วิศวกรรมสาร ม.ข. ปีที่ 31 ฉบับที่ 4 (377-394) ตุลาคม - ธันวาคม 2547
KKU Engineering Journal Vol. 31 No. 4 (377-394) October -December 2004

Investigated Study of Close Range Photogrammetry for High Precision Measurement

Chattichai Waisurasingha
Lecturer Department of Civil Engineering, Faculty of Engineering, Khon Kaen University.

Abstract

High precision measurement system is very important for industrial line production, molding design part and quality control part. Normally, for high precision measurement, this system uses a Digital Laser Scanner to scan the surface of an interested object, but this method is very expensive in order to get the high precision for this measuring system. So, we need to look for another method that can offer or produce the same precision as this system and cheaper than this system in order to support Thai Small and Medium Enterprises (SME) Industrial production which now has been fully supported by Thai Government.

The experiment output indicates the produce results of all case studies that the accuracy obtained usual not greater than 80 micron measured by close range digital photogrammetry. The main features of successful case studies are: number of camera exposure stations, type of camera calibrations, type of control and tie points marking, accuracy of control points, type of targets and lighting environment control.

Introduction

High precision measurement system is very important for industrial line production, molding design part and quality control part. Normally, for high precision measurement, this system uses a Digital Laser Scanner to scan the surface of an interested object, but this method is very expensive in order to get the high precision for this measuring system. So, we need to look for another method that can offer or produce the same precision as this system and cheaper than this system in order to support Thai Small and Medium Enterprises (SME) Industrial production which now has been fully supported by Thai Government.

Digital Close Range Photogrammetry will be applied in this research to solve this problem. This research will be considering about the measurement in different type of digital camera calibration in order to find the case which can give a high accuracies (approx. 80 micron).

Literature Review

There were many research studies concerning close range photogrammetry. Linkwz (1972) investigated camera calibration method. Karara studied about the accuracy of measuring by non-metric camera. Fraser (1997) investigated about digital camera calibration for close range photogrammetry and studied high precision measurement for industrial photogrammetry using professional camera.

Objectives of The study

1. To study and to design procedure for high precision measurement by using digital close range photogrammetry.
2. To analyse and conclude the potential of digital consumer grade camera for high precision measurement.

Theories of The study

Collinearity Condition

The fundamental characteristics of frame imaging is that the perspective center, the image point and the corresponding object point lie on a line in space. This line can be expressed as vector components in the image space coordinate system, as vector component or as vector components in the object space coordinate system.

The image space coordinate of a frame camera system will have a z coordinate fixed at the negative of the principle distance. In addition, there may be small offsets x_0 and y_0 from a principle point to a perspective central origin. These are reflected in the revised image space coordinates.

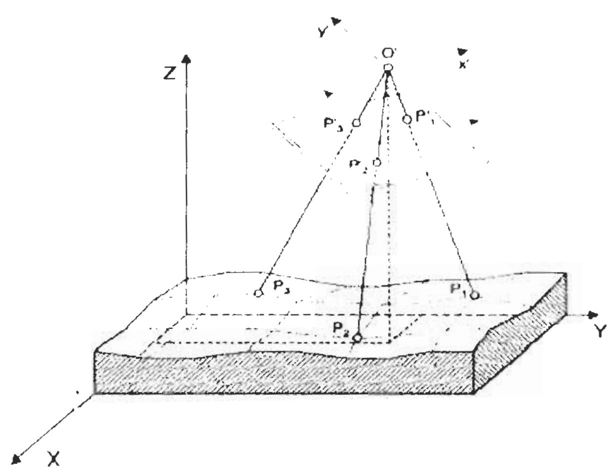


Figure 1 Collinearity Condition

$$\begin{bmatrix} X - X_o \\ Y - Y_o \\ Z - Z_o \end{bmatrix} = \frac{1}{S} R \begin{bmatrix} x - x_o \\ y - y_o \\ -f \end{bmatrix} \qquad (1)$$

Where

X, Y, Z	=	ground object coordinate of point P
X_o, Y_o, Z_o	=	ground coordinate of exposure station O
S	=	photographic scale
R	=	rotation matrix that transforms the ground coordinate system to the image coordinate system
x, y	=	image coordinate of any point P
x_o, y_o	=	principle point
f	=	focal length

Error Lens Distortion

Images from all camera lenses usually distort to some extent. If lens distortion is not taken into account by a photogrammetric program, the resulting accuracy is greatly reduced. This research does compensate for both radial and de-centering lens distortion to give the highest accuracy measurements and modeling.

