THE DESIGN AND REALIZATION OF LARGE PLANE COLOUR CCD DIGITAL AERIAL CAMERA SYSTEM

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ABSTRACT:

On the basis of a $9k \times 9k$ size single plane array CCD (SPAC-1), we study and establish a digital aerial *photogrammetry* camera system, which adopts a "3+1"modular design method, i.e., three $2k \times 2k$ CCD modules for recording RGB band images and one $9k \times 9k$ CCD module for recording the panchromatic image. Every module has an independent optical system, with the same ground coverage obtained at the exposal instant. After the flight, $2k \times 2k$ size true colour images are first synthesized with RGB band images, then $2k \times 2k$ true colour images are fused with $9k \times 9k$ panchromatic images, and finally $9k \times 9k$ colour images are obtained. A comprehensive flight test was carried out with this camera system in Qufu area, Shandong province in May, 2005. In the flight conditions of a 800m-flight height and a 150 km/hr velocity, this camera achieved the 10cm GSD design index. Employing these images, we plot a 1:1000 topographic map and field precision test shows that the horizontal mean square error of outstanding points relative to the nearest GCP is 0.3 m, the vertical mean square error 0.45 m. So far, 340 km^2 of Guangzhou City aerial *photogrammtry* task has been finished by using this system.

1. INTRODUCTION

1.1 Current Status of Digital AerialCamera

Z/I imaging company declaim to develop digital mode camera (DMC) in 1999(Hinz A., 1999; Hinz A. 2000), ADS40 digital aerial camera which designed by Leica company come out in 2000(Rainer Sandau.,2000), large plane array CCD camera ULTRACAMD（UCD）designed by Vexcel company come out in 2003(Leberl, F. 2003). Digital aerial camera has already entered the project application state from experimental state after almost ten years development.

These kinds of cameras choose different technical path. ADS40 choose a 12,000 pixel linear CCD, POS is used to provide high precision of state and position which are used for image correction. DMC is composed with four high resolution $7k \times 4k$ size CCD adopting synchronous exposal mode, four $7k \times 4k$ size images are obtained in the same time, and these images are used to join a large plane image nearing $14k \times 8k$ size. UltraCamD use four plane array CCD, obtaining image by multi lens of identical place in delay expose mode, a 11500×7500 size image are obtained by joining these images. Vexcel company push out another new UCX using 14430×9420 pixels in 2006(vexcel-china, 2006).

1.2 Research Background of SPAC-1 Digital Camera

Analyzing the demand of aerial photogrammetry especially the large scale, the practical digital aerial photogrammetry camera must have high resolution and large field of view. High resolution guarantees the mapping precision and large field of view guarantees the work efficiency. But high resolution and field coverage of aerial photogrammetry camera are a pare of contradiction, the image special resolution and the ground coverage is an inverse ratio relation at the condition of a given size of image. Increasing the image resolution certainly will decrease the ground coverage. One efficient way to settle this problem is to enlarge the size of the image, and to the sensor of CCD is to add the amount of pixel.

At the support of national "863"project, we begin the research of large plane array colour CCD digital aerial camera technology, a large plane array colour CCD digital aerial photogrammetry camera system is established, naming SPAC-1, the single central projection picture format of this system is the largest in the world now.

2. SYSTEM THEORY

2.1 System Structure

The camera hardware mainly includes four components: the camera host system, the camera control system, the image data record system, the GPS survey and navigation system. Every module of the camera host system has an independent optical system, the shutter synchronous control device guaranteed the system obtain four images of identical ground coverage at the exposal moment. The core of the camera control system is an airborne computer, which is in charge of coordinating the work of every segment of the hardware. The fast record ability of the

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image data record system guaranteed the host system can shot one frame per 3 second continuously. The GPS surveying and navigation system is in charge of recording the dynamic GPS data, and it can also provide the pilot and the camera operator with visualization information of the flight. This camera system adopt a modularizing structure which is composed with one $9k \times 9k$ size CCD panchromatic camera module and three $2k \times 2k$ size colour camera modules, an interface for infrared module is also added during the camera frame design. The modules position arranged according to Figure 1. Every modules of the camera has independent lens and shutter device, identical field of view and the axis of lens are all parallel, these design are all for the aim of same ground coverage.

