Chapter 7
Analysis and Test of the Exposure Synchronization of the Multi-Sensor Aerial Photogrammetric Camera System

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Abstract Detailed analysis of exposure synchronization is made aiming at high precision matching and combining the images captured by multi sensor camera system. Exposure mechanism and motion of shutter blades or curtains become the main source of asynchronic error among individual cameras. Two methods are used to test the exposure asynchronization according to both between lens shutter and focal plane shutter configurations. Analysis of the results shows the consistency of theoretical analysis and test measurements.

Keywords Exposure synchronization · Multi-sensor aero photogrammetric camera · Shutter configuration · Ground sample distance

7.1 Introduction

Multi-sensor aerial photogrammetric camera introduces larger format, longer base line, less flight course, more efficiency and less after-work under the same task situation, making it possible to reduce task cost [1]. Such kind of camera is included into resource, grid line supervision, land mapping, city planning and other applications widely.

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Digital sensor could not achieve the traditional film aero photogrammetric cameras' format due to limitation on semiconductor technics and sensor construction [2]. Multiple sensors are integrated to form a large format [3]. Each sensor and corresponding lens form an imaging system, which records images and exposure information separately. Images are matched and combined after to form large format digital images. Two factors influence the combining process: the relative outer orientation elements and the exposure asynchronization of each camera system. Stability of relative outer orientation elements is guaranteed by precise design and producing, thus the exposure asynchronization becomes the key factor affecting the image combination precision. Synchronic exposing control is one of the most important technologies in multi-sensor aero photogrammetric system integration, for the asynchronic error effects the whole image acquisition and processing progress. Asynchronic error must be reduced in an acceptable range to guarantee the combining precision.

Considering digital cameras' construction, exposure mechanism and signal transmitting, analysis and tests are made for both sensitization aspect and shutter motion aspect. Testing data is analysed to validate stability.

7.2 Analysis of Exposure Synchronization of Multi-Sensor System

Camera exposes at a specific position on signal sent by Flight Management System (FMS). Instead of sending different exposure signal for each camera system, the FMS sends one single exposure signal. Images captured by each camera will not accord the designed relative position if cameras do not expose synchronically. The combination process highly relies on steady relative position. The asynchronic exposure leads to harder combination processing, or even wrong results. Figure 7.1 shows the relative position of four images under synchronic exposure (a) and asynchronic exposure (b).

7.2.1 Exposure Process and Analysis of Asynchronic Error Source

Exposure process can be idealized as a step response process [4]. The shutter opens after receiving the exposure signal and allows the light to go through. After the required shutter speed has been reached, the shutter closes to block the light. The response time for the step process equals to the required shutter speed (Fig. 7. 2).

Exposure process can be divided into the electronically controlled phase and the mechanical phase. In the electronically controlled phase, the time difference for synchronization is small since the exposure signal is an impulse, which is a low voltage, low frequency signal, and transmits a short distance. The mechanical

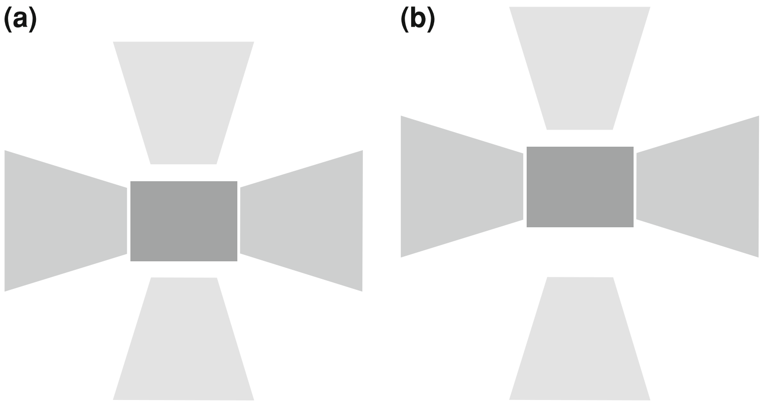
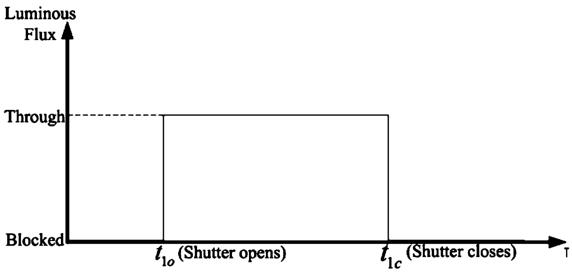


Fig. 7.1 Relative position of four images. **a** Synchronic exposure, **b** asynchronic exposure

Fig. 7.2 Step response of the shutter



phrase begins when the shutter receives the electronic signal. The driver unit drives the blades to expand to a required period and then closes them [5]. The various types of driver unit among different products result in uncontrollability and randomness in mechanical phrase.

