RELATIONSHIP BETWEEN FORMAT AND RESOLUTION OF METRIC CAMERA AND MAPPING ACCURACY

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Abstract

The characteristic parameters of a metric camera, such as focal length, field of view in flight direction and resolution , are related to desired mapping accuracy. From the view point of ensuring the measured accuracy of ground points, and according to the desired accuracy of map , for example, a 1:100000 scale topographic map, the relationship between characteristic parameters and mapping accuracy is demonstrated . And the relationship between resolution distribution curves relative to various fields and mapping accuracy is mainly discussed. It is also discussed that the varying resolution distributions in the same format can satisfy the requirements of the various mapping accuracy. The reasonable distribution of resolution for a metric camera is found to select these characteristic parameters correctly, so that the difficulty of manufacturing a space metric camera can be eased.

Keywords: photogrammetry, mapping, camera, accuracy, resolution, design.

1. Introduction

As a designer of metric camera, he should analyze the relationship between the characteristic parameters of the camera and the accuracy wanted for topographic map at first, when the scale of topographic map and the accuracy are given in the work of satellite photogrammetry,so as to get the most reasonable design of the camera. There are close relationships between the camera parameters, such as focal length,image format width in the line of motion, resolution and distortion error, and the accuracy of topographic mapping(simply called mapping accuracy).There is a certain dependence of focal length image format width in the line of motion on mapping accuracy.There is no direct functional relationship between the resolution and mapping accuracy, but the resolution, in the engineering, is still an important parameter to evaluate the feature of photogrammetry and the image quality of the camera and it will directly affect the measured accuracy of ground points. The main problems discussed in the paper are how to choose the characteristic parameters of camera, how to distribute the resolution in the image format and how to make the design not only satisfy the requirement of mapping accuracy but also ease the developing difficulty. Taking a topographic map with the scale of 1:100000 as an example , author put more emphasise on the relationship between the resolution distribution curve in different area of field and mapping accuracy.The different mapping errors can be got in the same format using different resolution distribution, so that more reasonable resolution distribution of metric camera can be found.

2. Relationship between the focal length, resolution of metric camera and mapping accuracy

As we known, in the photogrammtry,the errors in horizontal location and elevation of the target are all related to the photographic scale, ground resolution and base-height ratio, while the photographic scale and ground resolution are closely related to the focal length and resolution of metric camera.Therefore,the focal length and resolution of camera are two important factors to guarantee the mapping accuracy.

Since the satellite photography is developed,the ground resolution has been an important parameter to evaluate the feature of a satellite photogrammetrical system.The ground resolution in space photography can be calculated according to the following formula:

$$Rg=\frac{M}{R}=\frac{H}{fR} \qquad (1)$$

where M = photographic scale:H/f, H = altitude of camera, f=focal length of camera. R = resolution(low contrast)of satellite photography . In all countries, the relationship between mapping accuracy and ground resolution is provided definately . The Chinese standard[1] can be seen in table(1):

Tab.(1) Map-Accuracy Requirements

Map-Scale number	Std.Error in Position(m)	Contour interval(m)	Std.Error in Elevation(m)	ground resolution m/lp	m/pixel number
1000,000	500	250	75	160	57
250,000	125	50	15	39	14
100,000	50	20	6	17	6
50,000	25	10	3	8	3
25,000	12.5	5	1.5	4	1.5

From the table , the requirement of ground resolution for making a 1:100000 scale topographic map is 17 meters. According to formula(1), R is equal to 41 lp/mm when the photographic height is 210 km and the optimum focal length of camera is 300mm.

3. Relationship between the format width in the line of motion and mapping accuracy

The image format width in the line of motion of a metric camera is mainly related to the elevation error of a topographic map, the standard error of elevation is also given in the table(1). In the photogrammetry, stereoscopic coverage should be required in order to measure the elevation. The error in height determination is dependent upon the base-height ratio of the stereoscopic model,that is

$$\sigma_h=(H/f)(H/B)\ P_x \qquad (2)$$

where: σ_h = error in height determination;
P_x = error in parallax measurement;
H/B = the reciprocal of base-height ratio.

