

ANALYSE ON IMAGE DISTORTION CAUSED BY CAMERA TILTING ANGLE IN MOSAIC CAMERA

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KEY WORDS: camera mosaic, tilting angle, image distortion, Two-Mosaic, Four-Mosaic, ratio of GSD change

ABSTRACT:

Digital aerial photogrammetry has the virtue of high precision and efficiency, but the plane array of single digital camera is not wide enough, so the land coverage and base-height ratio of single digital camera is smaller than the traditional film camera. So people always array several single digital cameras (usually two or four) together as one camera, and it's called multiple plane array digital photographic camera or mosaic camera, the angle of single digital camera is not level as usual, it circumgyrates around it's own axis of lens to get large land coverage, and it has become the focus in recent research. The tilting angle of single camera is the most important parameter in multiple plane array digital photographic camera system; it determines the image quality and the useful land coverage (effective virtual picture format). The image distortion caused by camera incline was studied particularly in the process of multi-lens aerial digital camera exterior marriage in this paper. The formulas on the GSD change ratio of any pixel caused by camera incline in two-mosaic, four-mosaic(DMC) and film camera were deduced and calculated. It has important significance in the design of multiple plane array digital photographic camera.

1. INTRODUCTION

Aerial photogrammetric system develops in two main ways: one is the image acquisition system, aerial camera and flight platform; the other is image post-processing system. The appearance of digital photogrammetric work station make aerial photogrammetric post-processing system change enormously. But the imaging mode and imaging medium have no distinct transformation during prime hundred yeas. Traditional film camera is bulky, expensive, weather-dependent strongly, long cycle and low efficiency, which has an urgent demand in digital production in aerial images collection[3-5]. Single small format camera brings on low efficiency and small base- height ratio, low vertical accuracy; the foreign large format digital aerial cameras, such as DMC, UltraCamD ADS40 and so on, cost high and have cumbersome customs procedures, which impact their wider application. To the end, drawing lessons from DMC, SWDC, and developing reasonable integrated and cost-effective domestic multi-format digital aerial camera to use is very important. In the process of developing multi-format digital aerial camera, the tilt angle of single camera is an extremely important parameter, which directly affect the quality of the virtual image. This article focuses on the image distortion caused by camera incline, which has important significance to design multi-format digital aerial camera.

2. METHOD OF IMAGE DISTORTION EVALUATION

Traditionally, people express image deformation using image point displacement. There are pixel displacements caused by

camera tilt or by ground fluctuations. During camera mosaic designing, assumed that the ground is level, only consider camera's tilt, shown in Figure 1. Locate four points A, B, C, D on level plane, that formed a square graphic. In the photograph on level camera, the image points a0, b0, c0, d0 form a square too, while in tilted photograph, the image points a, b, c, d form a trapezoid. In the double layer map(Figure 1), the two radius vectors are in the same line, the difference $\delta_a=ca-ca^0$, is image point displacement caused by image tilt. After calculation, the image point displacement formula [6], is shown as Formula (1), in which, φ is the angle of any pair of image points a and a0. rc is radius vector, and α is camera tilt angle, f is camera focal length.

For photography with digital camera, the Ground Sampled Distance(GSD) is one of the primary parameters, so I put GSD change ratio according to camera angle changing as image deformation index mark. GSD means one pixel' size in object space. GSD change ratio means GSD in level photograph divided by GSD in tilt photograph. The ratio has nothing to do with the flight altitude. After the photograph is tilted, the size in image of individual pixel will not change, but only GSD of the pixel changed. The angle caused pixels' GSD are different form each other, resulting in image deformation from the actual surface features.

$$\delta_a = - \frac{r_c^2 \sin \varphi \sin \alpha}{f - r_c \sin \varphi \sin \alpha} \quad (1)$$

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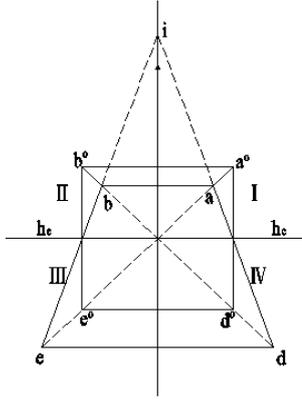


Figure 1. Image point displacement caused by camera tilt in double-format mosaic camera

3. IMAGE DEFORMATION OF MULTI-FORMAT DIGITAL PHOTOGRAPHIC CAMERA

Definite photo coordinate system as Figure 2, this section will analyze image deformation caused by camera tilt in double-format mosaic and four-format mosaic.

