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Three-Dimensional Coordinate Determination By Close Range Photogrammetric Method: An Experiment Using Contax RTS III

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Abstract

Film unflatness is one of the factors that reduce the accuracy of photogrammetric method in coordinate determination. The problem is that it is not possible to model by internal orientation.The CONTAX RTS111 is a 35mm camera with an in-built vacuum attached to the camera's back plane. The camera incorporates a ceramic pressure plate and real time vacuum system which attracts the film onto the pressure plate when the firing is depressed. It was tested to see if it did provide a reliable result. A calibration range consisting of 94 retroreflective targets at CURTIN University of Technology, Perth, Western Australia was used in the test.

1.0 INTRODUCTION

The three-dimensional measurement of an industrial and engineering objects using close range photogrammetry is becoming more popular with the rapid development of cameras of varoius types: metric camera, semi-metric camera and large format camera. Better quality and cheap lenses and films have also been developed. In addition, with a cheaper and better quality of stereoplotters and stereocomparators, more surveyors can afford to use photogrammetric system for three-dimensional measurement of an industrial and engineering object.

With the advent of new powerful computers, more sophisticated algorithms can be implemented for the optimisation and adjustment computations. The current development uses the photogrammetric technique of bundle adjustment to determining the X, Y and Z coordinates. With this method the image coordinates can be observed monoscopically and adjusted simultaneously.

This paper presents information on the experiment carried out for the determination of three-dimensional coordinates using a new CONTAX RTS III camera. This paper highlights the hardware used in the test, the field work, the computer programs used to process the data, and finally the result.

The hardware used to carry out this project was the RTS III for the photography, a Wild BC2 Analytical Plotter for the measurement of image coordinates, a computer for transferring data and the VAX computer to process data. PREPRO software (Fraser, 1982) is used to create a coordinate data file which is for input to SPGA software (Fraser, 1992). Finally, the SPGA produces the adjusted space coordinates.

2.0 THE EXPERIMENT

2.1 Hardware

The hardware used in the experiment was the CONTAX RTS III camera, a Wild BC2 Analytical Plotter , a personal computer and VAX main frame computer.

(i) Camera

The CONTAX RTS III (see Figure 1) is a semi-metric camera made by Carl Zeiss. The camera has a vacuum system to suck the film onto the focal plane plate so as to reduce the effect of film distortion. The lense system is made of plannar lens with focal length of 50 mm and the aperture settings of f 1.7

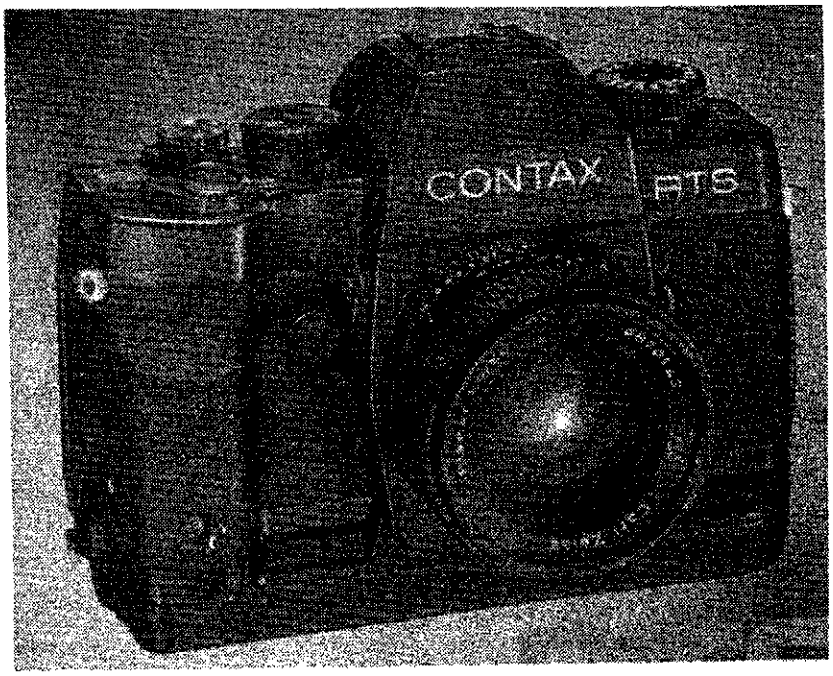


Figure 1: The CONTAX RTS 111

Kodak Black and White, 35 millimetres print film was used in the camera. When processed on precise mono/stereo comparator an image accuracy of 5 micrometers is expected, which will give an object accuracy of 3 millimetres. Canon Speed-light 188a, set on automatic, ASA 64, f-2, for a distance of 5.6 m was used with conjunction with CONTAX camera.

