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A Lightweight Stereocamera And Its Application In Seismoiogy And Geology

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Abstract: This instrument is designed for measuring the strike and inclination of fault in seismology and geology. Because of lower accuracy requirement of measurement, the stereocamera can be made simply and lightly and with the non-metric camera. This paper not only describes the model for selecting camera, determining of photogrammetric base-line, setting of focus and the feature of construction design of the lightweight stereocamera, but also emphatically discusses the installation, the adjustment and the calibration of stereocamera and the data processing related to the determinaion of photogrammetric coordinate and computation of strike and inclination etc. Finally, the way for simplifying the data processing, which the corrected image coordinates are obtained using the nomogran, is presented in order to spread the stereocamera system use in non-photogrammetric departments.

1. Introduction

China is a mult-earthquake country. The earthquake hazard must be measured rapidly after a great earthquake in order to supply a basement data for the assessment of intensity. The strike and inclination of the building crack and the surface fault are one of the necessary contents in the seismic measurement. Because some cracks or faults appear in high or dangerous place which is difficult to close, the investigators in the past only took a single picture for reference in analysis and can't get the necessary data.

The stereophotogrammetry is a mon-contact surveying and is suitible for measuring the objects which are difficultly accessed to. We had recorded the earthquake hazards with the phototheodolite in some past earthquakes. However this instrument lacks the accessories needed by seismic measurement and is difficult to spread because of the complex operation and data processing. In addition to this, it is expensive and clumpy so that the bus must be provided in the field measurement, which is not quite convenient in the case of the traffic block in the earthquake area. These disadvantages had greatly restricted the applicalion of photogrammery to the seismology and geology.

Therefore developping a lightweight stereocamera and a method of data processing is very significant for the application and expansion of photogrammotry in seismology and geology.

2. Consideration of Accuracy

As contrasted with the metric camera, the non-metric camera contains the great lens distortion and unstable inner orientation and is lack of the flattening device and fiducial marks. Some of these disadvantages can be overcome. For example, the fiducial marks can be cut artificially in each side of frame. Other disadvantages make the non-metric camera only has lower accuracy comparing with the metric camera.

However it is well known that the accuracy requirement of the seismic and geological measurement is quite low, where the determination of strike and inclination are measured only in the accuracy of(1°-2°). For example, the measuring error $\delta\alpha$ of inclination α of the fault AB is assumed to be 1° (See Fig. 1), then

$$\frac{\Delta S}{S} \approx \frac{\delta\alpha}{\rho} \approx \frac{1}{57.3}$$

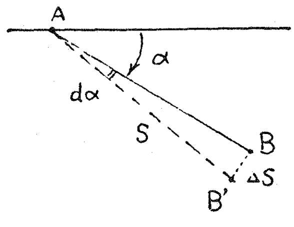

Fig.1

where S is the length of fault, ΔS is measuring error of length from point B to A. The equation indicates that the tolerance of scale error is considerable and the relative accuracy of the photogrammetric base-line is very low, only requiring about 1/60. In addition, the requirement of measuring and setting the exterior orientation of stereocamera is greatly lowered because of the considerable tolerance of inclination measurement. For example, the accuracy of levelling the stereocamera in photography can be tolerated up to degree. These low requirements give the favourable chance for designing the simple and lightweigh stereocamera.

3. The Characters of Lightweight Stereocamera

In view of the main application of Stereocamera for field observation and measurement in seismology and geology, the following requirements should be satisfied:

* Lightweightness of instrument and simplicity of operation and data possessing;
* Basically fixed exterior and relative orientation of stereocamera;
* Capability of measurement of magnetic orientation;
* Capability of photographing the most objects distroyed in earthquake;
* Capability of determination of objects set in high place.