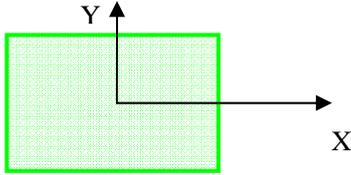


Figure 2. Photo Coordinate definition

3.1 IMAGE DISTORTION CAUSED BY CAMERA TILT ANGLE

Now see the image distortion rule: suppose we get three images from one camera station, shown in Figure 3. one is level image(black line); another one is oblique photograph with φ angle in Y axis(blue line); the other is oblique photograph with φ angle in Y axis and ω angle in X axis(red line). Level image and two corrected oblique images are shown in Figure 3.

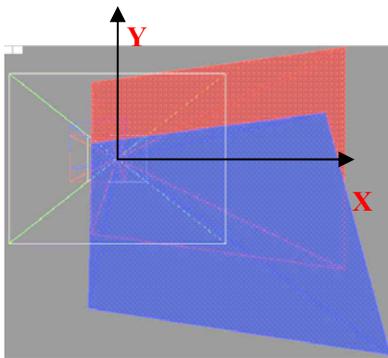


Figure 3. Image deformation

So, image presents almost inerratic trapezia(red line) when camera tilt in Y axis. This instance is seen in Two-Mosaic and Three-Mosaic camera; image presents anomalistic quadrangle(blue line), which is seen in Four-Mosaic camera.

3.2 GSD CHANGE CALCULATION IN DISTORTION IMAGE

3.3 GSD CHANGE CALCULATION IN TWO-MOSAIC CAMERA

In this paper, GSD formula of arbitrary point is derived as follows.

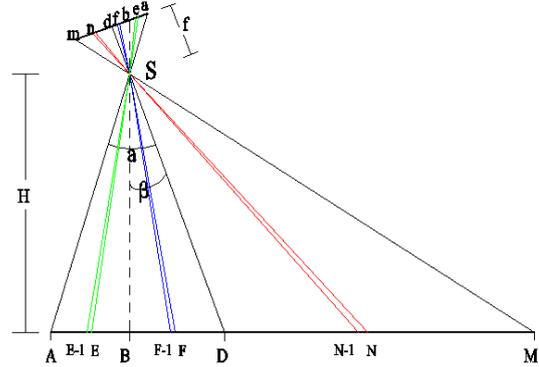


Figure 4. The special points in tilted photograph

As shown in Figure 4, point A corresponds to the first CCD (point a), and point M corresponds to the finally CCD(point m). Segment AM corresponds to ground cover of the whole CCD. Point B is ground nadir point corresponds to plate nadir point b, and point D corresponds to d, the principal point of photograph. Point E refers to any ground point in segment AB, and point (E-1) is the left adjacent point of point E on the ground. Point F is arbitrary point in segment BD, point N is any point in segment DM. α is half of angle of view. β is tilt angle. The physical size of single CCD format is μ . The focal length of single camera is f , flight altitude is H. And then calculate the GSD of the three situations as follow.

(a) Calculate GSD of point n

$$N_{GSD} = BN - B(N-1) \\ = H \times \left[\text{tg}(\beta + \text{arctg} \frac{(n-m/2)}{f} \mu) - \text{tg}(\beta + \text{arctg} \frac{(n-1-m/2)}{f} \mu) \right] \quad (2)$$

(b) Calculate GSD in point e

$$E_{GSD} = B(E-1) - BE \quad (3) \\ = H \times \left[\text{tg}(\text{arctg} \frac{m/2-e}{f} \mu - \beta) - \text{tg}(\text{arctg} \frac{m/2-e}{f} \mu - \beta) \right] \\ = H \times \left[\text{tg}(\beta + \text{arctg} \frac{e-m/2}{f} \mu) - \text{tg}(\beta + \text{arctg} \frac{e-1-m/2}{f} \mu) \right]$$