From the formula (2) , if other parameters are fixed, the increasing multiple of base-height ratio is as many as that of accuracy in height measurement.

From the table (1) , to a 1:100000 scale topographic map, the standard error in elevation , σ_h = 6 meters , ground resolution Rg= 17 meters. The figures in the table (1) can be varied according to the requirement in different countries. In some countries, the error in elevation is 8 meters and the ground resolution is 10 meters. In general, as long as the accuracy of elevation meets the mapping requirement, the accuracy of horizontal position and the contour interval will also meet the requirements . So that , in the map-accuracy requirements , the error in elevation is an important feature.

The accuracy of elevation [2] is determined by base-height ratio, while there is a following relationship between base-height ratio and the format width in the line of motion:

$$B/H=b/f=W_f(1-OL)/f \tag{3}$$

where : W_f= image format width in the line of motion;
OL= fraction overlap;
b=base length on the picture.

From (3) , the format width in the line of motion is connected with the mapping accuracy by the base-height ratio. If the format width in the line of motion increases from 230 mm to 460 mm, the base-height ratio increases two times. Thus the accuracy of elevation will improve two times. It's seen that the format width in the line of motion will have direct influence on the error in elevation. As a designer of metric camrea,he should put enough emphasis on the selection of format width in the line of motion.

4. Relationship between the allowable error of measuring an image point and mapping accuracy

In photogrammetry , the following dependence shows the relationship between the allowable error[2] of measuring an image point and the elevation error:

$$\sigma_m=\frac{\sigma_h}{S_p\sqrt{2}} \times \frac{b}{f} \tag{4}$$

where : σ_m = allowable error of measuring an image point, S_p= allowable photo-scale number.

According to the equation (3) and (4), the allowable errors of measuring an image point desired can be calculated, when the format width in the line of motion, the base-height ratio and the error in elevation are varied. The results are listed in table (2).

Tab. 2 Error of Measuring an Image Point (mm)

$A*\omega_f$	OL →	60%			40%			20%		
	σ_h \ b/f	0.3	0.46	0.61	0.46	0.69	0.92	0.61	0.92	1.23
230*230	6	0.0018			0.0028			0.0037		
	7	0.0021			0.0032			0.0043		
	8	0.0024			0.0037			0.0050		
230*345	6		0.0028			0.0042			0.0056	
	7		0.0032			0.0049			0.0065	
	8		0.0037			0.0056			0.0074	
230*460	6			0.0037			0.0056			0.0074
	7			0.0043			0.0065			0.0087
	8			0.0050			0.0074			0.0099

From the table , it is not difficult to find that if the overlapping percentage of stereo coverage and the error in elevation are the same , the allowable error of measuring an image point will increase with the increasement of format width in the line of motion,or to say, if the format width in the line of motion and the base-height ratio are the same,the more the accuracy of measuring an image point is improved, the better the precision of measured elevation is . In measuring the picture , whether the accuracy of measuring an image point can be improved or not depends on, to a great extent, the image quality or dynamic resolution of the metric camera.

5. Relationship between resolution distribution in the image format and mapping accuracy

In the satellite photogrammetry , the picture quality includes two contents. One is measured characteristics or geometrical features (e.g. lens distortion, the accuracy to hold the film flat, film deformation) . The better the geometrical accuracy of the target on the picture, the higher the measured accuracy of the target . The other is imaging feature, that is the resolution of the Ifcamera. If the resolution is higher , we can get more information from the ground points. So that the measured accuracy of ground points will be higher. A metric camera should be qualified in these two features. There are many factors to limit the improvement of the features of lens , it is difficult to improve the resolution in the edge field of view , especially for a lens with large field of view . Some problems about the resolution distribution in the centre or edge field of view will mainly discussed as followings.