Considering above requirements, the design of stereocamera should be characterized as follows:

(1) Selection of camera Model

The Hai-Ou camera 120 made in China is selected because the frame size is bigger and the focus distance is longer than the camera 135. Camera 120 have two models of double and simgle lens. The Hai Ou 203 simple lens camera can be easily fixed in the base platform without many refiting and its measured orientation not influenced by the interchange of film roll after camera is fixed. In addition, it is lighter and cheeper than the double lens camera.

(2) Selection of Base Length

In view of the most photogrammtric distance (10~20m), the fixed base length is used as B=1.4m. such as, from the point of the effect of stereophotogrammetry, the good auuracy can be obtained in the area of coverage from 5.6^m (4B) to 21^m (15 B). The objects far from 30^m (about 20 B) can be photographed when the accuracy requirement is not high.

(3) Determination of Setting Focus of Camera

Based on the parameters of 203 camera : $f=75^{mm}$, relative aperture=1:3.5, the hyperfocal distance H can be computed from following equation:

$$H = \frac{f^2}{\varepsilon K}$$

where ε=diameter of the blurry circle. Letting $\varepsilon=0.1^{mm}$, we can get $H=16^m$ if f=75 and k=3.5.

when the focus is setted on the focusing distance 10^m, we obtain:

the front scenc distance $D_1 = \frac{H.D}{H+D} \approx 6^m$

the rear scene distamce $D_2 = \frac{H \cdot D}{H-D} \approx 26^m$

This depth of field is very suitable for our most photogrammetric objects.

(4) Selecting The Way of Stereophotography

Considering that most objects are located uphill, + 25° equal obligue photography is designed besides the normal case.

The efficient picture size of 203 camera is $5^{cm} \times 5^{cm}$. When $f=75^{mm}$, the angle of image field can be calculated

$$I = 2 \times \text{arctg}\,\frac{2.5}{7.5} = 36.6^{\circ}$$

When +25° oblique photography is used, the ascending vertical angle of the photography is 43°.3 (see Fig.2). In this way, the elevation of objects which can be photographed is the same as the distance of camera-to-subject.

(5). Characters of Constructive Design of Stereocamera

* The standard products— the existing tripod and theodolite mount are used;
* The pin seal is generally applied in order to guarantee the connecting precision and to make load or unload conveniently;
* The mount of whole central support is constructed as a single unit. This is helpful for strengthening the firmness. In addition, both of arms are lengthened as far as possible in order to strengthen the connection of support mount with base arm;
* The instrument is levelled using the independent level and a trough is cut only in the tube(wrap arc 25°) in the design of +25°.oblique angle in order to simplify the stereocamera as far as possible.

The appearance of stereocamera is shown in Fig.3. The weight of one set of instrument (including the tripod) amounts about 7 kg..

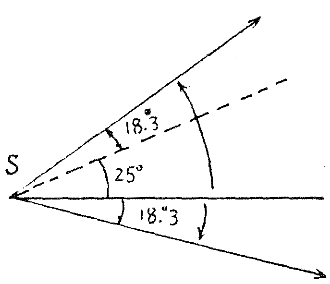

Fig. 2

4. Calibration of Stereocamera

The purpose of camera calibration is determining the interior and relative orientation of camera. The calibration is completed by the indoor three-dimensional control field and the program of space resection of a single photograph for camera calibration in the photogrammetric department of Wuhan Technical University of Surveying And Mapping. All of the image coordinates are measured in Stecometer. The outputs of program consist of the interior and exterior orientation parameters: the principal distance f; the coordinates of principal point x_o, z_o; the parameters of lens distortion k_1, k_2; the parameters of affine transformation $ds, d\beta$; the coordinates of perspective center X_s, Y_s, Z_s and the elements of angular orientation φ, ω, κ. The photography and computation are made in three periods: 1986.11, 1987.3 and 5. One of the calibrated images is shown as Fig.4.

