# MAKE WIDE-ANGLED AERIAL CAMERA BY COMBINING SMALL-SIZED AREAL ARRAY CCD SENSORS


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## ABSTRACT

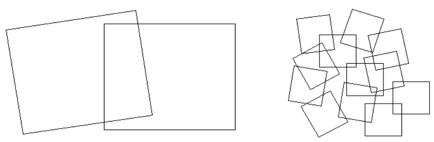
A new method for combining small-sized areal array CCD sensors to make one wide-angled digital aerial photography system is studied in this paper. The method is to install several small-sized areal array CCD cameras in the way that their perspective projecting centers form a line or a square, with their principal optical axes slanting fixed angle along designed directions. Such installation aims at getting one big frame of image, which is the exact mosaic of group image captured by combined cameras at one time, equivalent to the one taken directly by a wide-angled aerial camera. The system parameters: position relationships between cameras, exact principal distance of each camera and optical distortion parameters of each lens are obtained with high precision through our designed camera calibration method – space resection with several images of calibration field. The research work and experiments in this paper can guide the production of whole wide-angled high-resolution digital camera.



**Keywords:** wide-angle digital camera, multi-camera system, equivalent image, camera calibration, high resolution aerial image.


## □. INTRODUCTION

Due to the limitation of technical level, the size of current areal CCD sensor is not big enough to be used to make the high-resolution wide-angled aerial camera. Although it is no problem to make the normal-angled camera with CCD sensor of normal size, if using it to capture high-resolution image, its shortcoming of too small imaging size causes the problem - the necessary image overlapping area required in conventional aerial photography is hard to keep under the limited flying control condition of nowadays. As illustrated in Fig.1, in terms of same flying control precision, big images in Fig.$1_a$ are able to meet the overlapping requirement, while small images shown in Fig.$1_b$ can even hardly reach the requirement of seamless overlay.



$1_a$ $1_b$

Fig. 1: Flying control error affects image overlap

On the one hand, what we have is small-sized areal CCD camera; on the other what we desire is large-sized high-resolution aerial image. In order to solve this dilemma, this paper presents a method using small-sized CCD sensors to compose the wide-angled aerial camera.

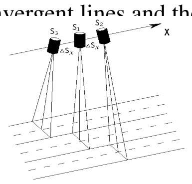
## □.MULTI-CAMERA COMBINED AERIAL PHOTOGRAPHY SYSTEM

The wide-angled high-resolution aerial photography system made from multi-camera combination may have 3- camera and 4-camera structure. This part studies the two types of structure, equivalent image converting etc. in detail.

### 2.1 3-camera combination scheme

1). Structure

The 3 small-sized cameras are laid out on the airplane's platform in the following way (Fig. 2): the projecting centers of the three camera ( $S_2, S_1, S_3$ ) are in one line, parallel to airplane's platform and to flying direction. The distance between two adjacent camera's projecting centers is $\Delta S_x$. The middle camera $S_1$ has its principal optical axis $SO_1$ perpendicular to airplane's platform, the second camera $S_2$ 's principal optical axis $SO_2$ is vertical to flying direction but tilts left a certain angle from $SO_1$, and the third camera $S_3$ 's principal optical axis $SO_3$ is vertical to flying direction but tilts right a certain angle from $SO_1$. In this case, if there is a set of parallel lines on the ground and they are vertical to flying direction, the respective image formed in the 3 cameras will be as Fig. 3 shows. That is, image of the middle camera is parallel lines. Image of the second camera (left-tilt camera) is left convergent lines and the main vanishing point is $I_2$. Image of the third camera (right-tilt camera) is right convergent lines and the main vanishing point is $I$



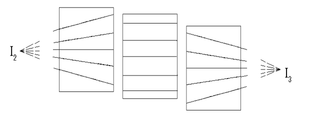
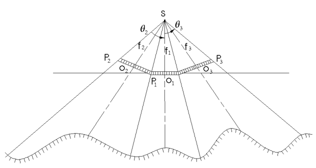