During the hardware design process, we resolved several key technology problems, such as the CCD chip driver, the multichannel image data fast record, the design and manufacture of large field and low distortion imaging objective lens, which achieved the integration of light, machine, electricity of multi-lens and multi-CCD sensor in the same frame.

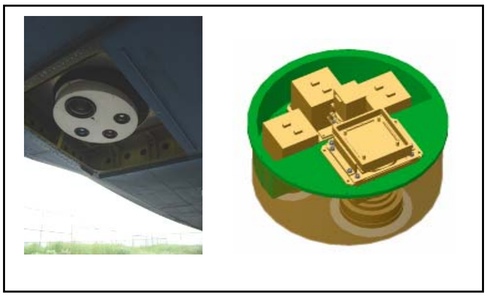

Figure 1. Distribution structure of the host modules

Figure 2. SPAC-1 Digital Camera on Y-5B plane

2.2 Camera Primary Parameters

As shown in Table 1, the panchromatic image pixel size is 8.75 μm and the lens focal length is 70.5 mm ; the colour module pixel size is 14 μm and the lens focal length is 24.83 μm ;The panchromatic module and the colour module have the same field of view which is 60º × 60º, the panchromatic distortion is less than 3 μm ; and image displacement compensator is assembled for the panchromatic module, but not for the colour modules.

Camera parameter	Colour module	Panchromatic module
Field of view $\alpha \times \alpha$	60°×60°	60°×60°
Focus f (mm)	24.83	69.84
Optical image height h (mm)	20.27	57.02
Diagonal field of view2ω (°)	78.5	78.5
Pixel angle resolution θ (″)	116.3	25.8

Table 1. The Camera parameters

2.3 GSD and Ground Coverage of the Image

The photographic scale concept f/H already can't reflect the mapping capability of the CCD image. Only the ground sample distance (GSD) can reflect the interpretation ability and positioning accuracy of the image target(WU Yundong,2007) . GSD affect the image mapping capability and work efficiency directly, basing the experience of nowadays digital photogrammetry, and considering both the precision of precision and efficiency, it's better to choose GSD of 5-10 cm while the mapping scale is 1:1000, and choose GSD of 10-15 cm while the mapping scale of 1:2000.

Theoretically, GSD is depending on focus f , relative flight altitude H and pixel size S , GSD calculating formula is as below:

$$GSD = \frac{H}{f} \cdot S \tag{1}$$

The ground coverage $A \times A$ of every image at different flight altitude can be calculated as follows:

$$A = 2H \cdot \tan(\alpha / 2) \tag{2}$$

Which H denotes the flight altitude, and α denotes the field of view.

The relation between GSD and A for the $2k \times 2k$ camera is as below:

$$\text{GSD=A/2048} \tag{3}$$

The relation between GSD and A for the $9k \times 9k$ camera is as below:

$$\text{GSD=A/9216} \tag{4}$$

H(m)	800	1000	1500	2000	2500
GSD(cm)	45.1	56.4	84.6	112.8	140.9
GSD(㎝)	10.02	12.53	18.79	25.06	31.32
A×A(㎡)	924 924	1155 1155	1732 1732	2309 2309	2887 2887

Table 2. $A \times A$ and GSD at different flight altitude

3. DATA PRETREATMENT

During the aerial photography process, the shuttles of the four cameras open synchronously, acquiring four images of the same area, of which one is a $9k \times 9k$ size image and the others are the $2k \times 2k$ size images, during the behind data pretreatment process, the $2k \times 2k$ size true colour images are composited with the RGB band images, then the $2k \times 2k$ true colour images are fused with the $9k \times 9k$ size panchromatic images, then the $9k \times 9k$ size colour image obtained.