Firstly, radial lens distortion can express the distortion as a polynomial function of odd powers of the radial distance as shown in an equation (2) below.

$$\Delta r = k_1 r^3 + k_2 r^5 + \ldots\ldots + k_n r^{2n+1} \tag{2}$$

Where

$k_1, k_2, ..k_n$	= coefficient of Radial Lens Distortion
Δr	= radial Lenses Distortion
r	= radial Lenses Distance
n	= Odd Number

Secondly, Tangential lens distortion is often referred to as decentering distortion which can express in an equation (3) below:

$$\begin{aligned} \Delta x &= P_1\left(r^2 + 2\bar{x}^2\right) + 2P_2\bar{x}\bar{y} \\ \Delta y &= P_1\left(r^2 + 2\bar{y}^2\right) + 2P_1\bar{x}\bar{y} \end{aligned} \tag{3}$$

Where P_1, P_2 = Coefficient of Tangential Lens Distortion, $r = \sqrt{x^2 + y^2}$

Sub-Pixel Target Marking by Intensity Weight Centroid Method

Sub-pixel target marking by The Intensity Weight Centroid method is the method that can mark the target precisely. This method can mark points in an accurate and consistent manner with the use of targets. This method has be described by an equation (4) below.

$$\bar{x} = \frac{\sum_{i=1}^{n} x_i g_i}{\sum_{i}^{n} g_i}; \bar{y} = \frac{\sum_{i=1}^{n} y_i g_i}{\sum_{i}^{n} g_i} \tag{4}$$

Where

$\bar{x}, \bar{y}$ = position of target center (mm)

x_i, y_i = image coordinates of target image (mm)

g_i = brightness value for each image coordinate corresponding to x_i, y_i

Error from target localization from Intensity The Weight Centroid Method can be described by an equation (5) be low

$$\sigma_{XM} = \left[\frac{1}{\sum g_i} \sqrt{\sum (X_i - X_M)^2} \right] \sigma_g$$

$$\sigma_{YM} = \left[\frac{1}{\sum g_i} \sqrt{\sum (Y_i - Y_M)^2} \right] \sigma_g \qquad (5)$$

Automatic Target Detection

This procedure uses the template least squares matching method to search for tie point correspondences in all images.

Camera Calibration Process

1. Camera Pre-Calibration is the procedure used to find the true parameters of camera that took your photograph before processing data. These parameters are focal length, lenses distortion parameters, and principle point displacement parameter. The calibrated plate for pre-camera calibration is shown in Figure 2 below.

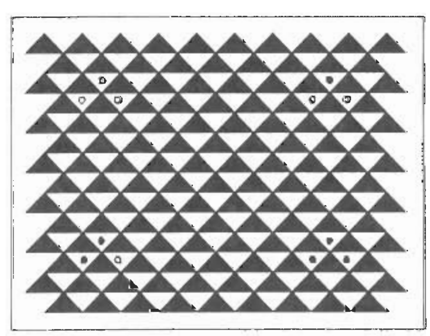


Figure 2 calibrated plate for pre-camera calibration

2. Self Camera Calibration is the procedure used to fine tuning camera parameters during processing data. This procedure can be classified in to two methods as follow.

   2.1 Self-Calibration General Method

   This method will use initial parameter from Camera Pre-Calibration process to adjust with control point from field works.

Self-Calibration General Method can conduct makes minor adjustments to the camera parameters on a per-photograph basis to account for any changes in focal length, principal point and lens distortion as the camera lens is focused.

2.2 Self –Calibration Inverse Method

This method will compute camera parameter from the filed work control points. This method has to give focal length parameters as an initial value and this method will be processed camera parameters from the scene.

Methodology of this study

This research used Sony digital camera model: S-75 for data capturing process and use Photomodeler Pro version 4.0g for data processing. This research determined conditions for capturing data and processing data in order to get the optimal accuracy which can get positional accuracy under 80 microns.

The conditions for analyzed process in this research are control point target, tie point target, control point measuring, tie point measuring and light control. Consequently, we can categorize different conditions of the method used in this study into 6 cases.

Table 1 data processing and data capturing

Detail of Study	Camera Pre-calibration		Self - Camera Calibration			
			General method		Inverse method	
	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Control Point Target	Signalized	Signalized	Signalized	Signalized	Signalized	Signalized
Tie Point Target	naturalized	Signalized	naturalized	Signalized	naturalized	Signalized
Control Point measurement	Point Pricking	Weight Centroid	Point Pricking	Weight Centroid	Point Pricking	Weight Centroid
Tie Point measurement	Point Pricking	Automatic	Point Pricking	Automatic	Point Pricking	Automatic
Light Control	Uncontrolled	Controlled	Uncontrolled	Controlled	Uncontrolled	Controlled

In addition, the process of data capturing has been divided into two types of camera network station. The first is capturing data from 4 symmetry exposure stations, and the latter is capturing data from 8 symmetry exposure stations.

The research has been tested on the object size 150x150x15 millimeters as shown in figure3. This object has been measured 34 check points and 6 check distances. The method of measurement for check point and check distance have been used the high accuracy equipment and use survey engineering method for obtaining the checking data.

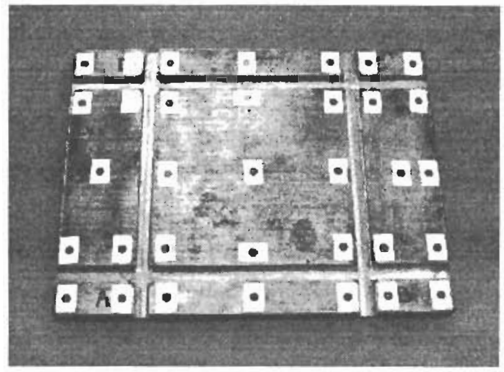


Figure 3 Object for study

Data Analysis

Data capturing case: 4 symmetry exposure station

The results of 4 symmetry exposure station from 6 cases data processing as shown in table 1 come produce 6 distance for evaluating error displacement with 6 standard distance which measures by the same accuracy as control point.