Fig. 2: Layout of 3 cameras Fig.3: Parallel lines' image in 3 cameras

2). Image conversion in 3-camera system

Generally, the three images can be transformed into the horizontal equivalent image $P_0$ through the algorithm given below. The transformation principle is illustrated in Fig. 4, where 3 cameras' projecting centers are virtually overlapped into one point *S*, along flying direction. Signs $\theta_2, \theta_3$ denote the tilt angles of $P_2, P_3$. Signs $f_2, f_1, f_3$ and $f_0$ denote the principal-distances of $P_2$, $P_1$, $P_3$ and the equivalent image $P_0$ respectively. The captured images are in the position of $P_2$, $P_1$, $P_3$ (left-tilt $P_2$, horizontal $P_1$ and right-tilt $P_3$).



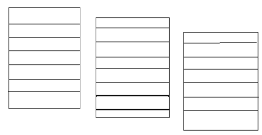


Fig. 4 Illustration of images conversation Fig.5: projecting center displacement

Assume that the flying direction is X coordinate axis. $\Delta S_x$ is the projecting center displacement between two adjacent camera , i.e. $S_2$ and $S_1$, $S_3$ and $S_1$ .Then, according to the principle of collinear equation, the transforming expression from $P_1$ to $P_0$ is

$$\begin{cases} x_0 = f_0 \dfrac{x_1}{f_1} \\ y_0 = f_0 \dfrac{y_1}{f_1} \end{cases} \quad (2\text{-}1)$$

The transforming expression from $P_2$ to $P_0$ is:

$$\begin{cases} x_0 = f_0 \dfrac{x_2}{y_2 \sin\theta_2 + f_2 \cos\theta_2} + \Delta S_X \\ y_0 = f_0 \dfrac{y_2 \cos\theta_2 - f_2 \sin\theta_2}{y_2 \sin\theta_2 + f_2 \cos\theta_2} \end{cases} \quad (2\text{-}2)$$

The transforming expression from $P_3$ to $P_0$ is:

$$\begin{cases} x_0 = f_0 \dfrac{x_3}{y_3 \sin\theta_3 + f_3 \cos\theta_3} - \Delta S_X \\ y_0 = f_0 \dfrac{y_3 \cos\theta_3 - f_3 \sin\theta_3}{y_3 \sin\theta_3 + f_3 \cos\theta_3} \end{cases} \quad (2\text{-}3)$$

Because practically, we are unable to position 3 cameras' projecting centers at exactly the same point in space, the projecting center displacement (See Fig.5) from second and third camera to middle camera $\Delta S_x$ needs to be added to formula (2-2) and subtracted from (2-3).

In 3-camera combination scheme, the field of view (FOV) of whole photography system is enlarged 3 times of a single camera in the direction vertical to flight. But the FOV along flying direction remains no change (Actually it shrinks.). So the longitudinal overlap should be increased in the course of aerial photography. In general, it is easier to control longitudinal overlap than lateral overlap. Hence, this method is practicable.

## 2.2 4-camera combination scheme

1).Structure

Other than the structure of 3-camera combination, in the 4-camera combination scheme, each camera ought to tilt outwards a certain angle so that the overall FOV is expanded in both X and Y directions. That is, each camera has to rotate angles $\theta_X$, $\theta_Y$ round X, Y coordinate axis respectively, as shown in Fig. $6_a$, $6_b$. In such a structure, the 4 cameras' projecting centers form a square, with their principal optical axes tilting fixed angle along designed directions.