The data pretreatment mainly includes five steps which are flaw pixels elimination, multichannel inconsistent elimination, image field illumination correction, colour composite and image fusion. Multichannel inconsistent elimination, image field illumination correction and image fusion algorithm are mainly introduced.

3.1 Multichannel Inconsistent Elimination

The panchromatic camera adopt 4 parallel buses to collect data, each bus's data reading speed is 10Mbyte/s, the colour camera adopt single bus to collect data, and the data reading speed is 40Mbyte/s. On the standard flight height of 1000 m, $9k \times 9k$ data is demanded to be read in at 5s photography interval. So we use three bus parallel transfer technical, because the biasing and gain of hardware channel is inconsistent, it will lead to minute difference of the lightness and contrast of each image channel, and large plane array CCD image that is reconstructed appear banding effect.

The ideal image splice result must satisfy two conditions, the first is that the whole intensity and contrast of the spliced image must be consistent; the second is that the scabbed gap shouldn't exist. When the CCD image is diverted in each bus, the bus which nears each other has no overlap. So simulative moving blurred image splice algorithm based on the analysis of random sequence is presented, and it can solve the holistic consistency of scabbed image, also can eliminate scabbed gap well(TONG Xiao-chong,2006).

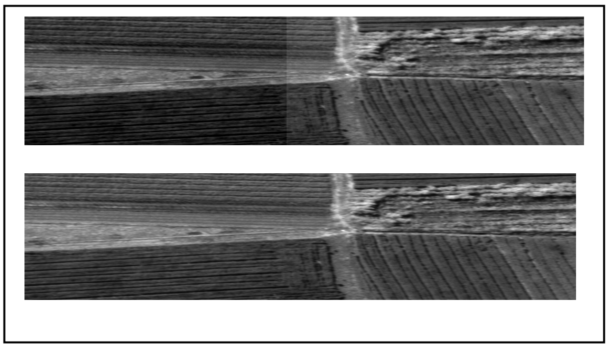

Figure 3. Multichannel inconsistent eliminating result (partial)

3.2 Image Field Illumination Correction

Theory analysis shows that the image illumination attenuating model varies according to 4 time power cosine function. There are also several other factors affecting the image illumination, for example the camera machining techniques, atmosphere attenuation, cloud, fog and so on, in order to obtain images with consistence lightness, proper algorithm that adapting multi error source to eliminate the image illumination inconsistency is demanded.

The original uneven illuminating image can be regarded as the result of an even illuminating image adding an uneven illuminating background image(LI Deren,2006), experiment analysis of the wavelet transform coefficients of emulational images, it is found that information of illumination non-uniformity mainly appears in wavelet approximate coefficients. Taking advantage of this property, the original image is first decomposed with multiresolution wavelet. Next, the natural logarithms of approximate coefficients are calculated, and then an appropriate attenuating operator is applied to implement the non-uniformity correction of approximate coefficients before exponentiating correction coefficients reversely, after linear contrast-stretch is applied to all the approximate coefficients. Finally, uniform illuminative aerial images are acquired through reconstruction of images. The experiments show that the wavelet analysis method can achieve a satisfying effect of removing the uneven illumination for digital aerial images and keeping well detail image features.

3.3 Image Fusion

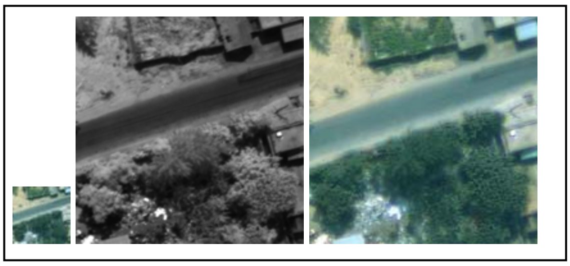

Figure 4. Image fusion result (partial)

On the base of the $2k \times 2k$ size true colour image composed from the R, G, and B band images, true colour image is fused with the $9k \times 9k$ size high resolution panchromatic image, $9k \times 9k$ size colour image is obtained in the end. According to the contrastive result of nearly seventy kind of image fusion algorithms in paper(Ma lan, 2005) , HPD fusion algorithm and wavelet fusion algorithm are adopt, results show that geometry resolution can be retained well and colour fidelity can also be retained.