5.1 Relationship between resolution distribution in edge field and accuracy of measuring an image point

There is a very close relationship between the accuracy of measuring an image point (i. e. error in determination) and the resolution, besides the geometrical accuracy.

It is known from Tab.(2)that if the accuracy of measuring an image point is improved, the accuracy of measured elevation will also be improved. But it is difficult to get the dependence of the accuracy of measuring an image point on resolution required . It is more reasonable to use the relationship between aim error in picture's measurement and the resolution .

After imaging,the images of two neighboring ground points with different brightness will present a transitional zone with blurred edge, of which the difference of the optical density[3] is $\triangle D$. When two points of the picture with different densities are measured , the dependence of aim error Mx on resolution will be:

$$M_x=\frac{1}{2.4R_h} \tag{5}$$

where, R_h=the resolution with high contrast.

In actual practice , most of targets are low contrast in the satellite photogrammetry . In general, we take $\sqrt{\triangle D}$ as descendant multiples, and let $\triangle D$=0.3, we have,

$$Mx=\frac{1}{1.3R_h} \tag{6}$$

In stereoviewing , the accuracy of measuring an image point can be improved $\sqrt{2}$ times, then formula

(6) can be rewritten into

$$M_x = \frac{1}{1.9R_h} \qquad (7)$$

M_x in the fomula(7) is σ_m. According to the formula(7), we can calculate the prospected standard error in measuring coordinates of image point if the resolution is given, or inversely , we can calculate the resolution required in the light of allowable error in measuring an image 'point. The measured accuracy of a modern precise stereometer can reach 3μ m, that means the resolution of matched picture should be 175 lp/mm. It is impossible to provide such high resolutions in whole image format.

Taking the error of measuring an image point listed in Tab. (2), we can calculate the correspondent resolution according to the formula(7), and with the descendant multiples of $\sqrt{\triangle D}$, we can calculate the resolution in the condition of low contrast, Rl. They are listed in Tab. (3).

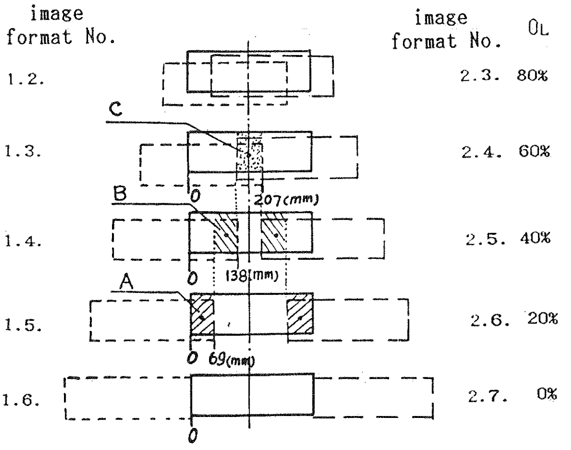

Fig. (1) different combination of base-height ratio

Tab. (3) Accuracy of measuring an image point and correspondent resolution. R (lp/mm); σ_h (m); σ_m (mm).

OL		60%									40%									20%								
b/f		0.3			0.46			0.61			0.46			0.69			0.92			0.61			0.92			1.23		
A×Wf	σ_h	σ_m	R_h	R_l	σ_m	R_h	R_l	σ_m	R_h	R_l	σ_m	R_h	R_l	σ_m	R_h	R_l	σ_m	R_h	R_l	σ_m	R_h	R_l	σ	R_h	R_l	σ	R_h	R_l
230×230	6	0.0018	292	163							0.0037	188	105							0.0037	142	80						
	7	0.0021	250	140							0.0028	165	92							0.0043	122	68						
	8	0.0024	219	122							0.0032	143	80							0.0050	105	59						
230×345	6				0.0028	188	105							0.0042	125	70							0.0056	94	53			
	7				0.0032	164	92							0.0049	107	60							0.0065	81	45			
	8				0.0037	142	79							0.0056	94	53							0.0074	71	40			
230×460	6							0.0037	142	80							0.0056	94	53							0.0074	71	40
	7							0.0043	122	68							0.0065	81	45							0.0087	61	33
	8							0.0050	105	59							0.0074	71	40							0.0099	53	30