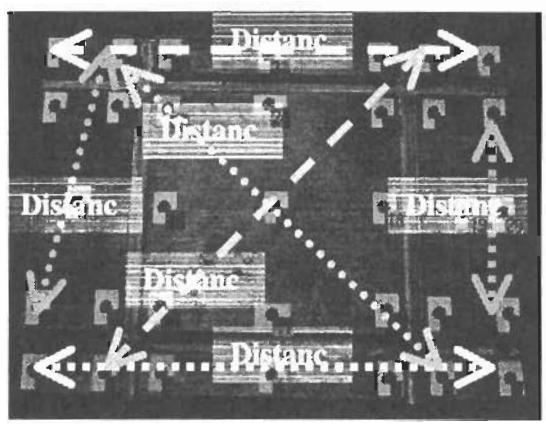
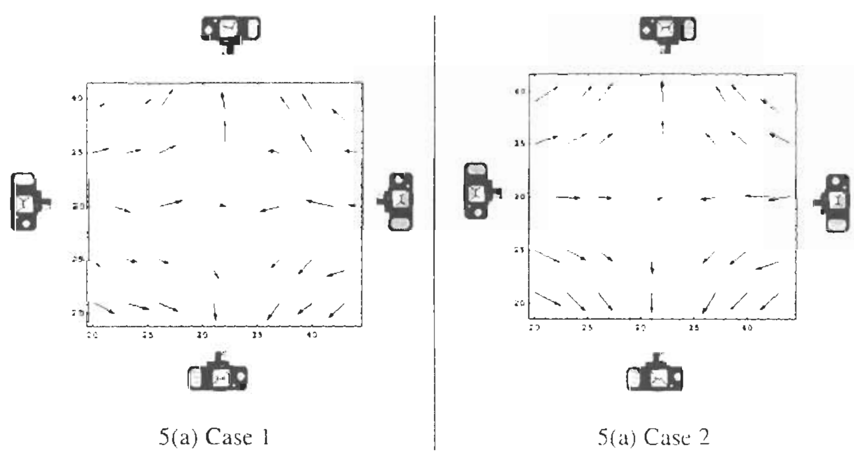


Figure 4 Checking Distance

Table 2 distance differentials

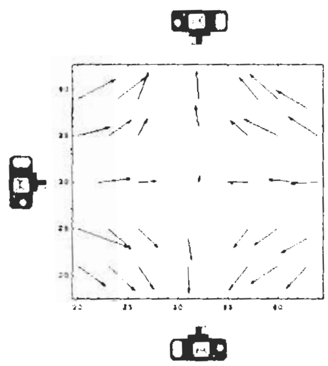
4 exposure Station	Differential Distance between check distance and observed distance (mm)					
	case 1	case 2	case 3	case 4	case 5	case 6
Distance 1	0.233	0.391	0.048	0.099	-0.425	1.497
Distance 2	0.343	0.423	0.142	0.097	-0.451	1.452
Distance 3	0.355	0.470	0.114	0.119	-0.489	1.543
Distance 4	0.315	0.455	0.079	0.097	-0.481	1.509
Distance 5	0.083	0.254	-0.073	0.040	-0.410	0.885
Distance 6	0.074	0.183	-0.027	0.045	-0.170	0.687

The distance differentials is shown in Table 2. There is no case which the accuracy of size measurement is satisfied by the target accuracy. The horizontal vector displacement of 34 check points is presented in Figure 5.a – 5.f. The vertical error displacement of 34 check points is also illustrated in Figure 6.a-6.f. From figure 5.d and 6.d, the minimum error displacement has been shown but the size of measurement is not satisfied.

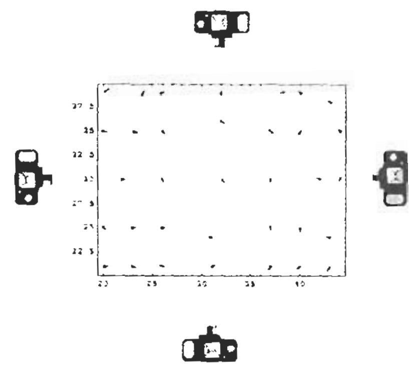


5(a) Case 1 5(a) Case 2

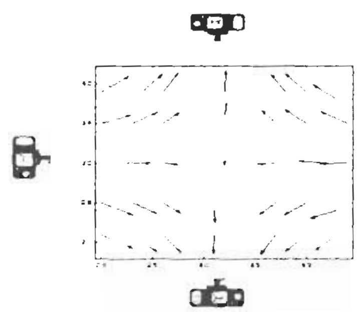
Figure 5: Exposure Station = 200 micron



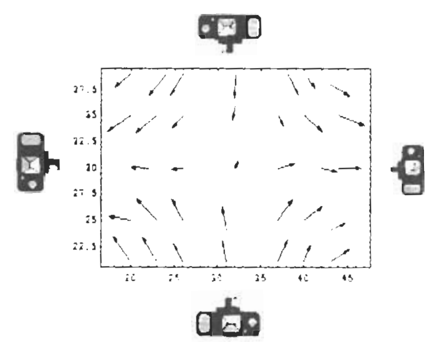
5(c) Case 3



5(d) Case 4



5(e) Case 5



5(f) Case 6

Figure 5: Exposure Station = 200 micron (continue)

From figure 5.a-5.b, the pattern of a vector field in case 1 has been shown the same direction as case 2, and vector filed plotting pattern in figure 5.c (case 3) and figure 5.d (case 4) are also in the same direction.

