# LOW ALTITUDE AERIAL PHOTOGRAMMETRY USING A KITE BALLOON

Taichi OSHIMA and Kiyoe MIYASHITA
College of Eng., Hosei University
3-7-2 Kajinocho,Koganei, Tokyo,JAPAN
Commission : V

## 1. Introduction

Various studies are under way to take aerial photographs simply at low cost at altitudes of several hundred meters for use for investigations of disasters,environments,etc. For this purpose, non-metri cameras are increasingly used.

The present study experimented to obtain not only elements of outer orientation but also those of inner orientation such as principal distance,principal point dislocation, lens distortion coefficients and film deformation coefficients,using 35 mm non-metric cameras for obtaining three dimensional coordinates from streo-photos and variously compared for examination.

This paper describes a kite balloon camera system with 35 mm camera gyro-controled of which allows to obtain stereo-photos from low altitude and methodology for three dimensional measurement. It was attempted to improve a simple aerial photographic system and as a result, a system could be obtained, which allows easy stereometric aerial photographing.

## 2. Photogrammetry using a non-metric camera

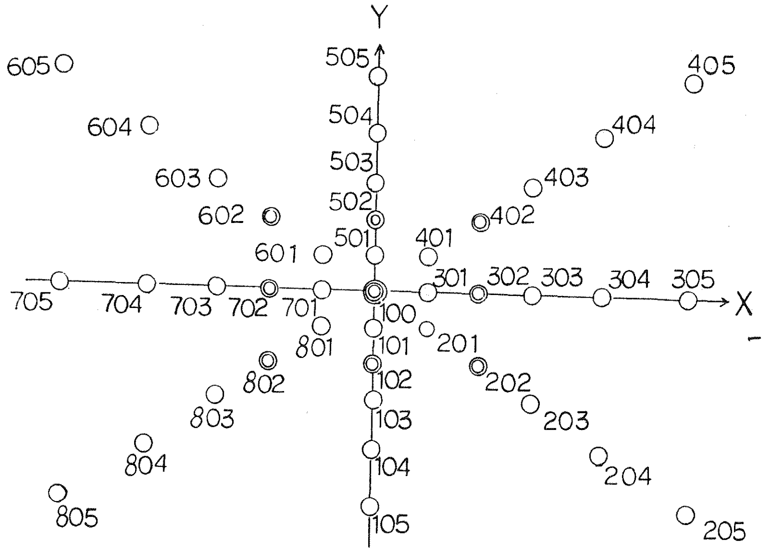
In general, a 35 mm camera is for non-metric without any index mark and is not accurate in geometrical elements such as principal point, principal distance, lens distortion and film flatness. The present study used a method of analytically obtaining such elements of inner orientation as principal point dislocation $(x_o, y_o)$, principal distance f, function coefficients $k_1$ and $k_2$ giving lens distortion and coefficients $p_1$ to $p_6$ of polynomials giving a film curved surface, using control points arranged three-dimensionally at very high accuracy.

The camera used in the experiment were 35 mm cameras of Olympus OM-1 (f=28 mm) and Nicon F3 (f=50 mm) and a 6 X 6 plate camera of Husselbrat MK70 (f=60 mm).

### 2.1 Photographing at experiment site

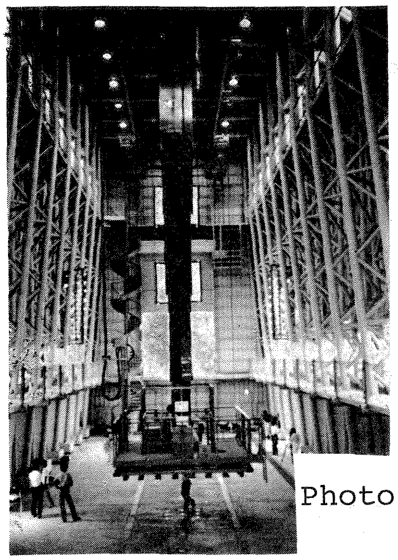
Highly accurate control points were arranged in an experiment site set in a remote sensing house of Geopgraphical Survey Institute, Ministry of Construction (Fig.-1). Total 41 control points were arranged with 5 points in each of eight radial directions from the center. 9 points among them, including the central control point were set at a height of 1.5 m, and the other points, at 0 m in three-dimentional arrangement.

