# ACCURACY ANALYSIS FOR NEW CLOSE-RANGE PHOTOGRAMMETRIC SYSTEMS

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**ABSTRACT**

Mobile mapping system is a close range photogrammetric system proved to be useful in many GIS applications. Whenever an area needs to be surveyed, a van equipped with all the necessary instruments and sensors travels into that area and takes a series of images of the objects and collects other information related to each images. The data is displayed on the workstation monitor. Through the interaction, the operator can measure all of the objects that appear in multiple images and subsequently calculate and store 3D data in GIS database.
Due to financial limitation it was impossible to have a mobile system. But using simple technique it was possible to investigate many factors, which could affect the accuracy and performance of such system. So, this study was done using professional non-metric 35mm camera. Image coordinates were measured using stereo-comparator and the data was processed on a personal computer using bundle with self-calibration aerial triangulation program. The description of the tests which have been carried out as well as the results and their analysis are presented.

## 1- INTRODUCTION

In 1989, the Center for Mapping of the Ohio State University established a major research program that focuses on the development of Mobile Mapping Systems (MMS). These devices capture a comprehensive set of land-related data from airplanes, cars, or trains. Spatial positions and attributes of objects are extracted automatically on the mobile platform or during post-processing, and are immediately transferred to a multi-media geographic database (Novak, 1995).

The University of Calgary and GEOFIT INC., a high-tech company in Laval, Quebec, Canada have jointly developed the same system The system named VISAT, stands for Video-Inertial-SATellite and integrates inertial and GPS technology with a cluster of CCD cameras (El-Sheimy, 1996 & Li , 1996).
The main objective of this research is to study some of the factors affecting the accuracy of any close range photogrammetric system such as the mobile mapping. The study area was a road 12mx100m at Assuit University campus. Professional non-metric (Voigatlander) 35 mm camera, mounted on a tripod, has a bubble for adjusting the horizontalty and has a handle with graduation for rotating was employed with black and white film as a data acquisition system. Natural points were selected as control and check points. Their coordinates were estimated using field survey techniques. Fig.1 illustrates the study area and the positions of camera stations and the object points (both control & check points.)
Image coordinates were measured four times using a stereocomparator and the average was used for data processing. The accuracy of the measurements can be assumed 2 or 3 microns. A Bundle adjustment with Self-Calibration (BSC) program developed and written by Novak from Ohio State University was utilized for photogrammetric triangulation. Bundle adjustment is an analytical method used to compute accurate object space coordinates of points from their photographic coordinates. Basically, a bundle is created by each exposure of a camera. The perspective center and the points in the image define this bundle in a local image coordinate system. The bundle solution tries to shift and rotate these bundles of light-rays so that they fit to some given control points. Additionally constraints can be included such as distances measured between object points or perspective centers, to further stabilize the solution (Novak 1991). Bundle adjustment can also be extended to calibrate the cameras and solve for additional parameters to model distortions of the images. These parameters, as well as, an open interior orientation, help to fit the bundles to the object control in a better way.

BSC allows the user to read image coordinates, which are the observations, ground coordinates, which can be used as control points, predefined camera parameters, approximations of unknown parameters, such as tie-points and exterior orientation parameters of camera stations, and distances between object points and perspective centers. The program computes the least squares solution of the specified data. The user can constrain certain parameters so that they do not change during the adjustment. One obtains as output the residuals of the observations, the precision of the computed parameters, and the correlation between the parameters of the interior orientation.

## 2- EXPERIMENTAL WORK

Mobile Mapping System (MMS) is mainly used for highway mapping, consequently, the study area for this research was a road inside Assuit University campus, approximately 12 m width, and 100 m length. Camera station positions were determined and fixed with 5 cm steel nails. Natural points were selected as control and check points. Their coordinates were estimated using a one-second electronic digital theodolite by measuring the two horizontal directions, and vertical angle of each point from two ends of a base line of 13.04 m length, in four rounds.

### 2.1 Objet-Space Coordinates System

In establishing the object-space coordinates of both control and check points, a local coordinate system was used. A base of 13.04 m was selected perpendicular to the road centerline (to give the same angle of view of the photography), near to the camera stations. The left point of the base line was assumed to be the origin, and the X-axes are the base line itself. Y-axis is parallel to the plumb line and Z-axes is parallel to the road centerline.