But the pattern of vector field in figure 5.e and 5.f is diverse. These mean that both camera pre-calibration and self-calibration General method can produce the consistency error displacement.

In contrast, the horizontal error displacement from self calibration Inverse method is upon the method of target marking.

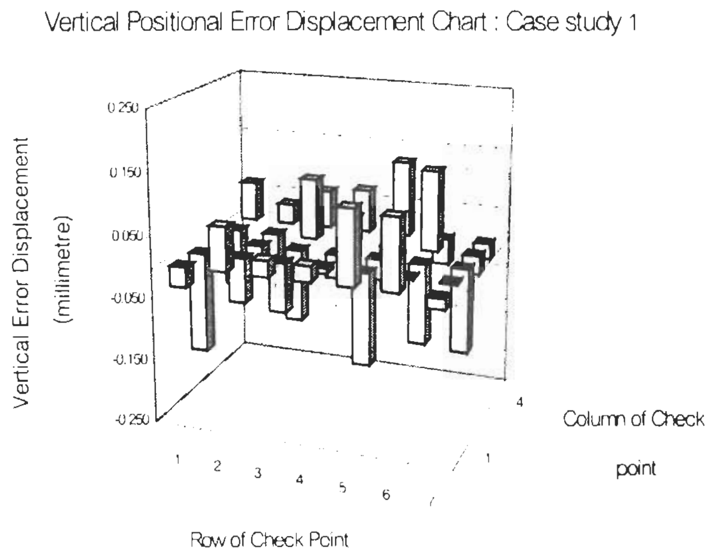


Figure 6(a) Case 1

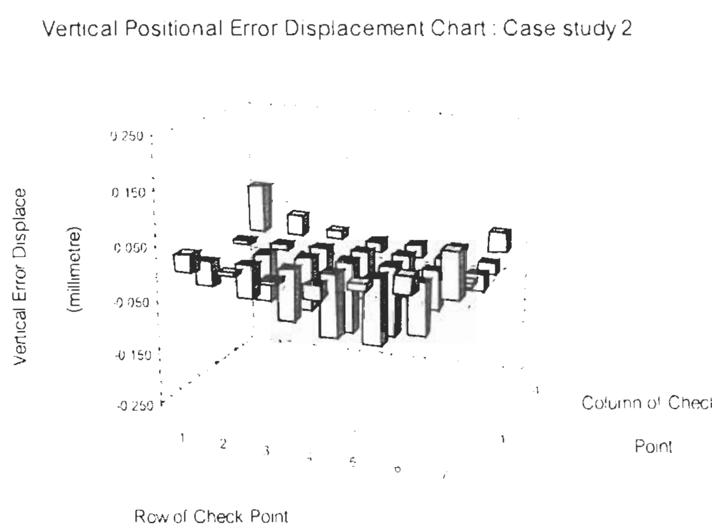


Figure 6(b) Case 2

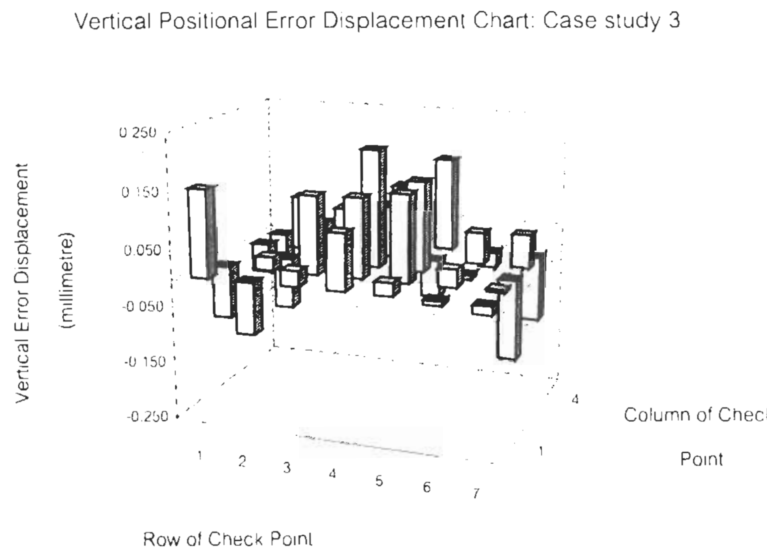


Figure 6(c) Case 3

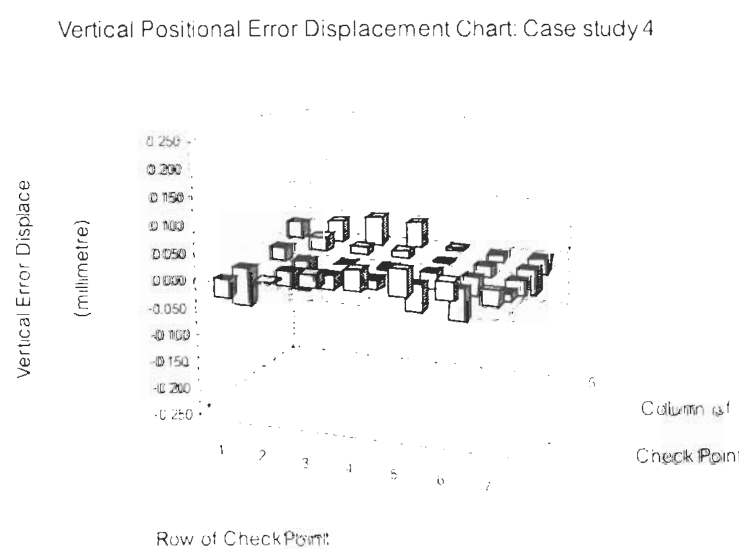


Figure 6(d) Case 4

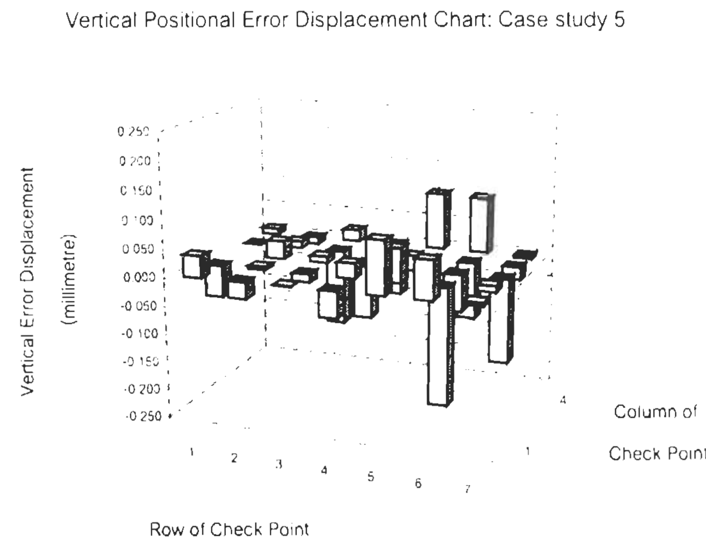


Figure 6(e) Case 5

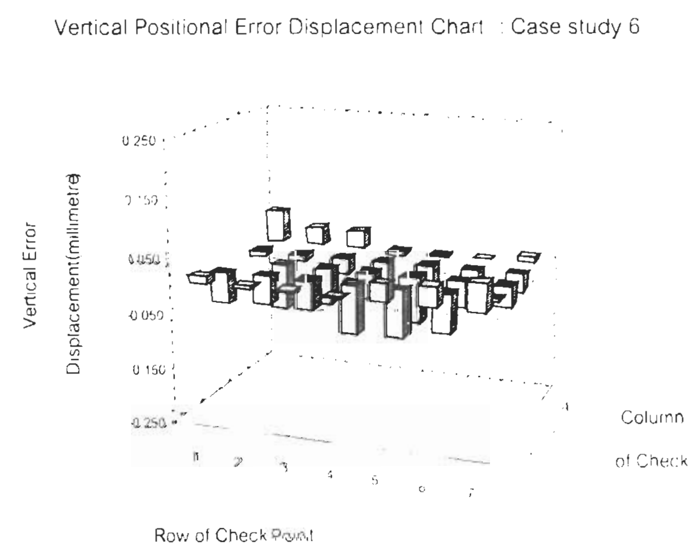


Figure 6(f) Case 6

Show from figure 6.a-6.f, the pattern of vertical displacement is inconsistency. The value in figure 4 is less than 50 micron or 0.05 millimeters.

Data capturing case 8 symmetry exposure station

The results of 8 symmetry exposure station for 6 cases data processing as shown in table 1 have been produced 6 distance for evaluating error displacement with 6 standard distance measured by the same accuracy as control point.