4. ACCURACY TESTING AND APPLICATION

4.1 General Situation of the Experiment Site

Flying experiment is done with this camera in Qufu area Shandong province in May, 2005. 4,036 images are obtained in this experiment, including 1009 panchromatic images, 1009 R band images, 1009 G band images and 1009 B band images.

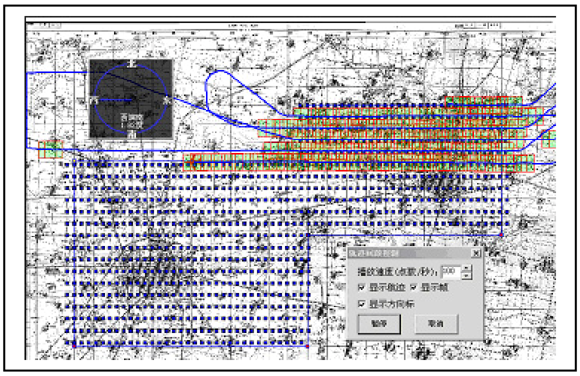

Figure 5. Flying trace in the experiment site

4.2 GSD Detection

The drone image of the ground GSD is shown in fig.6 in the condition of 800 m flight height, and 150km/hr flying velocity, the result shows that the mapping resolution of this camera's optical system achieves our design requirements (10 cm), and the validity of camera control like image motion compensation is also proved.

4.3 Mapping Precision Detection

Flying experiment is done with this camera in Qufu area Shandong province in May, 2005. In 800m flight height and 150 km/hr velocity flight conditions, our camera achieved the 10cm GSD design index. 1:1000 topographic map is surveyed using these images, through field completion, the mean square horizontal error of the outstanding points relative to the nearest GCP is 0.3 m, the vertical mean square error is 0.45 m.

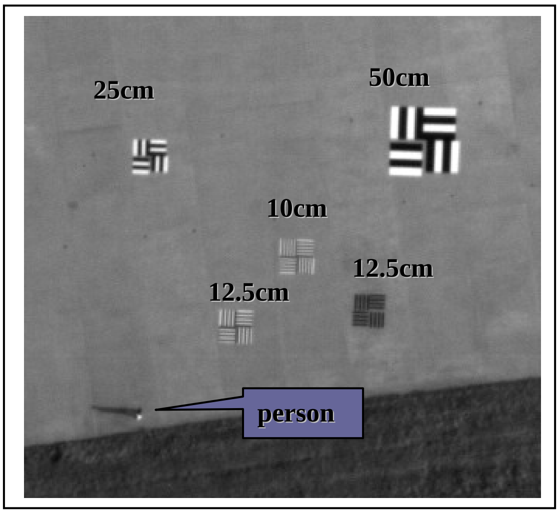

Figure 6. Ground drone experiment of GSD

5. CONCLUSION

The main technical specifications of this digital camera, including format size, geometric precision, ground resolution etc. are close to those of conventional film aerial camera. The system performance is stable, and it is capable of replacing conventional film aerial camera. The test results show that the camera possesses the following main characteristics:

1. It adopts an independent $9k \times 9k$ CCD to record the panchromatic image, which has a feature of strict central projection and helps to obtain high precision photogrammetry results.

2. Not only $2k \times 2k$ size true colour images, but also $9k \times 9k$ size panchromatic images as well as $9k \times 9k$ size true colour images after fusion can be supplied to the users.

3. Online flight quality and image quality detection function is provided. The system can display and browse the images real time so that the operators can adjust photographic parameters and check the job-cover conveniently.

4. Interface with PAV30 gyro-stabilized platform is supplied.

5. It can be stuck to the existing photogrammetric software well. Further improvement is made to the camera system based on the comprehensive flight test. So far, 340 km^2 of Guangzhou City aerial photogrammtry task has been completed by emplyong this aerial photogrammetry system.

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