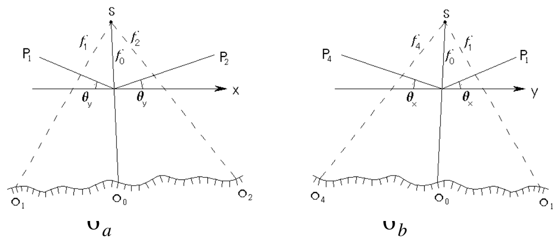
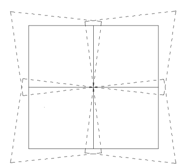


Fig. 6: Camera tilt in 4-camera combination scheme

The geometry shape of the 4 original images from 4-camera system is like the solid lines in Fig. 7. And after the rectification of them and mosaic them, the equivalent image is like the dash lines in Fig. 7 It shows that the virtual principal optical axis of the equivalent image $P_0$ is perpendicular to horizontal plane, while the four actual principal optical axes corresponding to the four cameras are biased $\pm\theta_x, \pm\theta_y$ from the virtual principal optical axis. Fig. 8 shows the analytical expression of $\vec{\theta}_x, \vec{\theta}_y$ in vector form.



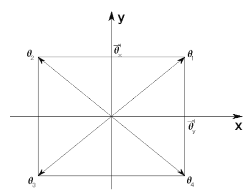


Fig. 7: Original and equivalent images Fig. 8: Bias of actual principal optical axes

2). Image conversion in 4-camera system

The image conversation from $P_1$, $P_2$, $P_3$ and $P_4$ into $P_0$ consists of the rectification of image tilt and the correction of projecting center shifts. The principal of tilt rectification is

$$\begin{bmatrix} x_0 \\ y_0 \\ -f_0 \end{bmatrix} = \begin{bmatrix} \cos\theta_y & 0 & \sin\theta_y \\ 0 & \cos\theta_x & \sin\theta_x \\ -\sin\theta_y & -\sin\theta_x & \cos\theta_x\cos\theta_y \end{bmatrix} \begin{bmatrix} x \\ y \\ -f \end{bmatrix}$$

that is,

$$\begin{cases} x_0 = -f_0 \dfrac{x\cos\theta_y - f\sin\theta_y}{-x\sin\theta_y - f\sin\theta_x + f\cos\theta_x\cos\theta_y} \\ y_0 = -f_0 \dfrac{y\cos\theta_x - f\sin\theta_x}{-x\sin\theta_y - y\sin\theta_x + f\cos\theta_x\cos\theta_y} \end{cases}$$

Add the correction value $\Delta S_x$ $\Delta S_y$ , then

$$\begin{cases} x_0 = -f_0 \dfrac{x\cos\theta_y - f\sin\theta_y}{-x\sin\theta_y - f\sin\theta_x + f\cos\theta_x\cos\theta_y} - \Delta S_x \\ y_0 = -f_0 \dfrac{y\cos\theta_x - f\sin\theta_x}{-x\sin\theta_y - y\sin\theta_x + f\cos\theta_x\cos\theta_y} - \Delta S_y \end{cases}$$

## □. MULTI-CAMERA SYSTEM CALIBRATION

The design in part 2 actually is an ideal situation that no error occurs during the process of system manufacture and assembly. However, the system error is inevitable. The real wide-angled photography system made of combined small-sized CCD cameras needs system calibration of high precision. The parameters to be calibrated ought to include:

1) Each camera's inner elements ( $x_0$ , $y_0$ , $f_0$ ) and optical distortion parameters.

2) Relative exterior elements ( $\theta_x, \theta_y, \theta_z, dS_x, dS_y, dS_z$ )in combination system.

### 3.1 Indoor and outdoor calibration field

In order to carry out the required calibration, we utilize both indoor (Fig. 9) and outdoor (Fig. 10) calibration field, which are built specially for the purpose of close-range camera calibration. Within the two calibration fields, controlling points array with rather big space depth are arranged. The coordinates of them are precisely determined by geodetic instrument and are checked for deformation correction caused by varied environment conditions periodically. So the coordinates values of controlling points in our calibration field can be used as true value in system calibration.