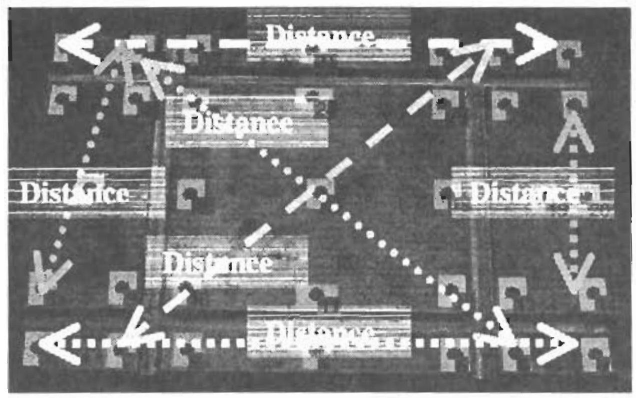


Figure 7 Checking Distance

Table 3 distance differentials of 8 stations data processing

8 exposure Station	Distance differential between check distance and observed distance (mm)					
	case 1	case 2	case 3	case 4	case 5	case 6
Distance 1	0.472	0.504	0.172	0.081	-0.514	-0.018
Distance 2	0.401	0.532	0.125	0.068	-0.423	0.012
Distance 3	0.565	0.644	0.215	0.060	-0.464	0.003
Distance 4	0.476	0.592	0.137	0.064	-0.574	0.011
Distance 5	0.206	0.331	-0.009	0.003	-0.338	-0.020
Distance 6	0.210	0.247	0.064	0.015	-0.212	-0.022

The distance differentials are illustrated in Table 3. There are 2 satisfied cases that can produce errors less than 80 micron or 0.08 millimeters. The horizontal vector displacement of 34 check points is presented in Figure 8(a) – 8(f) the vertical error displacement of 34 check points is shown in Figure 9(a)-9(f)

The case study 4 and the case study 6 as shown in figure 4.e and 4.f are less than the others. These vector filed pattern in figure 5 and figure 8 is not related to these corresponding case studies.