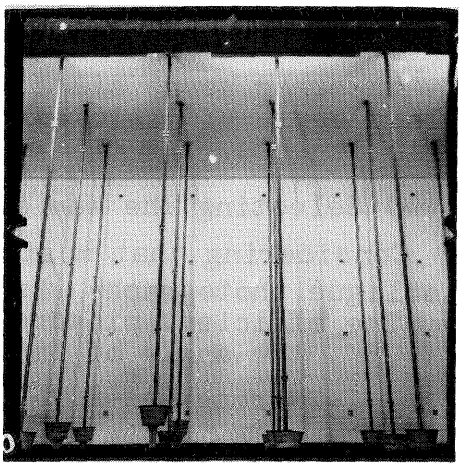

Fig.4

Because the stereocamera is arbitrarily setted in control field, in order to determine the stereophotogrammetric coordinate system based on stereocamera, the components of base-line are calculated by the coordinate differences of two perspective centers computed by each pair of pictures:

$B_x = X_{sr} - X_{sl}$, $B_y = Y_{sr} - Y_{sl}$, $B_z = Z_{sr} - Z_{sl}$,

and the direction angle of basd-line in photography is determined by following equation:

$$A = \tan^{-1}\frac{B_y}{B_x} \qquad (1)$$

Subtracting angle A from angle φ which is determined from calibration of each camera, the stereophotogrammetric coordinate system, which use the perspective center of left station as origin and the B_x direction as axis X, is formed (refer to Fig.5).

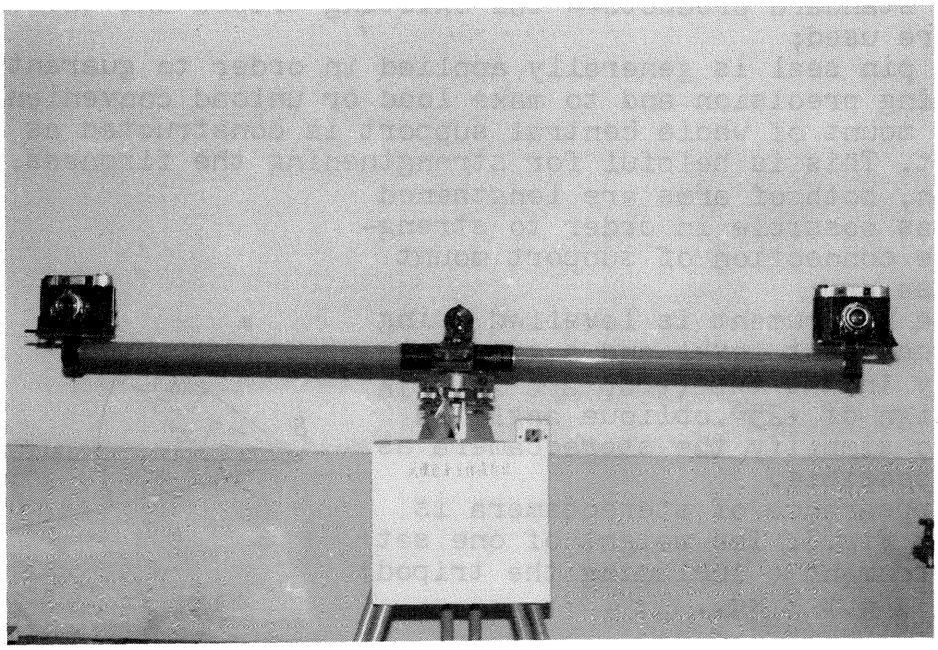

Fig. 3

The average camera parameters of the normal case and equal oblique photography, which are calculated from the data in different calibration period, are shown in table 1, where φ is the angle after subtracting the angle A.