Photographing was executed vertically downward or at a slight inclination from a single-point adjustable suspension scaffold shown in Photo 1, at an altitude of 8 m or 13 m at any of five points; central control point (0 point) and points of ± 1 m and ± 2 m in base length from the 0 point in X- axis direction. Photo-3 shows photos taken by Olympus OM-1.




◎ : H=1.5m ○ : H=0.0m

Fig. 1 Arrangement of Control points
Camera calibration



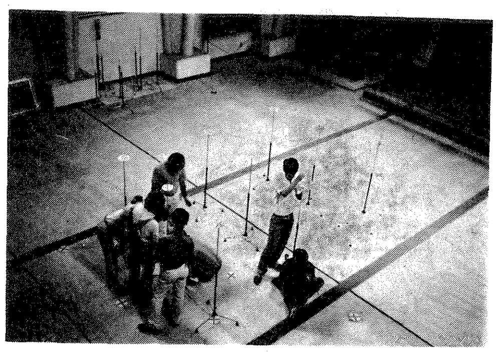
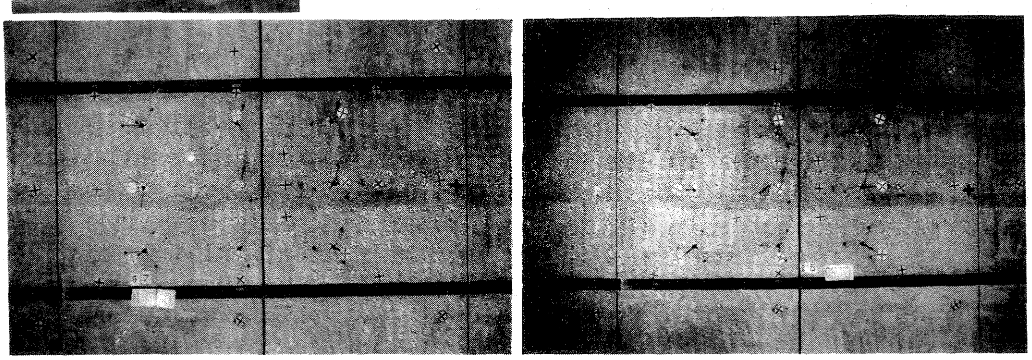


Photo 2 Control points

Photo 1 General view of Experiment site
for camera calibration



H=8 m H=13m

Photo 3 Stereo-photo for camera calibration
taken by Olympus OM-1

## 2.2 Self-Calibration by single photo orientation

The present study used the following equation :

$$x=-f\frac{a_{11}(X-X_0)+a_{12}(Y-Y_0)+a_{13}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)}+\Delta x$$

$$y=-f\frac{a_{21}(X-X_0)+a_{22}(Y-Y_0)+a_{23}(Z-Z_0)}{a_{31}(X-X_0)+a_{32}(Y-Y_0)+a_{33}(Z-Z_0)}+\Delta y$$

where :