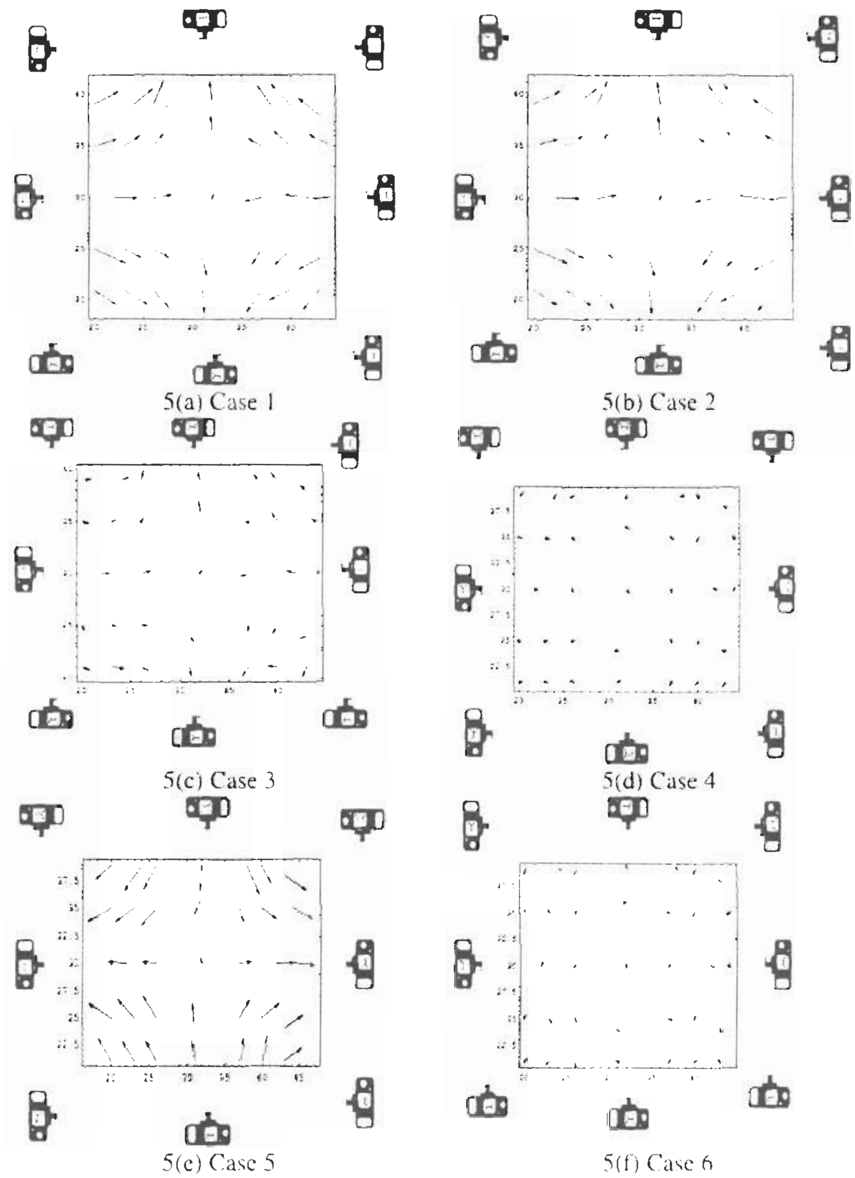


Figure 8: Exposure Station less than 80 micron

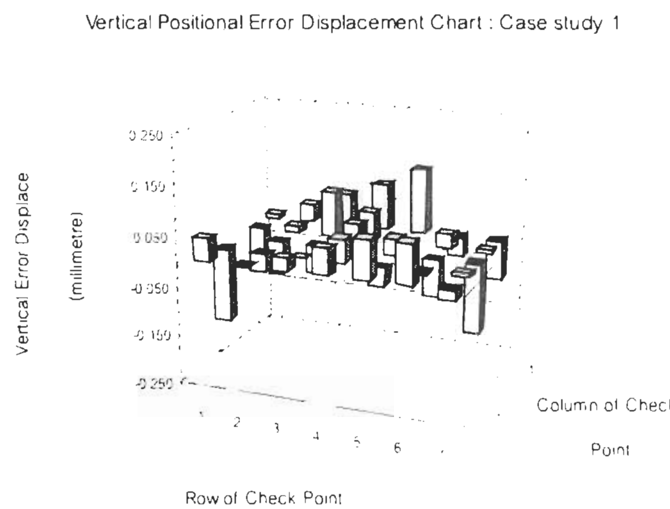


Figure 9.a: Case 1

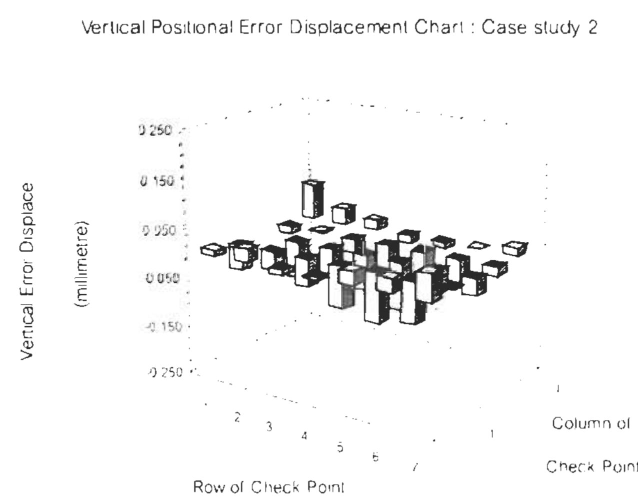


Figure 9.b: Case2

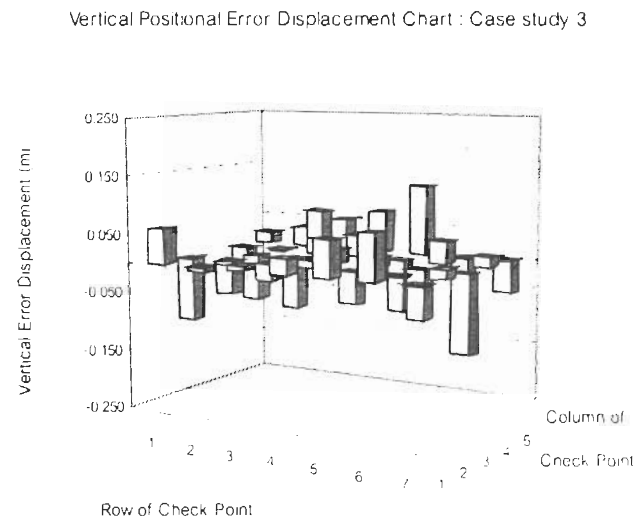


Figure 9.c: Case 3

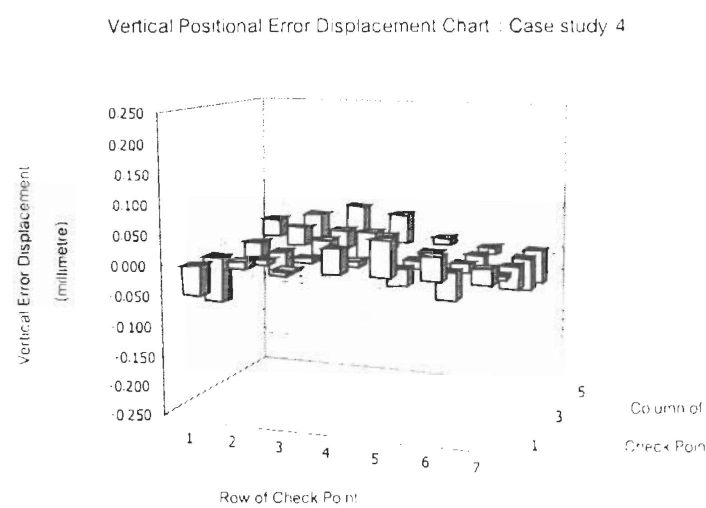