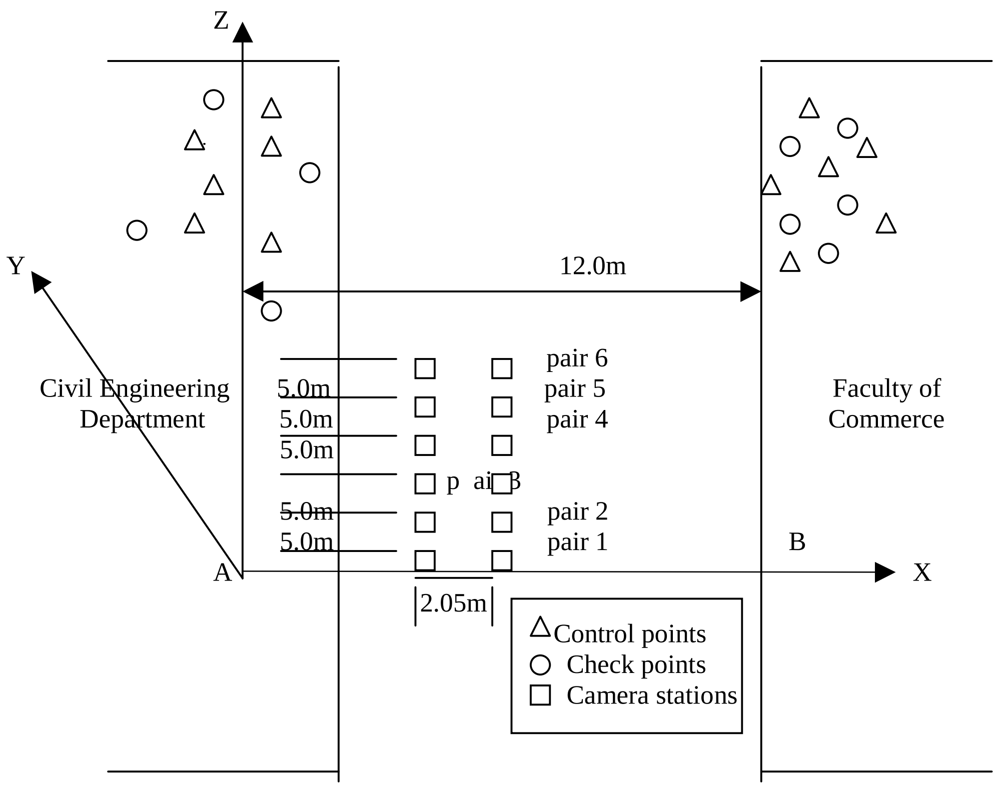


Fig. 1 - Camera Stations, Check and Control Points.

## 3. ANALYSIS AND RESULTS

### 3.1 Introduction

In establishing a GIS for a certain area using MMS, the exterior orientation parameters of the two camera stations can be calculated from the GPS and INS data. The GPS gives coordinates of camera stations. Rotation parameters can be determined using the INS or different technologies (Thrwat, 1996). Because non-metric camera was used, camera exterior orientation parameters could not be determined. Since in MMS the camera exterior orientation parameters are known and to have the same condition in our system, a group of control points were used to estimate these parameters through a resection for each photograph separately. The number of unknowns for each stereo pair are six exterior orientation parameters for each image, focal length, two (x, y) coordinates for the principal point, and six additional parameters to correct for systematic distortions as recommended for the used computer program. Hence, the total number of unknowns is given as:

$$N_u = 2*6 + 1 + 2 + 6 = 21 \qquad (1)$$

Consequently, the minimum required number of equations would be 21 for each stereo pair. The closest, average and fareast object-to- camera distances were 30,40 and 50 m, respectively. The average distances (Av-D.) between the stereo pair and checkpoints were calculated as follows:

$$\text{Av-D.} = (dmax + dmin)/2 \qquad (2)$$

where:

dmax.........The distance between farest check point and stereo pair

dmin..........The distance between closest check point and stereo pair

To evaluate the results of the tests, the average errors for check points coordinates (SX, SY, SZ) were calculated according to the following equation:

$$SX = 1/n \sum_{i=1}^{n} ABS\,(X_{fi} - X_{pi}) \qquad (3)$$

and similar equations for SY and SZ. The average error in the total direction

$$S\,T = \sqrt{Sx^2 + SY^2 + SZ^2} \qquad (4)$$

Where :

SX, SY, SZ and ST....... average error for the check points in X, Y, Z and T directions respectively.

$X_{fi}$, $Y_{fi}$, $Z_{fi}$ ...........Object - space coordinates of point i calculated by field survey.

$X_{pi}$, $Y_{pi}$, $Z_{pi}$...........Object - space coordinates of point i calculated by photogrammetry.

n .............................Number of check points.

Since the main objective of this paper is to study the effect of some factors on the accuracy of mobile mapping, several tests have been carried out. Abbass thesis (1996) has the detailed of all the tests and their results and analysis. In the following sections some of these tests and their results will be given.

### 3.2 Effect of Number of Control Points

The first test was carried out to determine the ultimate number of control points, which gives the best accuracy for object - space coordinates. A stereo pair of 2.05m base line was chosen. The number of the points measured in this model was 24 points. The model has been adjusted several times using 3, 4, 5,.........,12 control points. The average error for the rest of the points which are consider as check points were calculated using equations (3&4)

Table (1) illustrates values of SX, SY, SZ and ST for check points, against number of control points. It can be seen that values of average errors for check points decreases with increase in the number of control points to a certain limit, then it becomes constant. This limit is found to be 9-control points.. Consequently, this number of points will be used for all the tests when studying the other factors influencing the accuracy.

### 3.3 Evaluating the Accuracy of MMS

To evaluate the accuracy of the photogrammetric system, a test using six stereo pairs was carried out. All of the models have same base line length of 2.05m. From the 33 known points available in the test field 9 points were used as control and 12 points as check points. These points were chosen because they appear in the photos of all the tests.