(c) Calculate GSD in point f

$$F_{GSD} = BF - B(F-1) \quad (4) \\ = H \times \left[\text{tg}(\beta - \text{arctg} \frac{m/2-f}{f} \mu) - \text{tg}(\beta - \text{arctg} \frac{m/2-f+1}{f} \mu) \right] \\ = H \times \left[\text{tg}(\beta + \text{arctg} \frac{f-m/2}{f} \mu) - \text{tg}(\beta + \text{arctg} \frac{f-1-m/2}{f} \mu) \right]$$

In conclusion, GSD calculation formula of the i^{th} CCD in the main longitudinal section CCD-line is as follow.

$$i_{GSD} = H \times \left[\text{tg}(\beta + \text{arctg} \frac{(i-m/2)}{f} \mu) - \text{tg}(\beta + \text{arctg} \frac{(i-1-m/2)}{f} \mu) \right] \quad (5)$$

Suppose the focal length is 50mm, single CCD is $6.8\mu\text{m}$, flight altitude is 1000m, When the camera tilts 15 degrees, 18degrees, and 20 degrees in one direction, the GSD change (in Figure

5) and GSD change ratio (in Figure 6) in the main longitudinal section CCD-line are as follow.

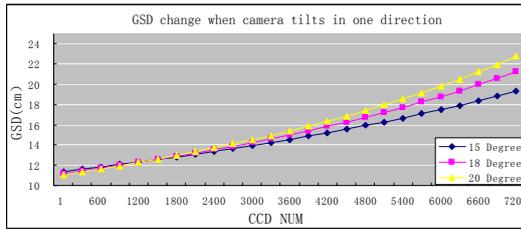


Figure 5. GSD change in double-format mosaic

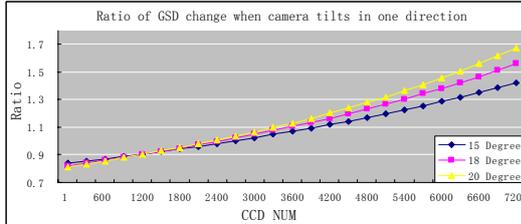


Figure 6. GSD change ratio in double-format mosaic

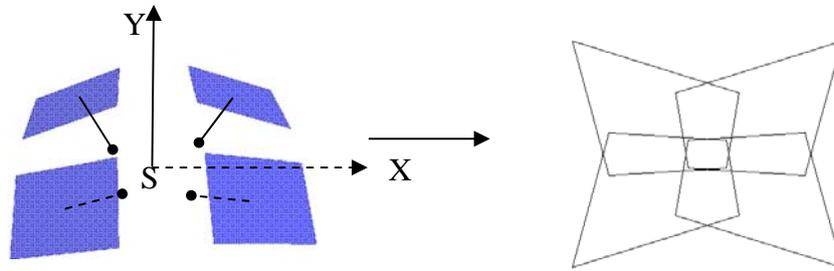


Figure 7. Ground coverage of four camera

Table 1 parameters of DMC and film

camera	number of single camera	Single CCD size(um)	Format of single camera(mm)	Focal length(mm)	Tilt angle(degree)
DMC	7168×4096	12	86.0×49.2	120	18/10
Film camera	11500×11500	20	230×230	88	3/3

From above diagram we can see:

(1) After camera tilted in one direction, the GSD in the main longitudinal section CCD-line has much difference. When $\beta = 15$ degrees, the smallest GSD is 8.91 cm, and the largest GSD is 13.12 cm; when $\beta = 20$ degrees, the smallest GSD is 8.85cm, and the largest GSD is 14.98 cm. After calculating, every GSD is 0.14m in image when vertical photography. So we can say, the GSD of downward-sloping image part becomes larger because of flight altitude extended in a sense; but the GSD of upward-sloping image part becomes smaller because of flight altitude shorten in a sense.

(2) The greater the angle is, the more obvious the GSD changes. GSD change trend is similar with GSD change ratio trend.