(ii) **WILD BC2**

WILD BC2 is an analytical streoplotter which has the facilities to deal with a single photograph or a pair of photograph. The menu of the software includes the "MMO" for digitizing points in X and Y directions.

2.2 The Computer Programs

There are several three-dimensional coordinates determination programs at Curtin University. Amongst them are: The Fraser's (1982) program PREPRO and SPGA, Direct Linear Transformation (DLT) method, and the Adam Technology's program used with ADAM Technology Stereoplotter.

(i) **PREPRO**

PREPRO (PREProcessor) is a resection/intersection, preprocessing routine for the self bundle adjustment SPGA (Simultaneous Photogrammetric and Geodetic Adjustment). The function of PREPRO is to create a coordinate data file for input to SPGA. The five stages through which the program progresses are:

- Two-dimensional image coordinates transformation. The measured image coordinates is transformed into the same system, therefore each photo will have its image coordinates centred on the fiducial coordinates system.

- Image coordinates are corrected for symmetric (K1, K2, K3) and asymmetric distortions for principal point offsets (Xo and Yo).

- Space resection to determine refined estimates for the exterior orientation. At this stage, the position and orientation elements for each camera exposure (camera position) is calculated. At least three objects control points is required to be seen on the photo to resect the camera position.

- Space intersection to determine the object coordinates.

The calculation of the resection and intersection is carried out by the technique of least squares adjustment using the collinearity equations. During the resection process the exterior orientation elements are refined at each iteration of the object coordinates during the intersection process.

(ii) **SPGA**

SPGA (Simultaneous Photogrammetric and Geodetic Adjustment Program) is a self-calibrating bundle adjustment program. Two input files are required to run SPGA:

- The output file from PREPRO which contains the improved exterior orientation parameters, corrected image coordinates and the estimate of the object coordinates.

- The file which contains program control data and estimates of the additional parameters such as symmetric lens distortion, asymmetric lens distortion, and principal point offset.

SPGA generates three output files: (i) A file consisting of the output listing; (ii) A formatted sequential file containing the adjusted object space coordinates; (iii) A sequential file containing the image coordinate residuals.

The output listing includes the value of additional parameters. The mathematical formulation for the determination of additional parameters are described by Fraser (1983) and Kniest (1990). The method of in-core sparse-matrix is employed for storage, solution and inversion of the normal equation matrix in SPGA.

2.3 Accuracy

The accuracies that can be achieved by this technique depend on the types of camera and coordinate measurement instrument used. With the use of a semi-metric camera such as CONTAX RTS III and with the measurement on BC2, the RMS error of 6 micrometers on image coordinates, an accuracy of the object coordinates of 3 millimetres can be expected. From previous work, this camera has achieved an accuracy of 4 micrometers on image coordinates and 1 millimetre of object coordinates. Nevertheless, the accuracies achievable is much dependent on the skill of the operator of the instrument and how he or she can place the floating mark on the centre of the image target.

2.4 Field Test

Field test was carried out with the objective of: (i) To determine the achievable accuracies of three-dimensional coordinate determinant CONTAX RTS III camera; (ii) To investigate the effectiveness of the Close Range Photogrammetric method application.

On-site work involved are: (i) The placement of camera locations; (ii) Taking the photographs; (iii) Processing

The camera locations from which the photographs were taken should ensure a satisfactory photograph coverage and the geometry of the photograph relative to the camera should be optimum to ensure high accuracy.

There is no target placement in the test as the 94 targets on the wall (see figure 2) were already on its places for camera calibration purposes. The type of target base was 3-inch squares of sheet metal stuck with an adhesive white sticker on one side with two black circular rings and one very fine dot on the centre (see figure 4).