Figure 9.d: Case 4

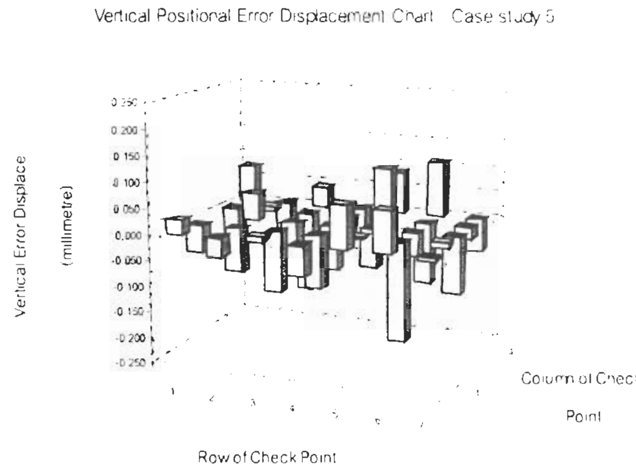


Figure 9.e: Case 5

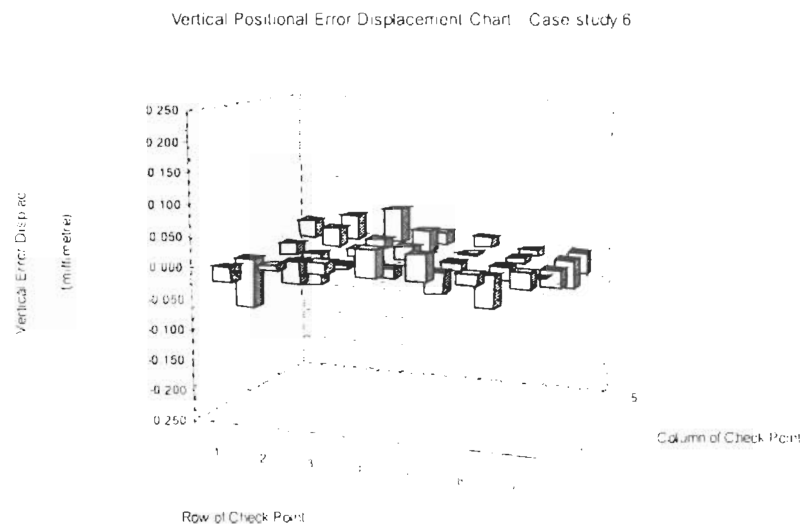


Figure 9.f: Case 6

From figure 9.e and9.f, the pattern of vertical displacement is relatively similar. The values in these cases are less than 50 micron or 0.05 millimeters and less than the other.