$(X, Y, Z)$; ground coordinates of an object

$(X_0, Y_0, Z_0)$; ground coordinates of perspective center

$f$ ; focal distance

$(x, y)$; image coordinates on the photos

$a_{ij}$ ; image of matrix element

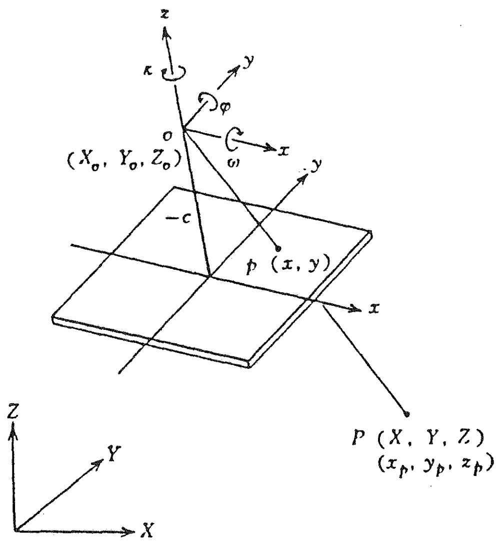



Fig. 2 Self-calibration by single photo orientation

$$R=\begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

$$=\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\omega & -\sin\omega \\ 0 & \sin\omega & \cos\omega \end{pmatrix}\begin{pmatrix} \cos\varphi & 0 & \sin\varphi \\ 0 & 1 & 0 \\ -\sin\varphi & 0 & \cos\varphi \end{pmatrix}\begin{pmatrix} \cos k & -\sin k & 0 \\ \sin k & \cos k & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$(\Delta x, \Delta y)$: Correction of elements of inner orientation

$$\Delta x = x_0 + x(k_1 r^2 + k_2 r^4) + (p_1 x + p_2 y + p_3 x y + p_4 y^2)$$

$$\Delta y = y_0 + y(k_1 r^2 + k_2{}^4) + (p_5 x y + p_6 x^2)$$

$$r^2 = (x^2 + y^2)/f^2$$

where :

$(x_0, y_0)$: Principal point dislocation

$(k_1, k_2)$: coefficient of radial distortion

$(p_1 \sim p_6)$: coefficients of film deformation

Though only six elements of outer orientation of $X_0$, $Y_0$, $Z_0$, $\omega$, $\varphi$, and are treated as unknown variables with a metric camera, the above mentioned elements of inner orientation, i.e., $x_0$, $y_0$, $k_1$, $k_2$, $p_1 \sim p_6$ were treated as unknown variables in addition to the elements of outer orientation with a non-metric camera. Image coordinates were measured using original negative films directly by stereocomparator (minimum reading 1μm ) of Zeiss Jena, East Germany and owned by the Institute. The observation was made twice independently.

Since the observed values are machine coodinates, they must be transformed into image coordinates with the film center as the origin. However, since a non-metric camera does not have any index mark, respectively two points on four sides, i.e. total eight points are selected as showned in Fig. 3, to obtain

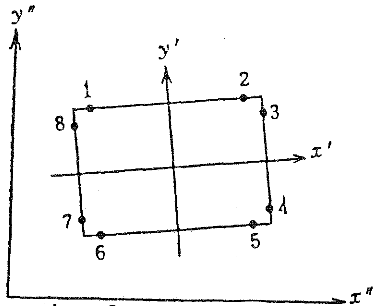


Fig.3 Determination of image axis

the center of each side with the method of least square applied to affine transformation, for replacing the index coordinate system.

The orientation works hve been done in following four cases :

(1) Case 1

The initial approximate solution of elements of inner orientation were given, to obtain only the elements of outer orientation. The number of unknown variables was six: camera position( $X_0, Y_0, Z_0$ ) and camera inclination( $\omega, \varphi, k$ ).

(2) Case 2

Total nine unknown variables were obtained, including the elements of outer orientation obtained in Case 1, principal point dislocation( $x_0, y_0$ ) and focal distance f.

(3) Case 3

The elements of outer orientation, principal point dislocation and focal distance obtained in Cade 2 were given, to obtain lens distortion coefficients $k_1$ and $k_2$.

(4) Case 4

The elements of orientation obtained in Case 3 were given, to obtain film flatness deformation coefficients $p_1$ to $p_6$.

## 2.3 Result and Discussion

Table 1 lists the elements of inner orientation obtained by photographing at an altitude of 8 m using Olympus OM-1.