(3) Greater camera angle will get wider ground coverage. But GSD on the edge of the image changes seriously, and this image part becomes blurry after resampling. So GSD change restriction is needed to ensure image quality.

$$X = X_s + \frac{(Z - Z_s)(a_1x + a_2y - a_3f)}{c_1x + c_2y - c_3f}$$

$$Y = Y_s + \frac{(Z - Z_s)(b_1x + b_2y - b_3f)}{c_1x + c_2y - c_3f} \quad (6)$$

3.4 GSD CHANGE CALCULATION IN FOUR-MOSAIC CAMERA

The image distortion in single camera is much complex in Four-Mosaic camera. Camera tilt in both X, Y and Z axis. How to get the distortion rule? Set ground reference frame in Figure 7. The center of the four camera stations is the point of origin. X axis is the flight line direction, Z is vertical axis, Y axis is decided by right-hand rule. Form following formula, we can calculate the object coordinates of any point.

In formula(6), $a_i, b_i, c_i (i=1,2,3)$ is the rotation matrix. f is the focal length of camera, (x,y) is image coordinate of any point. Here, principal point of photograph coordinate is ignored.

When four cameras are set symmetrically and the distances of lens are L_1, L_2 , so, $X_s = \pm L_1/2, Y_s = \pm L_2/2$. Suppose the ground is level. When flight height is H , we can calculate the ground range of four images, which is shown in Figure 7.

Put GSD in vertical photography divides the ground distance of point (x_1, y_1) and nearest point (x_2, y_2) to get the GSD change ratio of the point.

$$\frac{f\sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2}}{dH} \quad (7)$$

In formula(7), (X_1, Y_1) and (X_2, Y_2) are the ground coordinates of image points $(x_1, y_1), (x_2, y_2)$. f is focal length. D is size of single CCD. H is flight height. Now, we put DMC, film camera(88mm lens)[8] as an example. Calculate the GSD

change ratio of splicing edges(A'B' and A'D'), seen in Figure 8 and Figure 9. Parameters of the two cameras are in table 1.

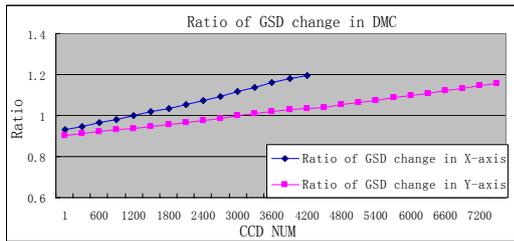


Figure 8. ratio of GSD change in DMC image

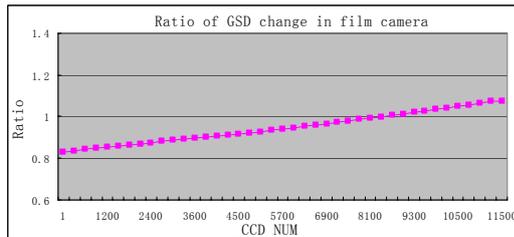


Figure 9. ratio of GSD change in film image

We can see from the chart:

- (1) Image distortion trend above is similar to ratio of GSD change in image tilted in one direction.
- (2) Ratio of GSD change of two spliced sides in DMC image is between 0.9 and 1.2, and ratio of GSD change on both sides of film camera is between 0.8 and 1.1.
- (3) Reference to the scope of the ratio of GSD change in the existing aerial camera, reasonable GSD change threshold can be set out. Then cut off the image part where GSD change is greater than the threshold with a rectangle.
- (4) After analysis, ratio of GSD change formula in two-mosaic camera is a special case of formula in four-format mosaic camera when single camera tilt angle in X axis is zero degree.

4. CONCLUSION

In this paper, the image deformation caused by camera incline in Two-Mosaic and Four-Format mosaic digital aerial camera development process is studied particularly. I have derived formula for calculating the ratio of GSD change in Two-Mosaic camera by myself, and have found the way to calculate the ratio of GSD change in four-format mosaic camera using collinear equation. The ratio of GSD change in image when single camera tilts in Y-axis 15 degrees, 18 degrees and 20 degrees is got. And image deformation of DMC and film camera is computed, too. Ratio of GSD change formula in Two-Mosaic camera is a special case of formula in Four-Format mosaic camera. So, after camera tilted, we can calculate any pixel's GSD change rate through the formula. For setting right camera angle to retain more eligible image, it has a great significance.

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