Conclusion

Investigated study implicated the accuracy obtained from in dimension measurement of object size 240x240x15 millimeters by close range digital photogrammetry is not greater than 80 micron or 0.08 millimeters.

The main features of successful case studies (case study 4 and 6 of 8 camera exposure stations) are:

1. Number of camera exposure stations is 8 stations.
2. Type of camera calibrations: self-camera calibration (both general method and inverse method can produce the target accuracy).
3. Type of control point target: signalized control point.
4. Type of control point marking: weight-centroid method.
5. Type of tie point target: signalized tie point.
6. Type of tie points marking: Automatic tie point.
7. Accuracy of horizontal control point 0.01 millimeters.
8. Accuracy of vertical control point 0.02 millimeters.
9. Lighting environment has to be controlled for the data capturing process.

The usefulness of this research covered Geo-spatial Technology such as remote sensing and GIS will be investigated to this study.

References

วิชัย เยี่ยงวีรชน. 2529. คู่มือปฏิบัติการสำรวจด้วยภาพถ่าย 2. ภาควิชาวิศวกรรมสำรวจ คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย กรุงเทพมหานคร: **สำนักพิมพ์แห่งจุฬาลงกรณ์มหาวิทยาลัย**.

วิชา จิวาลัย และปรีชา วงศ์วิทวัส. 2531. หลักการเบื้องต้นของการสำรวจด้วยภาพถ่าย กรุงเทพมหานคร: **สำนักพิมพ์แห่งจุฬาลงกรณ์มหาวิทยาลัย**.

Atkinson, K.B. 1980. Developments in close range photogrammetry -1. London: **Applied Science Publisher**.

Clarke, T.A. 1995. An Analysis of the prospects for digital close range photogrammetry. ISPRS **Journal of Photogrammetry&Remote Sensing.** 50(March 1995): 4-7

Deng, F.and Faig, W. 2001. An Evaluation of an Off-the-shelf digital close-range photogrammetric software package. **Photogrammetric Engineering & Remote Sensing**. 67(February 2001): 227-233

Fedak, M. 3D Measurement accuracy of a consumer-grade digital camera and retro-reflective survey targets. Available form : **www.photomodeler.com/pdf/fedak1**.pdf

Forlani, G. Guissani, A. and Scaioni, M. 1996. Target detection and Epipolar geometry for image orientation in close-range photogrammetry. **International Archives of Photogrammetry and**

Remote Sensing. 31(August 1996): 518-523

Fraser, C.S. 1984. Network design considerations for non-topographic photogrammetry. **Photogrammetric Engineering&Remote Sensing.** 53(August 1984): 1115-1126

Fraser, C.S. and Brown, D.C. 1986. Industrial photogrammetry: new development and recent applications. **Photogrammetric Record**. 12(October 1986): 197-127

Fraser, C.S. 1992. Photogrammetric measurement to one part in a million. **Photogrammetric Engineering&Remote Sensing**. 58 (March 1992) : 305-310

Fraser, C.S. 1997. Digital camera self calibration. **ISPRS Journal of Photogrammetry & Remote Sensing**. 52(April 1997): 149-159.

Fraser, C.S. 1999. Automated vision metrology: a mature technology for industrial inspection and engineering surveys. **6th South East Asian Surveyors Congress Fremantle.** Western Australia (November 1999) : 1-6.

Karara, H.M. and Abdel-Aziz ,Y.I. 1974. Accuracy aspect of non-metric imageries. **Photogrammetric Engineering**. 38(November 1974): 1017-1117.

Katri Oksanen. 1995. The design and simulation of video digitizing by using three–dimensions CAD-models. **International Archives of Photogrammetry and Remote Sensing**. 31(April 1995): 518-523.

Luhmann, T. 2000. **Nahbereichs-Photogrammetrie**. Heidelberg: Herbert Wichmann Werlag.

Mason, S. 1995. Expert system based of close-range photogrammetric networks. **ISPRS Journal of Photogrammetry&Remote Sensing**. 50(May 1995): 13-34.

Mikail, E.M. 2000. **Introduction to Modern Photogrammetry.** USA: John Wiley & Son.

Pappa, R.S., Giersh, L.R. and Quagliarroli, M.J. **Photogrammetry of a 5m Inflatable space antenna with consumer digital cameras.** Available form : http://www.photomodeler.com/pdf/NASA.pdf

Wang, X. and Clarke, T.A. 2001. Separate in close-range photogrammetry. **ISPRS Journal of Photogrammetry&Remote Sensing.** 55(2001): 289-298

Wolf, P.R. 2000. **Element of Photogrammetry**. USA: McGraw-Hill.