Table 1 Calibration data of olympus OM-1

| orientation factor | | $X=+2$ m | $X=+1$ m | $X=0$ m | $X=-1$ m | $X=-2$ m | mean |
|---|---|---|---|---|---|---|---|
| focal distance | (mm) | 28.144895 | 28.116159 | 28.111610 | 28.123866 | 28.097620 | 28.11883 |
| principal point | $X_p$ (mm) | 0.112821 | 0.119975 | 0.107373 | 0.129291 | 0.115021 | 0.11689 |
| dislocation | $Y_p$ (mm) | 0.023717 | 0.005486 | 0.023828 | 0.035665 | 0.025675 | 0.02287 |
| lens distortion | K 1 | 1.43E-4 | 1.44E-4 | 1.52E-4 | 1.46E-4 | 1.50E-4 | 1.47E-4 |
| | K 2 | −2.14E-7 | −2.20E-7 | −2.30E-7 | −2.19E-7 | −2.30E-7 | −2.23E-7 |
| film deformation | P 1 | −1.62E-3 | −8.81E-4 | −1.72E-3 | −1.27E-3 | −1.27E-4 | −1.40E-3 |
| | P 2 | −1.31E-3 | −5.21E-4 | −7.00E-4 | −3.80E-4 | −1.27E-4 | −3.48E-4 |
| | P 3 | 2.46E-5 | 6.72E-5 | 5.52E-5 | 2.38E-5 | 2.87E-5 | 3.99E-5 |
| | P 4 | 4.21E-5 | 3.33E-5 | 6.29E-5 | 5.64E-6 | 8.11E-6 | 3.01E-5 |
| | P 5 | 4.12E-5 | 1.97E-5 | 3.55E-6 | −2.35E-5 | −5.25E-5 | 4.08E-6 |
| | P 6 | −2.47E-5 | −4.85E-5 | −1.34E-5 | −3.17E-5 | −3.01E-5 | −2.97E-5 |

The elements of inner orientation were different fron photo to photo, but showed almost similar trends. Therefore, the mean value were obtained, as elements of inner orientation for the non-metric camera used for analysis.

Table 2 lists the accuracies of single photo orientation. They are mean errors on negatives. It can be seen that more elements of inner orientation considered give higher accuracies. Especially, in Case 3 where the focal distance, principal point dislacation and lens distortion were included, the accuracies were enhanced remarkably. This suggests that a non-metric camera

Table 2 Orientation accuracy of single photo

| | height | base | ケース 1 | ケース 2 | ケース 3 | ケース 4 |
|---|---|---|---|---|---|---|
| Olympus OM-1 | 13 M | +2 | 24.125 | 17.802 | 4.091 | 3.477 |
| | | +1 | 22.880 | 19.895 | 4.550 | 3.903 |
| | | 0 | 22.973 | 21.027 | 4.733 | 3.832 |
| | | −1 | 27.660 | 16.517 | 4.185 | 3.278 |
| | | −2 | 24.753 | 19.928 | 5.141 | 4.623 |
| | 8 M | +2 | 38.726 | 38.930 | 7.454 | 4.944 |
| | | +1 | 44.636 | 40.548 | 7.117 | 5.322 |
| | | 0 | 53.473 | 43.876 | 8.439 | 5.136 |
| | | −1 | 43.997 | 41.465 | 6.443 | 4.056 |
| | | −2 | 42.848 | 41.747 | 6.833 | 5.228 |

is very large in lens distortion and can be used for measurement by correcting it. In Case 4 where all the elements of inner orientation were considered, orientaion could be made at error of 3 to 6 μm, to improve the accuracies almost to the level of a a metric camera.

## 2.4 outline of camera with fiducial mark

A non-metric camera does not have any fiducial mark as mentioned aboce, and the machine coordinates are trnsformed into fiducial mark coordinates on the assumption that the four sides of a film are straight. However, actually the four sides are certainly uneven. The freedom from fiducial mark brought about many difficulties in observation. If a non-metric camera at least had a fiducial mark, it was surmised that the accuracy could be further enhanced. For this reason, a newly made non-metric camera with fiducial mark, it was surmised that the accuracy could be further enhanced. For this reason,this camera was also added for the experiment. In addition to the fiducial mark, the production Co. provides the orientation data of camera tested by Company,such as focal distance, principal point dis-location and lens distortion as test value for the camera.