The source of error for the exposure asynchronization mainly comes from the variety of the blades and driver units. The error exhibits a certain degree of randomness and can be analyzed by using a large amount of observed data (Fig. 7.2).

7.2.2 *Calculation of the Maximum Exposure Synchronization Difference*

The actual shutter speed $\Delta T_i (i = 1, 2, \ldots, 4)$ is not exactly the same in practice for a multi-sensor camera system [6, 7]. However, the difference can be neglected since it has little impacts on the synchronization. Analysis aims at the moment when the shutter closes. Δt is defined as the time difference between the moment when the first camera finishes the exposure process and the moment when the last camera finishes the exposure process. The allowed maximum exposure asynchronization is calculated under the following conditions: (1) camera and plane orientations are ignored; (2) plane moving at a constant speed without the impacts of wind; (3) the maximum displacement caused by the exposure asynchronization should be within one Ground Sampling Distance (GSD).

$$\Delta L_{\max} = \Delta t_{\max} \times v_G \tag{7.1}$$

$$\Delta t_{\max} \times v_G \leq GSD \tag{7.2}$$

where: v_G stands for the ground speed of the plane at the moment of exposure
Δt_{max} stands for the allowed maximum error in exposure
ΔL_{max} stands for the allowed maximum displacement of images
GSD stands for the ground sampling distance

Taking the ground speed for middle and large size aerial photography plane as 250 km/h and GSD as 10 cm, the allowed maximum exposure difference among the cameras is calculated.

$$\Delta t_{\max} \leq \frac{GSD}{v_G} = \frac{10\ \text{cm}}{250\ \text{km/h}} \approx 1.44\ \text{ms} \tag{7.3}$$

Factors such as the wind speed at the moment of exposure, the instantaneous change of the orientation of plane and adjustment of the camera orientation during flight, will affect the value of ΔL. Therefore, the value of Δt_{max} should be adjusted to satisfy the accuracy and quality required by the data process considering the above factors.

7.3 Test of Exposure Asynchronization

The following two test methods are used [8]:

1. Taking photographs of a timer with high accuracy

Use two cameras to take photographs of the high accurate timer simultaneously for several times. The time difference showed between the two images is the exposure time difference in synchronization. Results are then recorded and analyzed. This method is easy to operate and does not require extra apparatus. Also it can be applied to various types of shutters. The accuracy solely depends on the accuracy of the timer.

2. Using photodiode circuit to capture the moment when shutters are fully opened

Several lenses are placed aiming at the same light source as a group. Each photodiode is placed at the position where shutter is fully opened. Protections are

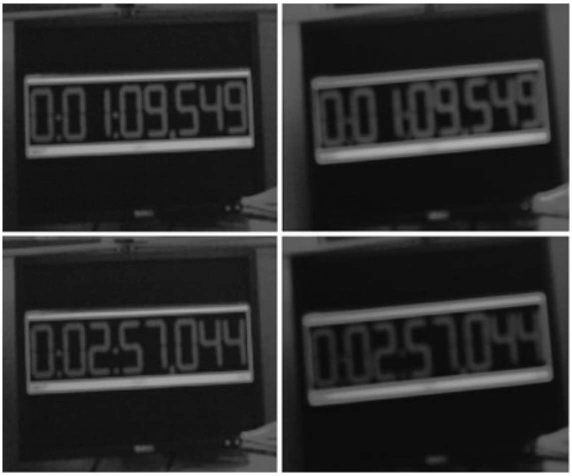


Fig. 7.3 Testing images from Cam1 and Cam2

made to avoid stray light. Exposure signals are sent simultaneously to each shutters. And the signals from the photodiode are captured by the oscilloscope. The time difference of synchronization is the difference between the rising edges of each signals. The camera which finishes first is treated as the reference, and time difference of synchronization of other cameras is calculated. Statistical methods are employed to analyze all the results. This method requires constructing photodiode circuit to produce a more accurate result and is only measurable for between-the-lens shutters (Fig. 7.3).