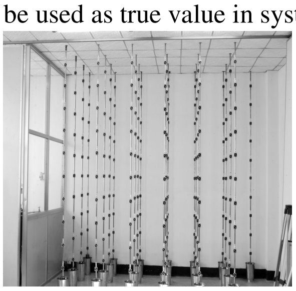


Fig. 9: Indoor calibration field  Fig. 10: Outdoor calibration field

### 3.2 Principle and algorithm of camera calibration

To peel off the correlative influence between inner and exterior elements (including distortion parameters), we specially designed the solution called space resection with multiple images. The method uses several images that cover a certain number of controlling points of calibration field, takes the coordinates of controlling points in image as observation value, solves exterior elements, optical distortion errors, other parameters affecting light beam shape as well as exterior elements of multi-images as a whole, on the basis of collinear equation, with the controlling points' coordinates in object space taken as true value.

Denote exterior elements as $X_{ex}$ , inner elements of image as $X_{in}$ , some added parameters as $X_{ad}$ , observation values as $V$ . According to collinear equation in photogrammetry, the error equation can be written as:

$$V = AX_{ex} + BX_{in} + CX_{ad} - L$$

Where, the denotations carry the following matrix expressions:

$$V = \begin{bmatrix} v_x \\ v_y \end{bmatrix}^T \qquad X_{in} = \begin{bmatrix} \Delta f & \Delta x_0 & \Delta y_0 \end{bmatrix}^T$$

$$A = \begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} & a_{15} & a_{16} \\ a_{21} & a_{22} & a_{23} & a_{24} & a_{25} & a_{26} \end{bmatrix}$$

$$C = \begin{bmatrix} \overline{b_1} & \overline{b_2} & \cdots & 0 & 0 & \cdots \\ 0 & 0 & \cdots & \underline{c_1} & \underline{c_2} & \cdots \end{bmatrix}$$

$$X_{ex} = \begin{bmatrix} \Delta X_S & \Delta Y_S & \Delta Z_S & \Delta\varphi & \Delta\omega & \Delta\kappa \end{bmatrix}^T$$

$$X_{ad} = \begin{bmatrix} a_1 & a_2 & \cdots & \beta_1 & \beta_2 & \cdots \end{bmatrix}^T$$

$$B = \begin{bmatrix} a_{17} & a_{18} & a_{19} \\ a_{27} & a_{28} & a_{29} \end{bmatrix} \qquad L = \begin{bmatrix} x-(x) & y-(y) \end{bmatrix}^T$$

Suppose three images I□II□III are captured, and each one possesses the communal points 1,2, …n and has four added parameters $a_1$ □ $a_2$ □ $\beta_1$ □ $\beta_2$ , then the error equation is

$$\underset{6n\times 1}{V} = \underset{6n\times 18}{A}\,\underset{18\times 1}{X_{ex}} + \underset{6n\times 3}{B}\,\underset{3\times 1}{X_{in}} + \underset{6n\times 4}{C}\,\underset{4\times 1}{X_{ad}} - \underset{6n\times 1}{L}$$

That is,

$$
\underset{6n\times 1}{V}=\begin{bmatrix} A_{\text{I£-1}} & 0 & 0 & B_{\text{I£-1}} & C_{\text{I£-1}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ A_{\text{I£-n}} & 0 & 0 & B_{\text{I£-n}} & C_{\text{I£-n}} \\ 0 & A_{\text{II£-1}} & 0 & B_{\text{II£-1}} & C_{\text{II£-1}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & A_{\text{II£-n}} & 0 & B_{\text{II£-n}} & C_{\text{II£-n}} \\ 0 & 0 & A_{\text{III£-1}} & B_{\text{III£-1}} & C_{\text{III£-1}} \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & A_{\text{III£-n}} & B_{\text{III£-n}} & C_{\text{III£-n}} \end{bmatrix}_{6n\times 25} \begin{bmatrix} X_{\text{I£-}ex} \\ X_{\text{II£-}ex} \\ X_{\text{III£-}ex} \\ X_{in} \\ X_{ad} \end{bmatrix}_{25\times 1} - \begin{bmatrix} x_{\text{I£-1}}-(x_{\text{I£-1}}) \\ \cdots \\ y_{\text{I£-n}}-(y_{\text{I£-n}}) \\ x_{\text{II£-1}}-(x_{\text{II£-1}}) \\ \cdots \\ y_{\text{II£-n}}-(y_{\text{II£-n}}) \\ x_{\text{III£-1}}-(x_{\text{III£-1}}) \\ \cdots \\ y_{\text{III£-n}}-(y_{\text{III£-n}}) \end{bmatrix}_{6n\times 1}
$$