In the test, the Contax RTS III camera was mounted on the tripod about 1.6 metres high (see figure 3) and was used to obtain photographs from three different camera locations (see figure 5). Two photographs (horizontal and vertical) from each location were taken to make six photographs altogether.

All six processed photographs were measured on a WILD BC2 analytical plotter separately. The plotter was used to digitize the relative locations of target images on each negative. Since the negative from this camera has no fiducial marks, the coordinate of the four corners were firstly determined. This was done by digitizing five points on each four edges. These points form four lines. An intersection of the four lines gave the four corner points.

Measurements from the BC2 were transferred into a PC via KERMIT software and input to a program known as SCDAT2. This program computes the four corners of the photograph. The principal point was also computed by the intersection of the diagonal lines through these four corners. The digitized coordinates were then transformed into the system as the four corners, with the origin (0,0) is at the centre (approximately the principal point). The type of transformation chosen was a conformal transformation. The transformed object point coordinates and the four corner pointcoordinates were transferred to VAX terminal to be processed in PREPRO. Other input data required are:

(i) The initial approximation of the exterior orientation elements which includes camera positions and orientations (see table 1).

NO.	OMEGA	PHI	KAPPA	S.OMEGA	S.PHI	S.KAPPA
NO.	XL	YL	ZL	SXL	SYL	SZL
1	104 50 23.1	47 33 57.4	-98 15 38.8	300.1153	300.1153	300.1153
1	75.7963	42.9397	5.8520	0.5000	0.5000	0.5000
2	99 38 48.9	-2 41 26.7	-89 2 56.6	300.1153	300.1153	300.1153
2	57.3845	30.3469	6.7026	0.5000	0.5000	0.5000
3	100 21 31.8	-3 40 25.0	2 20 35.3	300.1153	300.1153	300.1153
3	57.3522	30.3977	6.5332	0.5000	0.5000	0.5000
4	100 22 48.6	-32 12 33.6	-82 42 25.2	300.1153	300.1153	300.1153
4	47.1997	39.1046	6.5113	0.5000	0.5000	0.5000
5	100 43 26.8	8 30 26.6	-89 37 29.9	300.1153	300.1153	300.1153
5	63.3802	31.1672	6.2491	0.5000	0.5000	0.5000
6	99 38 2.4	-16 57 33.9	-86 49 42.3	300.1153	300.1153	300.1153
6	50.3798	32.3271	6.6927	0.5000	0.5000	0.5000

Table 1: Exterior orientation element and their standard errors. (Angles are in deg,min,sec and std. errors of angles are in decimal minutes).

(ii) Additional parameters as follows:

NUMBER OF ADDITIONAL PARAMETERS - 4 CAMERA-INV. - 0 BLOCK-INV. - 4

PARAMETER MODEL ARRAY -
1 2 5 18

INITIAL ESTIMATES AND STANDARD ERRORS OF ADDITIONAL PARAMETERS (PARAM. NO., ESTIMATE, STD. ERROR) -

1 0.236E-04 0.70E-06 2 -0.173E-07 0.15E-08 5 -0.224E-04 0.57E-04 18 0.286E+00 0.22E-01

(iii) Other input data.