From Tab. (3), we can find that: (a) In the condition of the same error in elevation and the same overlap percentage, the requirement of resolution can be lowered with format width in the line of motion. (b) When the elevation accuracy is the same, the resolution values required at the different locations within the same format are different if the pairs of stereo image are combined in different ways.

So that, the relationship between the allowable accuracy of measuring an image point and resolution should be investigated so as to link the resolution and mapping accuracy. Then, how to distribute the resolution in the field of view will be a very important problem to affect the difficulty of camera design and the engineering.

In 80% forward overlap stereo photogrammetry, the overlap in a stereo model built by the first frame and the fifth frame is 20%. If the format length is 345 mm, the utilized format width on the right and left edges is 69 mm, that is about out of 19 field of view , shown in Fig.(1)A, when $\sigma_h = \pm 6$m, the correspondent resolution will be 94 lp/mm(see Tab.(3)), the overlap built by the first frame and the fourth frame is 40%, the correspondent format edge reaches 138mm , about out of 6.5° field of view. Let the resolution in the area between 138-69mm be 125 lp/mm shown as Fig(1)B. The overlap built by the first frame and the third frame is 60%, the edge width of format overlapped is 207mm , shown as Fig(1) C. The resolution between 207--138mm is 188 lp/mm. Take the average values of resolution in three areas saparately and draw a distribution curve of resolution in the format. In the same way, we can get a similar resolution curve when the image format is 460mm, shown as Fig. (2).

It is very difficult to design a camera lens to meet the requirements shown as Fig. (2), it means that the axile resolution of a camera should be very high. But the axile resolution cannot be very high because it is restricted by the relative aperture and resolving power of a film, and that it is also related to whether or not the lens is equipped with compensator for image movement. When f=300 mm, relative aperture=1/6 and the resolving power of the film ,Rf=400 lp/mm, the resolution in centre field, calculated by common resolution equation, is 152 lp/mm. The resolution nearer to the centre field of view, with accordance with Fig.(2), is higher than the limiting value of axile resolution and it is difficult to meet the requirement even if the relative aperture of camera were further increased or the resolving power of the film were further improved.

5.2 Resolution distribution in the image field

In general, if the aberration is well corrected, the resolution descended in the edge field of view will not exceed 40 percent of centre's resolution. When the dynamic factors are taken in account, the resolution in the centre field , R, will be further descended. Therefore, the resolution in the centre field and the edge field should be well distributed so as to meet the mapping requirement.