According to the least square principle: $V^T \times V = \min$ , so the unknown parameters $X_{\text{I£-}ex}$ □ $X_{\text{II£-}ex}$ □ $X_{\text{III£-}ex}$ □ $X_{in}$ and $X_{ad}$ can be solved by the following iterative process:

$$
\begin{bmatrix} X_{\text{I£}ex} \\ X_{\text{II£}ex} \\ X_{\text{III£}ex} \\ X_{in} \\ X_{ad} \end{bmatrix} = \left( \begin{bmatrix} A_{\text{I}} & 0 & 0 & B_{\text{I}} & C_{\text{I}} \\ 0 & A_{\text{II}} & 0 & B_{\text{II}} & C_{\text{II}} \\ 0 & 0 & A_{\text{III}} & B_{\text{III}} & C_{\text{III}} \end{bmatrix}^T \begin{bmatrix} A_{\text{I}} & 0 & 0 & B_{\text{I}} & C_{\text{I}} \\ 0 & A_{\text{II}} & 0 & B_{\text{II}} & C_{\text{II}} \\ 0 & 0 & A_{\text{III}} & B_{\text{III}} & C_{\text{III}} \end{bmatrix} \right)^{-1} \left( \begin{bmatrix} A_{\text{I}} & 0 & 0 & B_{\text{I}} & C_{\text{I}} \\ 0 & A_{\text{II}} & 0 & B_{\text{II}} & C_{\text{II}} \\ 0 & 0 & A_{\text{III}} & B_{\text{III}} & C_{\text{III}} \end{bmatrix} \begin{bmatrix} x_{\text{I£1}}-(x_{\text{I£1}}) \\ \cdots \\ y_{\text{III£n}}-(y_{\text{III£n}}) \end{bmatrix} \right)
$$

### 3.3 Calibration contents in multi-camera system

Though the principle and technique of CCD cameras is quite different from that of common analog cameras, the two categories are similar in calibration specifications and method. However, the calibration contents vary from different purposes. As for our multi-camera system, the following items are calibrated first : The inner elements of each camera: principal point□ $x_0$ , $y_0$ □and principal distance□$f$□;The optical distortion parameters : radial distortion factors□ $k_1$ □ $k_2$ □…□ and eccentric distortion factors□ $p_1$ , $p_2$ □.

After the inner elements and distortion parameters of each small-sized CCD camera has been obtained using the solution of space resection with multiple images, the cameras are mounted onto the platform specially designed for multi-camera combination system and they are electronically controlled to take the images of the same calibration field simultaneously. With these data, real exterior elements: linear elements □ $X_S$ , $Y_S$ , $Z_S$ □and angle elements □ $\varphi$ , $\omega$ , $\kappa$ □of the multi-camera system, relative exterior elements of each camera to the principal optical axis of equivalent image ( $\theta_x, \theta_y, \theta_z, dS_x, dS_y\ dS_z$ ) are to be determined.

### 3.4 Multi-camera system correction

The following corrections are indispensable for practical system. The corrections are based on system calibration results.

1) Exterior elements correction

The correction component of exterior elements ( $dS_x, dS_y, dS_z, d\theta_X, d\theta_Y, d\theta_Z$ ) is the difference between system design value and its corresponding calibrated value.