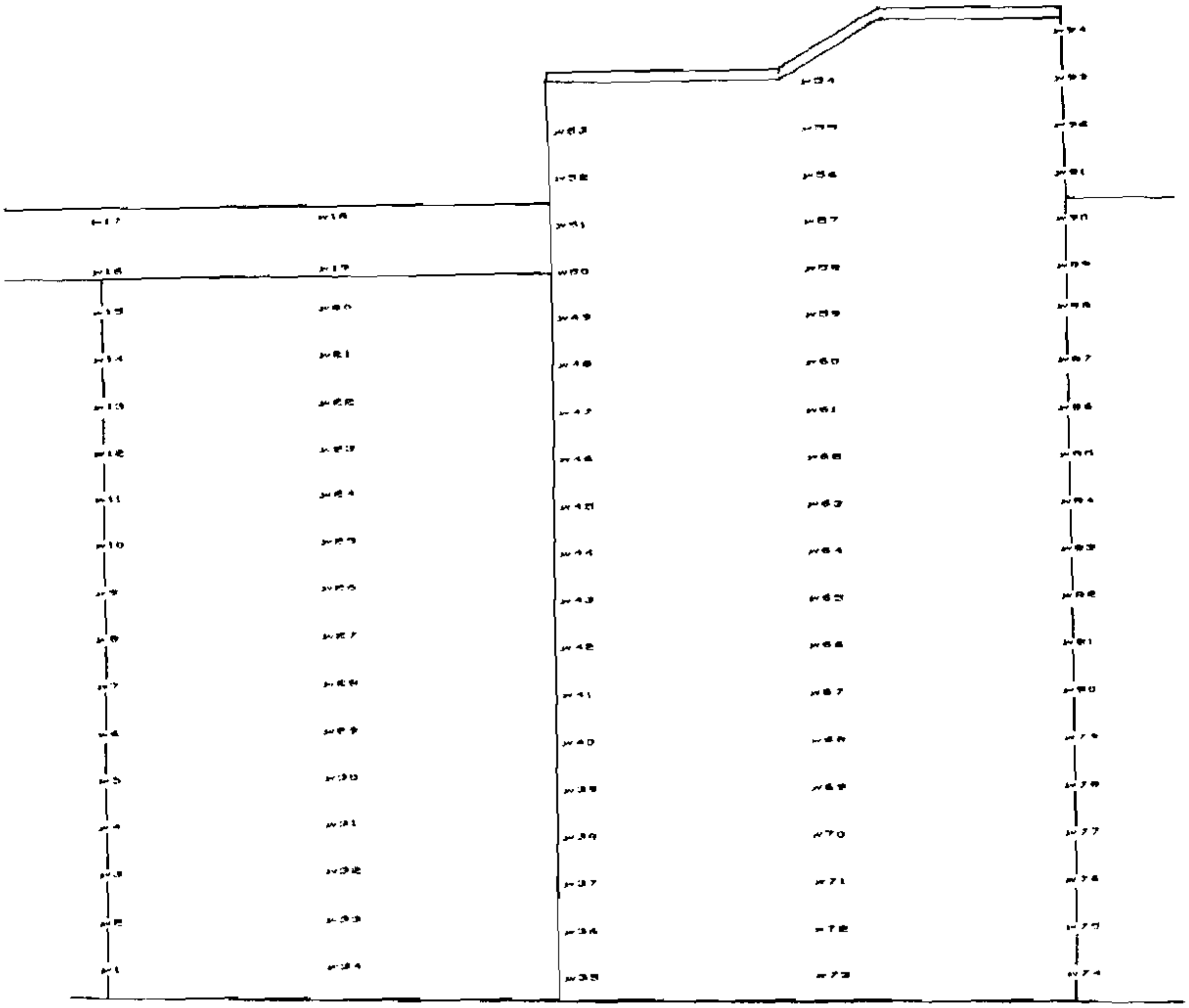
NUMBER OF CAMERAS USED - 1
NUMBER OF PHOTOS - 6
NUMBER OF OBJECT POINTS - 94
NUMBER OF SURVEYING OBS. - 0

In addition to the photo coordinate measurements, the degrees of freedom total will be incremented each time the standard error assigned to a parameter is less than:

i) OMEGA(I),PHI(I),KAPPA(I) - 200.00 MINUTES OF ARC
i . XL(I),YL(I),ZL(I) - 5.00
i) 3. X(J),Y(J),Z(J) - 5.00
iv) 4. DOF IS INCREMENTED FOR EACH AP & SURVEYING OBS.

The output of the ground coordinates were input together with a new file which consists of the computed additional parameters and control parameters in SPGA.

The reliability of the observation is tested with the 95 percent reliability. After rejecting some bad points on PREPRO input data, the corrected data were run on PREPRO and SPGA one more time.



FRONT VIEW

Figure 2: The position of targets on the wall

Figure 3: The picture of the CONTAX RTS 111 during Photography. The wall is on the back ground.