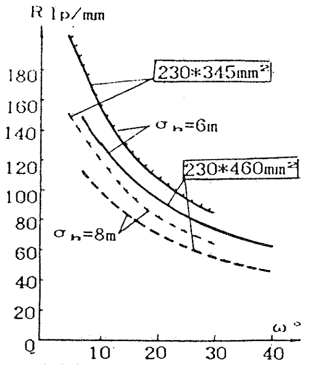

Fig. (2) resolution distribution in the edge field

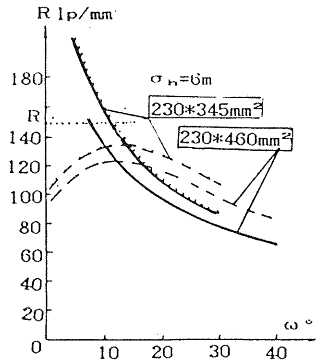

Fig. (3) prospected resolution distribution

On the basic of analyzing the Tab(3), Fig.(2) and the resolution that can be reached in the centre field without aberration,an assumption to distribute the resolution in the image field according to Fig.(3) is put forward.Because the area that the overlapping is 40-20% is mostly used in the stereo photogrammetry,it is effective and reasonable to drop the resolution properly in the centre field and to raise the resolution in the edge field, shown as Fig(3). Thus, the maximum resolution will not exceed the limiting value of lens centre.The values dropped in the centre area and raised in the edge area should be determined by combining the aberration correction in lens design with the mapping accuracy, so as to be realized in the engineering and to minimize the diffculty. In the same way, we can draw a set of curves shown in Fig.(4) according to Tab.(3). From Fig.(4),we can see: (a) With the same elevation accuracy , the distribution curve of resolution will be varied with different format width in the line of motion; (b) In the same format,the higher the resolution, the better the measured accuracy of elevation. (c) With the same elevation accuracy,the smaller the format width in the line of motion,the higher the resolution required.

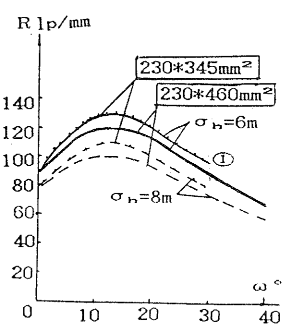

Fig. (4) reasonable resolution distribution for mapping a 1:100000 scale topographic map

If the problems mentioned above have not analyzed when the metric camera is designed,the resolution distribution curve in a format of 230×345mm² may be designed as the curve (2) shown in Fig(5) , not the curve(1) shown in Fig.(4).Now we can find that the curve(1) in Fig(4) can meet the requirement for mapping a 1:100000 picture , because the area weight resolution R_A=98 lp/mm,but the curve(2) in Fig. (5) can not,because th area weight resolution R_A=59 lp/mm.

A mapping camera(focal length= 300mm, format= 230×230mm²) is analyzed. At first , the distribution of resolution in the range of the format is measured. The distribution curve (1) of camera is shown in Fig.(6).If the photo height is 210km, the area weight of curve(1)R_A=40 lp/mm(low contrast) and the standard error in elevation that can be reached is about 15m . We should only redesign the lens and balance the aberration according to the curve(2) in Fig(6),in the condition that other parameters are not changed, R_A can reach 58 lp/mm and the standard error in elevation will be 11m, that is, the accuracy of elevation can be improved greatly.

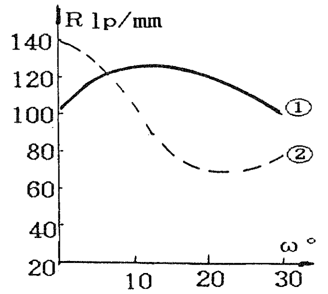

Fig. (5) different distributions of resolution in the same format

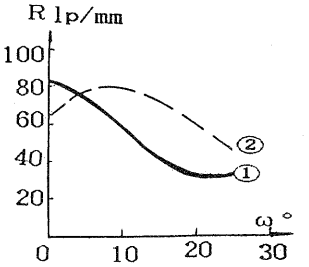

Fig. (6) different resolution distributions of a mapping camera

Two examples mentioned above have clearly presented that,in the same format, the different distribution curves of resolution can meet the different requirements of mapping accuracy. To a designer of metric camera, he should investigate the resolution's distribution in the image field, in the premise to guarantee the mapping accuracy, change the distribution of resolution and distribute the resolution reasonablely in the different area of format so as to ease the difficulty of making a camera.

6.Conclusion

The camera design and photogrammetry are two different professions. By the relationship between the characteristic parameters of the camera and the mapping accuracy, especially the accuracy of measuring an image point, the photo resolution can be connected with mapping accuracy. It is very important for the camera design. The satellite photogrammetry is a large systems engineering. There are many factors to affect the mapping accuracy. In this paper, only three main characteristic parameters of metric camera,focal length,format width in the line of motion and resolution, are related.

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