2) Image coordinates correction

Denote corrected image coordinates as ($x', y'$), observed image coordinates as ( $x_{im}$ , $y_{im}$ ),radial distortion factor as $k_1$ . (Since our multi-camera system use small-sized non-metric CCD cameras, we can take the radial distortion factor $k_1$ into consideration only.) Suppose $r$ is the radius from image point to principal point. Then correction model for image correction is:

$$
\begin{cases} x' = x_{im} - x_0 + k_1 (x_{im} - x_0) r^2 \\ y' = y_{im} - y_0 + k_1 (y_{im} - y_0) r^2 \end{cases}
$$

Where, $r^2 = (x_{im} - x_1)^2 + (y_{im} - y_1)^2$

3) Equivalent image correction

The equivalent image coordinates ($x$ , $y$) is calculated on the basis of ($x', y'$). Further, ($x$ , $y$) needs to be corrected by correction component of exterior elements. The correction equation is:

$$
\begin{cases} dx = ds_X + \dfrac{x}{f} ds_Z + (f + \dfrac{x^2}{f}) d\theta_Y + \dfrac{xy}{f} d\theta_X + y d\theta_Z \\ dy = ds_Y + \dfrac{y}{f} ds_Z + (f + \dfrac{y^2}{f}) d\theta_X + \dfrac{xy}{f} d\theta_Y + x d\theta_Z \end{cases}
$$

## □.EXPERIMENTS

The following experiments are carried out to test and verify the above mentions.

Four FUJIFILM FinePix 4700zoom areal CCD cameras are used in the experiments. FinePix type is characterized by small size, handy use, high light sensitivity, large storge etc..especially, the capabillity of locking principal distance.

3 and 4 FinePix 4700zoom cameras are mounted on experimental multi-camera platform to construct the 3-camera combiantion system (Fig. 12) and 4-camera combination system (Fig. 13).

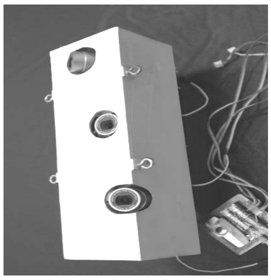


Fig. 12: 3-camera system

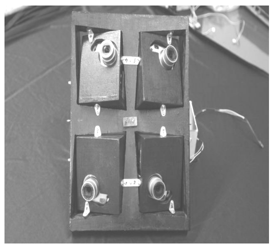


Fig. 13: 4-camera system

Table 1 gives the result for each single camera calibration. The cailbration is done through outdoor calibration field, employing the method of space resection with multiple images.( For each camera, 4 images are used.)

Table 1: Single FinePix 4700zoom camera calibration result.

| | | CAMERA I | CAMERA II | CAMERA III | CAMERA IV |
|---|---|---|---|---|---|
| Image No. 1 | $X_c$ (m) | 1015.198 | 1013.998 | 1013.889 | 1013.604 |
| | $Y_c$ (m) | 205.855 | 205.995 | 205.887 | 205.947 |
| | $Z_c$ (m) | -499.199 | -500.222 | -500.151 | -500.271 |
| | $\varphi$ (dms) | -49.3450 | -52.5359 | -50.2327 | -50.2122 |
| | $\omega$ ( dms) | 21.5354 | 22.5656 | 24.3053 | 24.3908 |
| | $\kappa$ ( dms) | -1.5025 | -1.4629 | -3.0603 | -6.2600 |
| Image No. 2 | $X_c$ (m) | 1015.067 | 1013.866 | 1013.771 | 1013.412 |
| | $Y_c$ (m) | 205.861 | 205.822 | 205.949 | 205.812 |
| | $Z_c$ (m) | -499.029 | -500.163 | -499.993 | -500.185 |
| | $\varphi$ (dms) | -55.2224 | -57.5505 | -52.0226 | -51.5416 |
| | $\omega$ ( dms) | 22.0429 | 22.3040 | 24.3618 | 22.4853 |
| | $\kappa$ ( dms) | 87.4625 | 85.5028 | 86.4004 | 83.0528 |
| Image No. 3 | $X_c$ (m) | 1017.916 | 1015.769 | 1015.682 | 1015.908 |
| | $Y_c$ (m) | 205.913 | 206.025 | 205.925 | 205.956 |
| | $Z_c$ (m) | -504.104 | -504.228 | -504.560 | -504.341 |
| | $\varphi$ (dms) | -65.2017 | -64.1110 | -62.4347 | -62.1503 |
| | $\omega$ ( dms) | 20.4813 | 22.1640 | 23.5959 | 25.5026 |
| | $\kappa$ ( dms) | 0.0851 | -0.4715 | -0.4551 | -2.4304 |
| Image No. 4 | $X_c$ (m) | 1017.863 | 1015.706 | 1015.623 | 1015.809 |
| | $Y_c$ (m) | 205.906 | 205.859 | 205.948 | 205.834 |
| | $Z_c$ (m) | -503.990 | -504.106 | -504.418 | -504.226 |
| | $\varphi$ (dms) | -71.4651 | -69.1735 | -63.5131 | -64.1245 |
| | $\omega$ ( dms) | 23.4640 | 24.5841 | 24.3252 | 23.1752 |
| | $\kappa$ ( dms) | 88.34050 | 87.1827 | 88.1544 | 84.4937 |
| $x_0$ (p) | | 6.22 | -24.03 | 38.95 | 1.26 |
| $y_0$ (p) | | 0.79 | 19.37 | 21.75 | 40.84 |
| $f$(p) | | 2690.33 | 2675.15 | 2727.05 | 2689.32 |
| $k_1$ ($p^{-2}$) | | -4.03e-008 | -4.15e-008 | -3.77e-008 | -3.86e-008 |