The outline of the camera is shown below :

Camera: Contax TRS II Quartz
Lens : Distagon T*35 mm F1.4, Focal distance F=35.743 mm
Weight: 1,340 g
Shutter: Radio Controlled with stroboscope
Winding: Contax Real Time Winder W-3, frame by frame
Other data are listed in Table 3.

Table 3 (a) Image Distortion

| 0 | 5 | 7.5 | 10 | 12.5 | 15 | 17.5 | 20 | (mm) |
|---|---|---|---|---|---|---|---|---|
| 0 | −7 | −23 | −54 | −101 | −165 | −275 | −342 | (1/1000 mm) |
| 0 | −0.14 | −0.31 | −0.53 | −0.80 | −1.09 | −1.38 | −1.68 | (%) |

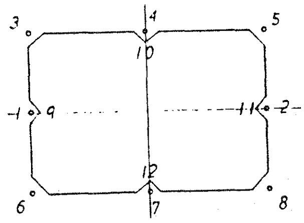
Calibration value

a) of fiducial mark

| | X | Y |
|---|---|---|
| 1. | −16.991 | 0 |
| 2. | +17.001 | 0 |
| 3. | −16.991 | +10.999 |
| 4. | + 0.003 | +10.995 |
| 5. | +17.008 | +11.001 |
| 6. | −16.991 | −10.994 |
| 7. | + 0.009 | −10.999 |
| 8. | +17.005 | −10.997 |
| 9. | −16.013 | − 0.001 |
| 10. | − 0.002 | +10.018 |
| 11. | +16.014 | + 0.004 |
| 12. | + 0.010 | −10.005 |

Coordinats of principal point

X,Y (−0.324, −0.102)



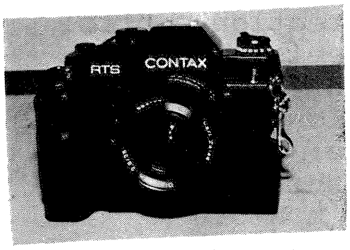




Photo 4 Contax RTS II Camera

## 3. Aerial photographing system using a kite balloon

Since it was confirmed that even the use of a non-metric camera allows three-dimensional measurement by analytical calibration, non-metric camera were mounted for developing a system for simple aerial photography. Unmanned platforms available now include a radio-controlled airplane,radio-controlled helicopter, kite balloon, crane etc. Considering operation convenience,etc.,it was decided to use a kite balloon for the system.

### 3.1 Features

Since the balloon has two strings attached, it ascends stably and can ascend upto about 600 m, though depending on gas volume, wind, etc. The length of strings and suspension condition allow the height and position to be presumed. The balloon can be very easily moved by a man who walks while holding a string. On the other hand, though it is suitable for fixed point observation, it is not suitable for moving in a wide area.

The balloon becomes very small when folded and can be simply charged or discharged with helium gas, to assure very easy preparation. But since the bolloon is made from a very thin PVC film, it is liable to be holed and requires careful handling.

### 3.2 Instruments and materials

The following instruments and materiala are required.

a. Platform

(1) Balloon: Made of PVC

i) Helium gas : 5.25 $m^3$

ii) Type: Airship type (streamlined)

iii)size:5.0 mlong, 1.2 m diameter

iv) Weight on board: Approx. 2.5 kg

v) Support method:Strings (2 strings)