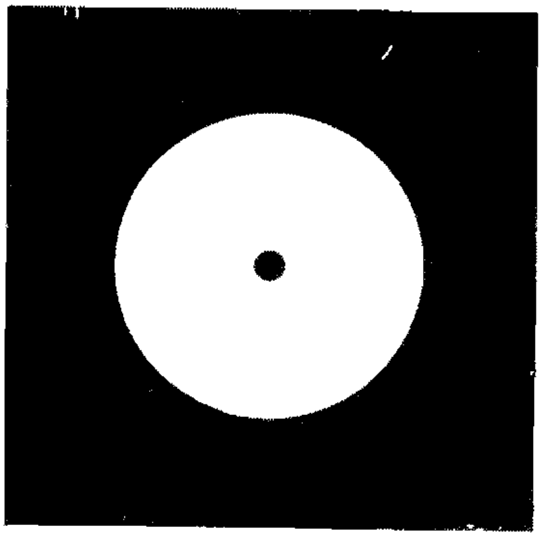


Figure 4: The type of target used in the test.

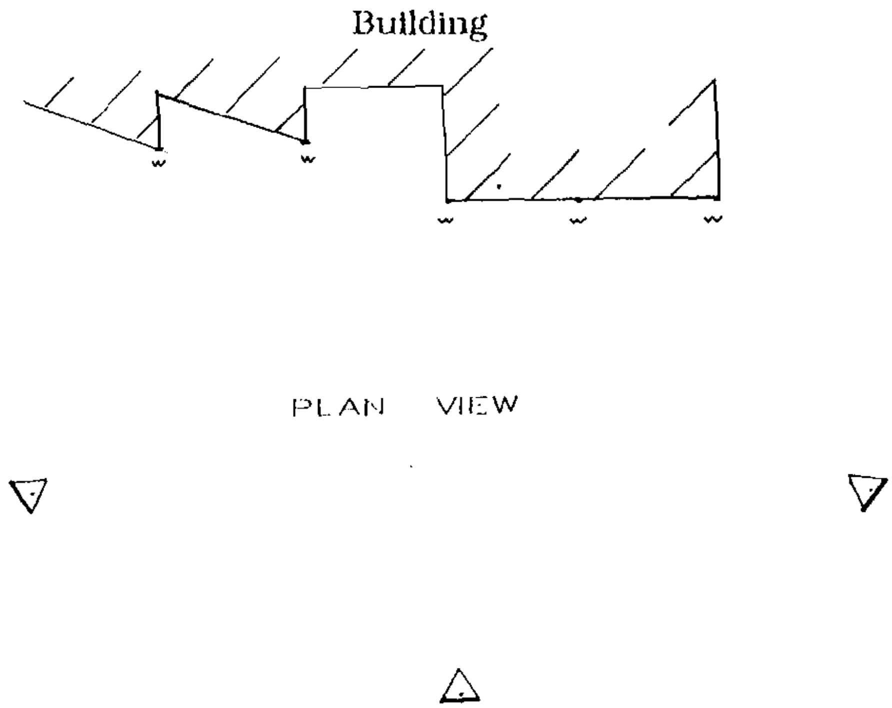


Figure 5: Camera locations

3.0 RESULT

The exterior orientation elements and their residuals after adjustment are shown in table 2 below.

NO.	OMEGA	PHI	KAPPA	V.OMEGA	V.PHI	V.KAPPA
NO.	XL	YL	ZL	VXL	VYL	VZL
1	104 47 53.8	47 33 27.0	-98 13 41.6	-2.4890	-0.5066	1.9542
1	75.8295	42.8986	5.8525	0.0332	-0.0411	0.0005
2	99 49 5.4	-2 46 8.1	-89 3 19.8	10.2750	-4.6901	-0.3871
2	57.3425	30.2989	6.6002	-0.0420	-0.0480	-0.1024
3	100 40 36.2	-3 42 58.4	2 21 50.1	19.0720	-2.5570	1.2462
3	57.3224	30.3734	6.3591	-0.0298	-0.0243	-0.1741
4	100 28 55.1	-32 20 34.5	-82 41 21.8	6.1089	-8.0152	1.0559
4	47.1547	39.1311	6.4746	-0.0450	0.0265	-0.0367
5	100 56 31.0	8 47 25.7	-89 39 55.9	13.0705	16.9858	-2.4332
5	63.5438	31.1501	6.1297	0.1636	-0.0171	-0.1194
6	99 46 23.3	-17 18 23.2	-86 45 59.5	8.3493	-20.8225	3.7137
6	50.1946	32.3554	6.6276	-0.1852	0.0283	-0.0651

Table 2: Exterior orientation elements and their standard errors (Angles are in deg,min,sec. and std. errors of angles are in decimal minutes).