Notes:

1.The above parameters units: *m* stands for meter, *dms* for degree minute second, *p* for pixel, $p^{-2}$ .for pixel$^{-2}$

2.The calibrated parameters of $x_0$ , $y_0$ ,$f$ are in pixel. To convert them into millimeters, multiply the size of each pixel.

3.The calibrated result is applicable for infinite distance.

The calibrations of 4-camera system and 3- camera system are also done through indoor calibration field. The image is got by electronically controlling 4 or 3 cameras to expose at the same time. Two sets of image data is used.. Due to space limitation in space, the data is not included in the paper..

The Unmanned Aerial Vehicle (UAV-II, developed by Chinese Academy of Surveying&Mapping, Fig. 14) has equipped with 3-camera system to take aerial images of Beijing suburb. Fig.15 is one image product of 3-camera system. It is the equivalent image from 3 single images' recitification and mosaic with cooresponding algorithms.

Fig.14: UAV-II equipped with multi-camera system

Fig. 15: One equivalent image of 3-camera

## □.CONCLUSION

Based on the research work and experiments in this paper, we have the following application ideas:

1.To construct multi-camera system using the common simple digital cameras. To equip simple Unmanned Aerial Vehicle equipped with such aerial camera to make low-altitude aerial photography will get high-resolution aerial images.

2.Guided by the researched principle, the whole camera with 3 or 4 lens and corresponding aeral CCD sensors can be developed. To perform precise calibration of such whole camera in factory in order that the inner and exterior elements approach theoretic design values to the utmost. Then wide-angled high-resolution digital camera is produced.

## REFERENCES


1.Zhizhuo Wang, *principle of photogrammetry*, Publishing House of Surveying and Mapping,Beijing,1979

2.Wenhao Feng, *Close-range photogrammetry*, Publishing House of Wnhan Univ.Wuchang, 2002

3.Wenhao Feng,, *Deduction of Constraint Condition in the Calibration of Stereo-Vision System.* Journey of Wuhan Technical Univ. of Surveying & Mapping, Vol.1, No.1, 1998

4.Axel Graser, *Synchronization of a Stereo Camera System for Auto-Zoom in the Rehabilitation Robot FRIEND*,

5.Fraser,C.S. *Some Thoughts on the Emergence of Digital Close-Range Photogrammetry.* The Photogrammetric Record, Apr.1998

6.FUJI Photo Film Co.,Ltd., *Owner's ManualFUJIFILM Digital Camera FinePix 4700zoom*, Japan,2001.