(2) Camera: 35 mm cameras

i) Olympus OM-1, f=28 mm
ii) Contax RTSII, f=35 mm
iii) Shutter: Radio controled with stroboscope
iv) Winding: Motor driven, frame by frame
(3) Gyro
i) direction control: Rasio controlled
ii) Direction: Vertical, changeable in 4 directions

b. Ground station
(1) Radio controled panel
i) Shutter button
ii) Gyro direction control
(2) String reels: 2 pcs.
i) Total length: 600 m
ii) Graduations: Marked at 20 m intervals
iii) Strings; Teijin Tetron trolling line, tension 36 kg
(3) Landing sheet: Made of PVC
i) Size: 5.2 m X 3.6 m
ii) Work: Unpacking, gas charging, discharging, folding
(4) Helium cylinder
i) Volume: 7 $m^3$
ii) Length: 1.37 m
iii) Price: Approx ¥20,000/pc
(5) Mooring net made of balloon
i) Size: 8 m X 5 m
ii) Object: Ground mooring of balloon

3.3 Phographing system

The photographing system used and airship type kite balloon with three fins. The front suspended string was connected with the control reel on the ground and the rear suspended string was about 2 m and connected with a streamlined suspended box made of styrene foam for containing a camera, receiver, etc. However, rotation, deflection, etc. were often caused at the contact between the string suspending the camera-containing box and the suspended string of the balloon, to let the balloon and the camera move respectively independently. Considering this point, a gyro for changing the direction of the camera was mounted, but it was difficult and almost impossible to confirm the direction of the camera at an altitude of decades of meters, from the ground.

As the result, among the photographs obtained, those which could be used for three-dimensional measurement were only several pairs. Therefore, it was decided to use this system for taking oblique photographs, etc., and to improve it for taking accurate stereo-photos.

To take accurate stere-photos, it is surmised to be best to mount a video camera for photographing with a point set. However, the balloon used by the authors cannot mount a video camera in veiw of its weight, and a video camera makes the system expensive in view of cost, contrary to a low cost system intended by the authors. Therefore, it was decided to improve the following points in the system.

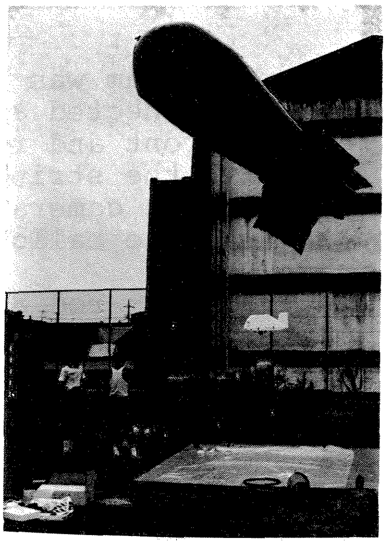
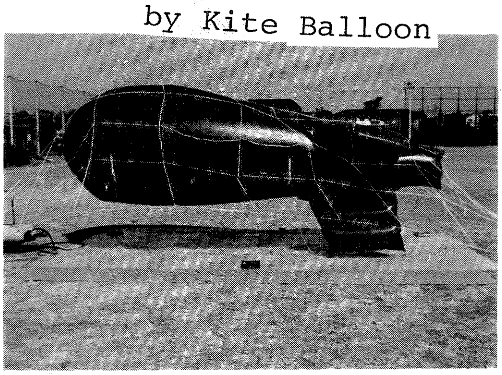