Table 1

parameters	normal case		equal oblique photograph.	
	left cam.	right cam.	left cam.	right cam.
f(mm)	80.66	80.84	80.58	80.74
x_o(mm)	-0.69	-0.67	-0.62	-0.59
z_o(mm)	0.36	0.38	0.43	0.31
k_1	-2.54×10^{-6}	-3.16×10^{-6}	-1.97×10^{-6}	-2.84×10^{-6}
k_2	5.97×10^{-9}	5.03×10^{-9}	6.13×10^{-9}	5.05×10^{-9}
ds	5.69×10^{-4}	-1.10×10^{-3}	-5.45×10^{-4}	-1.06×10^{-4}
$d\beta$	57!3	36.'2	63.'4	45.'5
φ	45.'3	11.'5	37.'6	18.'6
ω	-5.'6	16.'4	19°13.'5	20°34.'6
κ	22.'2	8.'1	21.'8	5.'6
B(mm)	1402.63		1401.92	

5. Determination of Strike And Inclination

(1) Field Photography And Survey

It would best if the base-line of photography is setted parallel to the rock face or fault which was surveyed. The stereocamera is leveled. The equal oblique angle is setted for the upper objects. The magnetic orientation is read after photography.

(2).Calculation of Photogrammetric Coordinates

A) Cumputation of orientation matrix of camera. The photogrammetric coordinate system of the lightweight stereocamera is shown in Fig.5. The rotation matrix of left and right camera can be computed from the average orientation elements which are determined from the above section as follows:

$$R=\begin{bmatrix} a_1 & a_2 & a_3 \\ b_1 & b_2 & b_3 \\ c_1 & c_2 & c_3 \end{bmatrix} = \begin{bmatrix} \cos\varphi\cos\kappa-\sin\varphi\sin\omega\sin\kappa & \sin\varphi\cos\omega & -\cos\varphi\sin\kappa-\sin\varphi\sin\omega\cos\kappa \\ -\sin\varphi\cos\kappa-\cos\varphi\sin\omega\sin\kappa & \cos\varphi\cos\omega & \sin\varphi\sin\kappa-\cos\varphi\sin\omega\cos\kappa \\ \cos\omega\sin\kappa & \sin\omega & \cos\omega\cos\kappa \end{bmatrix} \quad (2)$$

B). Correction of image coordinate. It consists of correcting following terms: x_o, z_o, ds, $d\beta$, k_1 and k_2, which are obtained from the camera calibration:

$$\Delta x'=-\frac{x'^2}{f^2}x_o+k_1(x'-x_o)r^2+k_2(x'-x_o)(r^4-r_0^4)+(z'-z_o)(1+ds)\sin d\beta$$

$$\Delta z'=z_o-\frac{x'z'}{f^2}x_o+k_1(z'-z_o)r^2+k_2(z'-z_o)(r^4-r_0^4)+(z'-z_o)[(1+ds)\cos d\beta-1] \quad (3)$$

where $r^2=(x'-x_o)^2+(z'-z_o)^2$

therefore we can get

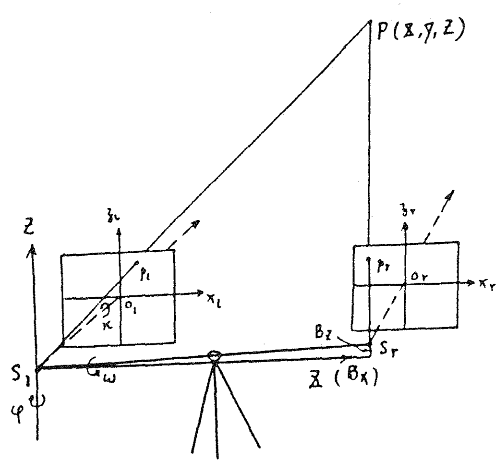

Fig. 5

$$x=x'+\Delta x' \qquad z=z'+\Delta z' \tag{4}$$

where x', z'=measured image coordinates.