7.3.1 Taking Photographs of a Timer with High Accuracy

This method is used for the full frame camera with a focal plane curtain shutter since the movement of shutters cannot be tested through physical tools due to camera structure. The tested camera model is Canon 5D Mark II, the target is a timer with a minimum display accuracy of 0.001 s. The procedure is as follows:

1. Change of the timer is modeled as a moving target, and photographs of the timer are taken simultaneously from each camera .
2. Compare the photographs from each camera and the difference between them is considered as the time difference in synchronization.
3. Record the time difference interval.

Parts of the test results are presented in the following.

Among all the 100 tested photographs, 92% indicate time difference less than 1 ms; 8% show very different timing between the two photographs in one test. This phenomenon results from the fact that the timer was actually refreshing at the

Fig. 7.4 Parts of the test results

	A	B	C	D
1	NO.	CAM1	CAM2	Time Difference (ms)
16	15	1:42.969	1:42.969	0
17	16	1:44.749	1:44.749	0
18	17	1:47.146	1:47.146	0
19	18	1:49.187	1:49.187	0
20	19	1:51.148	1:51.148	0
21	20	1:53.235	1:53.235	0
22	21	1:55.481	1:55.481	0
23	22	1:57.570	1:57.570	0
24	23	1:59.731	1:59.731	0
25	24	2:02.072	2:02.073	1
26	25	2:04.319	2:04.319	0
27	26	2:06.729	2:06.729	0
28	27	2:08.857	2:08.857	0

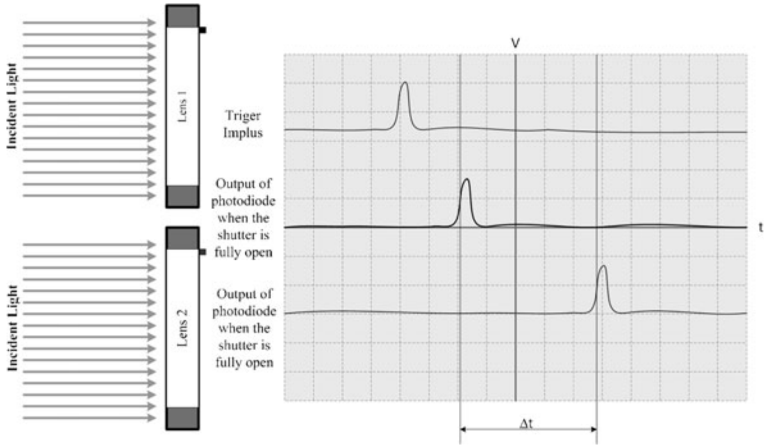


Fig. 7.5 Sketch map of the test

moment the photo was taken. Such results should be eliminated in the result analyzing. The usable accuracy should be no larger than 10 ms due to the refresh period of the timer.

This method relies highly on the accuracy of the timer and the refresh frequency of the display facility, so the accuracy of the testing result is limited. Further study will be done based on 7-segment LED monitor timer which has a refreshing period less than 0.1 ms. However, this method does not require the modification of the camera structure and is easy to implement. The result is directly readable and the method can be applied on various types of cameras, especially for full frame cameras with focal plane curtain shutter in low cost unmanned aerial vehicle applications (Fig. 7.4).

