.

Preparation of the enlarged photos

The STM is designed mainly for transferring of the one-fourth enlarged photos of format 23cm×23cm. In order to transfer the other format photos, eg 18cm×18cm, the enlargement coefficient (EC) of the photos has to be considered such that the overlapping area of the photos with different format should be in the same range as that of the photo of format 23cm×23cm is. The EC can be calculated as follows:

$$\beta_v = \frac{168}{b+\Delta p_{min}} \qquad (2)$$

where β_v--the EC calculated according to the structural parameters of the OSOS.

If $\beta_v < \frac{m}{M}$, then $\beta = \frac{m}{M}$ ——————————————— (3)

If $\beta_v > \frac{m}{M}$, then $\beta = \beta_v$ ——————————————— (4)

where β—actual EC

b—photo base of the original photo

m—denominator of the photo scale

M—denominator of the manuscript

Δp_{min}—p_x differences of two points situated in the lowest and the average height on the ground . This is always a negative value.

Testing results

In order to test the accuracy of the transferred maps and the stability of the STM, this STM has been tested by the Testing Center of the Soil Investigation, Hubei Province, China in a period of about one year. The results obtained are reported as follows:

(1) A Grid Test of 25 points

After the Grid orientation and scale adjusting, the RMSE of the Grid with 25 points transferred is obtained:

m = 0.44mm

where the errors of the Grid itself are included.

(2) Test of the LFOAF transferred from the one-fourth enlarged annotated photos with the original photo format 23cm×23cm

After the orientation of the photo base and the scale adjusting, the following RMSEs of the LFOAF transferred are obtained:

No. of stereo pairs	Max. relative height differences Δh_{max} (m)	No. of check points	RMSE (mm) ±	Remarks
1	400	50	0.94	The errors of the maps obtained by the Surveying and Mapping Department on the Precision Stereoplotter are included
2	100	30	0.75	
3	200	30	0.66	

It is obvious that the results have satisfied the Technical Regulations of such a special task.

Conclusion

This paper attempts to explain the practical significance of designing such an instrument and its features.

The testing results have shown that the accuracy of the LFOAF transferred has satisfied the designing requirements.

The STM can solve the transferring tasks of the one-fourth enlarged photos directly which is inconvenient or impossible to be solved in all existing transfer instruments directly so far. In addition, the STM has many advantages, such as simple structures, low cost, easy, comfortable and high efficient operation, needlessness of the 3-D GDF and the extraction of the LFOAF from the topographic map transferred. Only four planimetric control points per half stereo-model are needed for transferring. These planimetric control points can be extended by the Radial Triangulation. Therefore, the expensive photogrammetric instruments for extension of 3-D control are not necessary.

The STM is especially suited for the third world countries, such as China to fulfil the transfer tasks of the land use map of the status quo at the county level in whole China.

The STM can be used not only for transferring, but also for planimetric plotting, revision and stereo interpretation. Therefore, besides the STM can be used in the Land Administrative Department, it is also suited for other economic departments, such as Agriculture and reclaim, forestry, animal husbandry, geology, minerals, petroleum, city and rural area planning, highway, tourism and etc. to utilize extensively.

REFERENCES

/1/ Badjata, R.C.: Analytical Triangulation Using Variation of Coordinates. Photogrammetric Record, 1981, October

/2/ Hu Ruiming: Errors of Radial-line forward intersection and that of from photo centers for Stereo Transfer Master. Not yet published

/3/ Hu Ruiming: Graphical-Analytical transfer method for dead areas of Stereo Transfer Master. Not yet published

/4/ Manual of Photogrammetry. 1980, fourth Edition, ASP