C) Calculation of photogrammetric coordinates. First, the corrected image coordinates are transformed into the coordinates of parallel photographic case:

$$\begin{bmatrix} x_{nl} \\ f_{nl} \\ z_{nl} \end{bmatrix} = R_L \begin{bmatrix} x_l \\ f_l \\ z_l \end{bmatrix} \qquad \begin{bmatrix} x_{nr} \\ f_{nr} \\ z_{nr} \end{bmatrix} = R_r \begin{bmatrix} x_r \\ f_r \\ z_r \end{bmatrix} \tag{5}$$

where"L"and"r"present the left and right photograph individually.

Then the photogrammetric coordinates of the desired points are:

$$Y=Bf_{nL}f_{nr}/(f_{nr}x_{nL}-f_{nL}x_{nr})$$

$$X=Y\frac{x_{nL}}{f_{nL}} \qquad Z=Y\frac{z_{nL}}{f_{nL}} \tag{6}$$

(3) Computation of Geological Elements—strike And Inclination

A) Determination of Plane Equation of Rock Layer. The plane equation of rock layer is determined in order to determine the strike and inclination. The plane equation in three dimensienal space is defind as follows:

$$aX+bZ+cY=w \tag{7}$$

At least three known points are needed for finding the coefficients. The least squares adjustment is used for more points. Then the above equalion can be rewritten

$$Y=c_1+a_1X+b_1Z$$

For the arbitrary point i, the remainder is

$$r_i=Y_i-C_1-a_1X_i-b_1Z_i$$

where $i=1,2\cdots n$. A set of normal equations are formed with the least squares adjustment, which can be written by matrix symbol:

$$A\cdot V=B \tag{8}$$

where $A=X^TZ$, $B=X^TY$,

$$X=\begin{bmatrix} 1 & X_1 & Z_1 \\ 1 & X_2 & Z_2 \\ \vdots & \vdots & \vdots \\ 1 & Z_n & Z_n \end{bmatrix} \quad Y=\begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} \quad V=\begin{bmatrix} a_1 \\ c_1 \\ \\ b_1 \end{bmatrix}$$

Thus the unknown vector V can be detemined.

B) Computation of strike and inclination.

$$\text{strike } \alpha=90^\circ+\tan^{-1}(a_1)+Ao$$

$$\text{inclination } \beta=-\tan^{-1}\frac{(a_1^2+1)^{1/2}}{b_1} \tag{9}$$

where A_0 is the measured magnetic orientation of photographic direclion (refer to Fig.6).

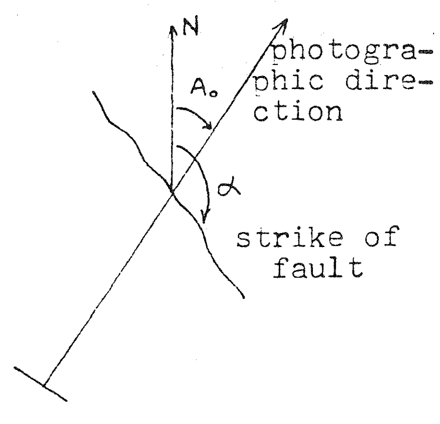

Fig. 6

6. Test Result

The scientific research building in Institude of Seismology is used as the test field (Fig. 7). First, the building is photographed using the phototheodolite. At the same time, the coordinates of 12 control points (are marked) are mrasured by the theodolite forward intersection and the magnetic orientation is surveyed.The influences caused by the change of orientation elements of camera in photography are corrected in terms of the controls and thus some known points in several planes of building are densified.All of the points are measured with stecometer.Then the strike and inclination are computed by the method of above section and used as the knowns data in order to check the accuracy of the lightweight stereocamera.