Photo 5 Photogrphing system by Kite Balloon



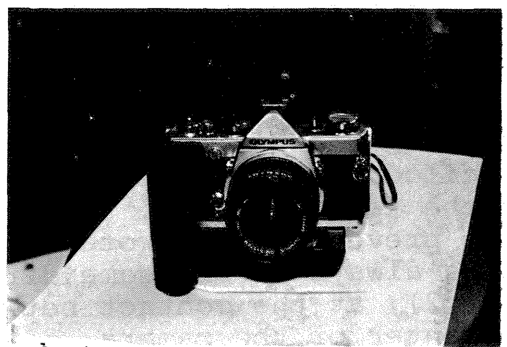


Photo 6 Olympus OM-1

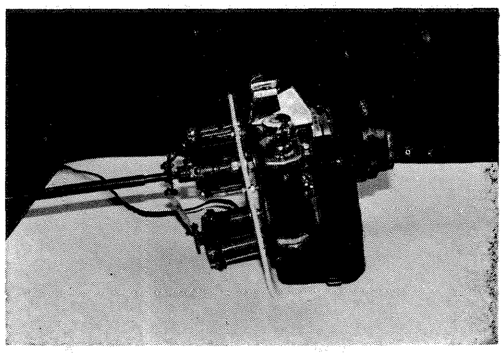
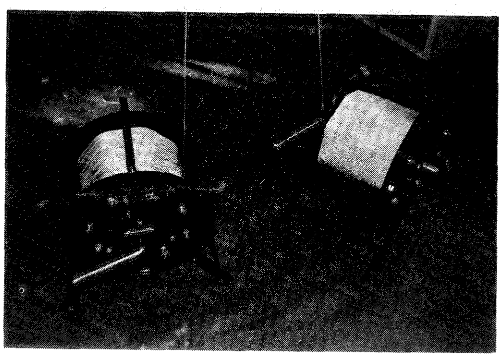


Photo 7 Gyro



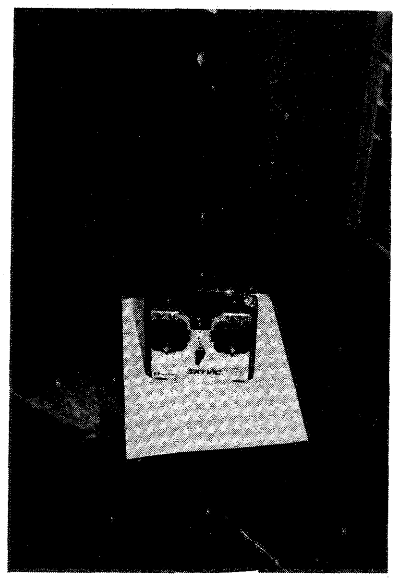


Photo 8 Ground operation station

Photogrphing system by Kite Balloon
remotely controlled

(1) To prevent the rotation of the suspende box, for keeping the balloon and camera in the same direction.

(2) To prevent the deflection and inclination of the camera proper.

For (1), the suspende box made of styrene foam was discarded. An about 2 m aluminium rod was used and connected at both the ends with the strings suspended from the front and rear ends od the balloon, instead of the connection with the string suspended from the rear end only. To the aluminium, the camera was fixed to be prevented from rotating, and to keep the balloon and the camera always in the same direction.

For (2), at the contact between the aluminium rod and the gravity center of the camera, a ball joint (joint designed to keep verticality constantly) was used, in design to keep the camera always turned vertically downward.

As a result of the above improvement, accurate sterophotos could be taken at a high probability. The improved photograhing system is shown in photo 9.