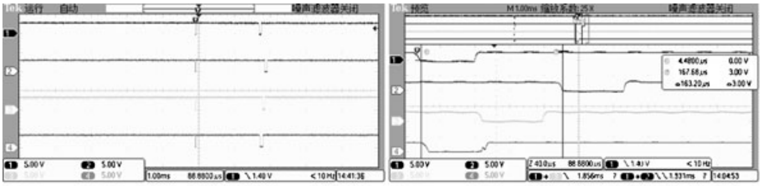


Fig. 7.6 Negative impulses captured by the oscilloscope

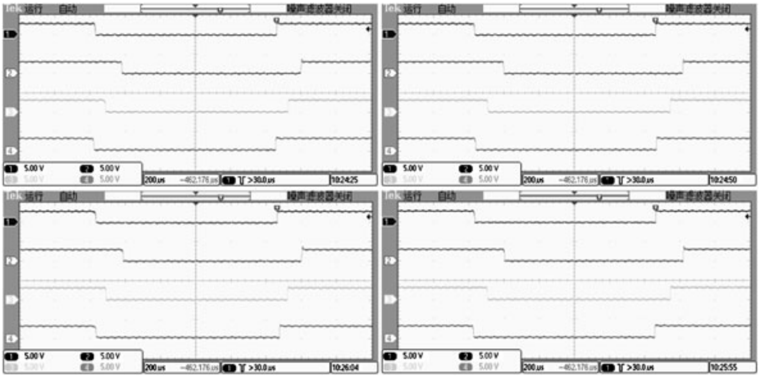


Fig. 7.7 Impulses captured by the oscilloscope under continuous exposure mode

7.3.2 Using Photodiode Circuit to Capture the Moment when Shutters are Fully Opened

Place lenses under the same light source and adjust the aperture to its maximum. Place photodiodes at the position where the shutter is fully opened, and keep the photodiode away from unexpected light. Apply the exposure signals to each shutter at the same time. The exposure signal is shown as the upper wave in Fig. 7.5. Capture and record the outputs from each photodiode with the oscilloscope. The difference between the rising edges of the two signals is the time difference of asynchronization. The targets are four Rollei Electronic Shutters in the Schneider Apo Digitar lenses.

Oscilloscope monitor display is shown below for all four camera channels. Two negative impulses are captured, and the falling edge of the second negative impulse indicates when the shutter is 90% open. The timing period between the first and the last cameras' second falling edge is the exposure asynchronization (Fig. 7.6).

Tests are implemented in manual exposure mode for five times, producing the following exposure asynchronization: 122.40, 149.00, 154.60, 157.60, 163.20 μs. Tests are implemented in continuous exposure mode for 50 times. And results

	A	B	C	D
1	NO.	First exposure(us)	Last exposure(us)	Time difference(us)
2	11	1011.1	847.1	164.0
3	12	1034.2	866.2	168.0
4	13	1030.0	861.0	169.0
5	14	64.5	105.9	170.4
6	15	4.4	167.6	163.2
7	16	1766.8	1922.2	155.6
8	17	8.6	140.2	148.8

Fig. 7.8 Parts of observed time difference

show identity with above. The maximum timing difference recorded is less than 200 μs. Some of the results are shown as follows (Figs. 7.7, 7.8).

7.4 Conclusion

Causation of the exposure asynchronization and its effects to after-process are analyzed based on the manufacturing of a certain large format combining-sensor system. Two methods are introduced to measure the timing difference of multi-exposure. Results show identity between the actual exposure asynchronization of the tested system and the theoretical analysis.

Method based on photodiode detecting can be introduced as a highly required test for such systems before shipping. Method such as using high accuracy timer can be applied as periodical test without disassembly. Both before-shipping and regular inspection and test are recommended to be involved into the industry standard and/or national standard to ensure the consistency and applicability of the images produced by such multi-sensor aero photogrammetric camera systems.

References

1. Deren LI, Wang S, Zhou Y (2008) Introduction to photogrammetry and remote sensing. Surveying and Mapping Publication, Beijing
2. Qian Y (2006) Principle and use of modern camera. Zhejiang Photography Publication, Zhejiang
3. Du Y, Liu B, Cao J, Zhang BH, Hu BL, Tang Y, Wang H, Lu M (2008) Control system of aviation digital camera based on P89C668 SCM. Comput Eng Des 29(1):129–141
4. Zhang Z (2004) Aspects on aerial digital cameras. Eng Surv Mapp 13(4):1–5
5. Talley BB (1938) Multiple lens aerial cameras, chapter IV in aerial and terrestrial photogrammetry. Pitman Publishing Corporation, Chicago, pp 91–116
6. D Light (2004) A basis for estimating digital camera parameters. Photogramm Eng Remote Sens 70:297–300
7. Jacobsen K (1988) Handling of panoramic and extreme high oblique photographs in analytical plotters, ISPRS congress Kyoto. Int Arch PhRS XXVII B2, pp 232–237
8. Schroth RW (2008) The challenge of process and management optimization for photogrammetric mapping. In: Proceedings of the colloquium for the 60th birthday of Prof. M. Ehlers, Osnabruck