The test field is photographed using the stereocamera from the different directions and distances and the magnetic orientation are measured.The homologous points measured by metric camera are identified in the films of lightweight stereocamera.All of the films are measured in the comparator 1818.Then the photogrammetric coordinates,the plane equations and the strike and inclination of each plane are calculated in the same way.Comparing the calculated results with the results determined by metric camera,the following table is obtained:

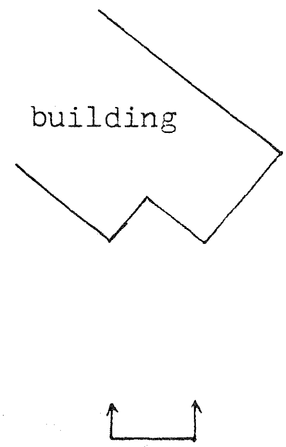

Fig.7

table 2 shows that the accuracy of strike and inclination determined by the lightweight stereocamera can reach the level of $\pm 1^{\circ}$ in the case of photogrammetric distance 25^{m},where the strike error is bigger because of the bigger reading error of the the compass.This accuracy still can satisfy the requirement of the seismological and geoloical survey.The measurement error of coordinate reach $\pm 1^{cm}$ in the case of photogrammetric distamce 10^{m}.Therefore the iustrument can be used to determine the width of fault or to record the traffic accident or the scene of a crime also.

table 2

mean photo. distance(m)	RMSE of point m_s(mm)	relative accuracy	strike error m_α	Inclination error m_β
10	11.3	1/900	1°02'	38'
20	32,4	1/620	1°23'	46'
25	43.5	1/570	1°25'	1°08'

7. Simplicity of Data Processing

The correction coefficients of equation 2-5 are constant for a certain camera while we use above computation method and can store in computer in advance.All of the operations can be completed by the fixed program in the computer PC-1500.These operations are not complex for photogrammetrists,but it can be trouble for some field geologists.In order to simplify the computation,the correction nomogram can be plotted in stead of computation of equation 2-5.

The Δx,Δz and Δf correction nomogram of left and right camera in the normal case and equal oblique photography can be plotted individually for a calibrated lightweight stereocamera. Figure 8 presents the Δx correction nomogram which is computed and plotted using the calibration parameters of left camera in normal case.Based on the measured image coordinate x',the correction Δx can be read directly in nomogram. The reading accuracy can be attained to 0.01^{mm}.

The image coordinates of points can be calculated from corrections $\Delta x, \Delta z$ and Δf determined by the corresponding nomogram as follows:

$$x_n = x' + \Delta x \quad , \quad z_n = z' + \Delta z \quad , \quad f_n = f + \Delta f \qquad (10)$$

The remaining equation can be computed by the pocket computer. Because of the simplicity of operation, This stereophotogrammetric system will be spread much easily in the non-photogrammetric departments.

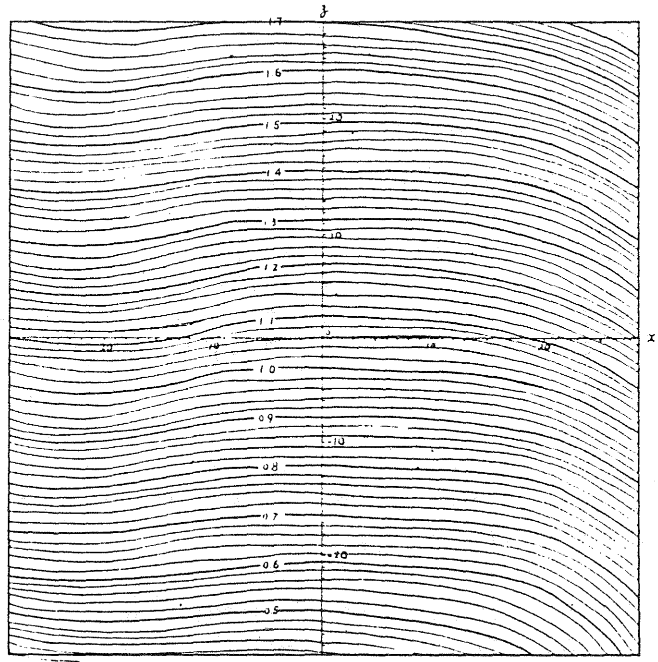

Fig. 8

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