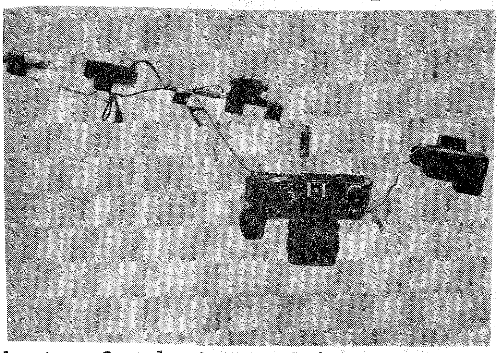


Photo 9 Photogrphing system remotely controlled

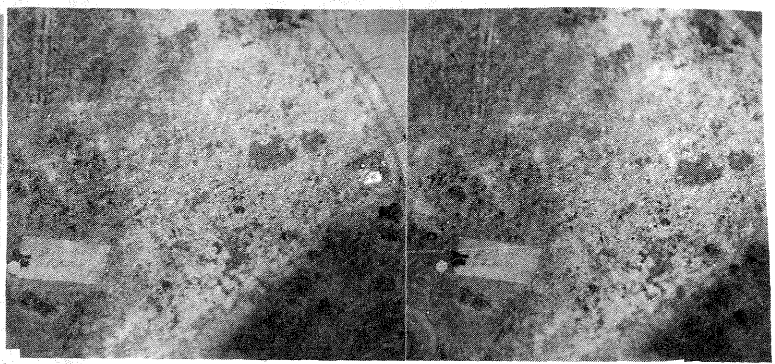


Photo 10 Example of stereo-pair

4. Examples of three-dimensional measurement by balloon

An area of about 180 m in length and about 100 m in width with a height difference of 5 m in Tokyo Metropolitan Koganei Park was selected as a test area, and 28 marks were set as control points on December 10, 1984, for photographing by two cameras of Olympus and Contax and for examining the accuracy. Photos taken by Olympus OM-1 were analyzed, using the values obtained by the calibration desbribed in 2.1, and those taken by Contax were analyzed, using the elements of inner orientation pribided by the camera maker. Examples of photo taken using Olympus and Contax are shown in Potos 10 (a) and (b).

The stereo-photos taken at an altitude of 100 m were analyzed using the authors'software and an anlytical stereoplotter,Planicomp C-100. The result are listed in Table 4.

The diffrence between calculated values and measured cordinates were 20 to 30 cm in plane and height with Olympus, and 2 to 3 cm in plane and 5 to 6 cm in height with Contax.

## 5. Conclusions

(1) Even a non-metric camera can provide sufficiently practical accuracy, by giving rhe results of calibration obtained in any experiment site.

Especially if the focal distance, principal point dislocation and lens distortion are given as results of calibration. accuracies fo 1/2,000 to 1/4,000 can be obtained. However, since film deformation is different from film to film, the values obtained in the experiment site fo not allow accurate correction.

(2) The use of a non-metric camera with fiducial mark allows more accurate three-dimensional measurement.

(3) It was confirmed by an experiment that aerial photography using a kite balloon can be done simply at low cost. This can be easily and conveniently used for three-dimensional measurement and photo-interpretation of small areas by those who intend todo so.

Acknowledgement:

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We also would like to express our appreciation to the saff in Geographical Survey Inst. of allowing ia to use the indoor control points for the calibration of cameras and the staff of Tokyo Metropolitan Koganei Park for allowing is to use it as a test area.

Table 4 Table of accuracy (differenc of geodetic coordinates and photogrammetric value)

| PRANICONP C-100 | | | |
|---|---|---|---|
| OLYMPUS. OM1 (m) | | | |
| POINT | DXG | DYG | DZG |
| 512 | −.420 | .171 | .365 |
| 513 | −.036 | .166 | .151 |
| 522 | .044 | −.640 | −.438 |
| 532 | .021 | .507 | −.005 |
| 533 | .390 | −.205 | −.075 |
| MEAN | .182 | .337 | .207 |
| CONTAX. RTS (m) | | | |
| POINT | DXG | DYG | DZG |
| 512 | −.033 | .054 | .070 |
| 513 | .012 | .017 | −.021 |
| 522 | −.023 | −.057 | −.102 |
| 532 | .033 | −.012 | .089 |
| 533 | −.068 | .037 | −.037 |
| MEAN | .034 | .035 | .064 |

| HOSEI-FACOM | | | |
|---|---|---|---|
| OLYMPUS. OM1 (m) | | | |
| POINT | DXG | DYG | DZG |
| 512 | .022 | −.025 | −.315 |
| 513 | .074 | −.157 | .217 |
| 522 | .522 | .252 | .456 |
| 532 | .011 | −.420 | −.008 |
| 533 | −.629 | .349 | −.351 |
| MEAN | .252 | .241 | .269 |
| CONTAX. RTS (m) | | | |
| POINT | DXG | DYG | DZG |
| 512 | −.005 | −.007 | −.046 |
| 513 | −.039 | .057 | .021 |
| 522 | .001 | −.079 | .092 |
| 532 | −.014 | .004 | −.081 |
| 533 | .056 | .025 | .013 |
| MEAN | .023 | .034 | .051 |