The sample output of the final adjusted object space coordinates and their residuals are shown in table 3. From the experiment, the RMS error of the image coordinates were 6.2 micrometers in X-direction and 6.9 micrometers in Y-direction. The mean RMS error of the object coordinates were 3 millimetres (X=1.7, Y=4.5 and Z=2.1).

NO.	X	Y	Z	VX	VY	VZ	SX	SY	SZ
1	52.9868	60.8268	5.3510	-0.0002	-0.0002	0.0000	0.0010	0.0010	0.0020
9	52.9845	60.8221	10.8409	-0.0015	0.0001	-0.0011	0.0010	0.0010	0.0020
17	53.0080	60.6811	16.3450	0.0000	0.0001	-0.0010	0.0010	0.0010	0.0020
51	58.9363	60.3699	16.3365	0.0003	-0.0001	0.0015	0.0010	0.0010	0.0020
90	65.2954	60.3760	16.3408	0.0004	0.0000	-0.0012	0.0010	0.0010	0.0020
82	65.3072	60.3739	10.8487	0.0012	-0.0001	-0.0013	0.0010	0.0010	0.0020
74	65.3048	60.3860	5.3555	-0.0002	0.0000	0.0015	0.0010	0.0010	0.0020
35	58.9277	60.3915	5.3661	-0.0003	0.0005	-0.0059	0.0010	0.0010	0.0020
2	52.9855	60.8315	6.0377	-0.0087	0.0075	-0.0048	0.0200	0.0200	0.0200
3	52.9905	60.8077	6.7277	-0.0010	0.0001	-0.0020	0.0010	0.0010	0.0020
4	52.9824	60.8196	7.4178	-0.0006	0.0001	-0.0009	0.0010	0.0010	0.0020
5	52.9833	60.8202	8.1002	-0.0003	0.0001	-0.0005	0.0010	0.0010	0.0020

Table 3: Final adjusted object space coordinates X,Y,Z and residual VX,VY,VZ.

The time taken to carry out the whole process can be divided into; taking the photographs, processing the photographs, measurement on BC2, transferring data, processing data on PREPRO and processing data on SPGA. The summary of the time taken is given in table below. For skilled professionals, the time can be reduced.

Type of work	Time taken
i) Taking the photographs	30 minutes
ii) Processing the Photographs	60 minutes
iii) Observations on BC2	90minutes(15 minutes-per photo.)
iv) Data processing on PREPRO	90 minutes
v) Data processing on SPGA	60 minutes
Total time	330 minutes (5.5 hours)

Table 4: The summary of the time taken for the whole stages of the test.

4.0 DISCUSSION AND CONCLUSION

The largest error is in the Y-direction, which is in the direction of the offset line from the object to the central camera. When compared to the manufacturer's accuracies, the accuracies gained in this test almost match the specifications which is good enough for the experiment test. When compared to the data from theodolite observation (which is not shown in this article), the discrepancies are not consistent. 76 percent of the sub-coordinates are below 10 millimetres which is the maximum acceptable value. When compared to the previous result of previous work using other non-metric cameras, the accuracy is much more superior.

It can be concluded that the achievable accuracies using RTS III is better than other non-metric camera but less accurate than metric camera, nevertheless for work that requires less accuracy such as for the monitoring of open pit mine and so on the use of this camera is recommended. Generally, the time taken using the photogrammetric method with RTS III in the determination of 3-D coordinate is less compared to the conventional theodolite intersection method.

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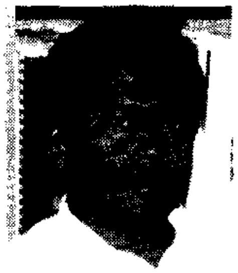

About the author

Baharin Ahmad recieved his M.Sc degree from Curtin University of Technology, Perth, Australia in 1992. His research interests lies in the field of 3D Coordinate Determination, Close Range Photogrammetry, Land Information System and Automation in Surveying.