Table (2) shows the relation between SX, SY, SZ and $S_T$ and the Av.D. For all models. It is clear that the average errors of check points in all directions are directly proportional to the average object to camera distances. The maximum average errors are in Z direction for all the models while the average errors for X and Y directions are nearly equal.

Table (1) Average Errors Against Number of Control Points.

| No. of Control Points | Average Error (cm) | | | |
|---|---|---|---|---|
| | SX | SY | SZ | ST |
| 3 | 6.23 | 5.63 | 9.56 | 12.72 |
| 4 | 4.86 | 4.53 | 8.35 | 10.67 |
| 5 | 4.35 | 4.02 | 7.87 | 9.85 |
| 6 | 4.12 | 3.74 | 7.48 | 9.32 |
| 7 | 3.91 | 3.43 | 7.19 | 8.87 |
| 8 | 3.67 | 3.30 | 7.05 | 8.61 |
| 9 | 3.54 | 3.24 | 6.95 | 8.45 |
| 10 | 3.61 | 3.22 | 7.03 | 8.53 |
| 11 | 3.56 | 3.29 | 7.18 | 8.66 |
| 12 | 3.60 | 3.21 | 7.11 | 8.59 |

Table (2) Average Errors Against Average Objects Distances.

| Stereo Pair | Average Objects Distance (m) | Average Error (cm) | | | |
|---|---|---|---|---|---|
| | | SX | SY | SZ | ST |
| 1 | 55 | 4.30 | 3.70 | 8.20 | 9.97 |
| 2 | 50 | 3.92 | 3.51 | 7.76 | 9.38 |
| 3 | 45 | 3.63 | 3.32 | 7.31 | 8.81 |
| 4 | 40 | 3.54 | 3.24 | 6.95 | 8.45 |
| 5 | 35 | 3.33 | 3.13 | 6.63 | 8.05 |
| 6 | 30 | 2.87 | 2.71 | 6.26 | 7.40 |

### 3.4 Effect of Base Line Length

Many photogrammetrists studied the effect of B/ H ratio on the accuracy of object -space coordinates. It is known that increasing base line length means bigger B/H ratio. This will lead to higher accuracy of object -space coordinates. In this paper, a base line of 1.8 was selected and an increase of 0.25 m was added to it, until the final base line length reached 3.05 m. All models have closest and fareast object-to-camera distance of 30 m and 50 m, respectively. Nine points were used as control and 12 points as check points.

Table (3) gives the average errors for X, Y, Z and T directions for check points against base line lengths. It is clear that increasing base line length improves the accuracy in object- space coordinates in all directions. The percentage of improvements in accuracy from using the model of 2.8 m base line instead of 1.8 m base lines are 23%, 24% and 42% in X, Y and Z directions respectively.

### 3.5 Effect of Object-to Camera Distance:

To study the effect of the distance between the camera and the observed points on the accuracy of the measurements, a test on a stereo pair of 2.05 m base line was carried out. The numbers of control and check points were 9 and 12 respectively. Table (4) gives the errors for each check point against its object to camera distance. It can be concluded that the distance between the van and the object point has a great effect on the accuracy. For example the improvements percentages in accuracy of a target point at a distance 30 m than that at 53 m are 25%, 23% and 40% in X, Y and Z respectively.

Table (3) Average Errors Against Base Line Lengths.

| Length of Base Line ( m) | Average Error ( cm ) | | | |
|---|---|---|---|---|
| | SX | SY | SZ | ST |
| 1.80 | 3.73 | 3.48 | 7.42 | 9.00 |
| 2.05 | 3.54 | 3.24 | 6.95 | 8.45 |
| 2.30 | 3.39 | 3.01 | 6.67 | 8.06 |
| 2.55 | 3.20 | 2.93 | 6.19 | 7.56 |
| 2.80 | 3.02 | 2.80 | 5.23 | 6.66 |
| 3.05 | 2.89 | 2.66 | 4.11 | 5.69 |

Table (4) Errors against Object to Camera distances.

| Point No. | Object to Camera Distance (m) | Average Error ( cm ) | | | |
|---|---|---|---|---|---|
| | | SX | SY | SZ | ST |
| 1 | 81.9 | 4.55 | 4.09 | 8.92 | 10.82 |
| 2 | 78.5 | 4.34 | 4.03 | 8.63 | 10.47 |
| 3 | 73.4 | 4.17 | 3.92 | 8.27 | 10.06 |
| 4 | 68.4 | 4.04 | 3.73 | 7.89 | 9.62 |
| 5 | 62.6 | 3.89 | 3.48 | 7.74 | 9.34 |
| 6 | 57.3 | 3.74 | 3.31 | 7.49 | 9.00 |
| 7 | 52.7 | 3.39 | 3.20 | 7.24 | 8.61 |
| 8 | 45.6 | 3.23 | 2.86 | 6.50 | 7.80 |
| 9 | 37.9 | 3.02 | 2.73 | 5.79 | 7.08 |
| 10 | 35.4 | 2.84 | 2.60 | 5.55 | 6.75 |
| 11 | 31.5 | 2.67 | 2.54 | 5.02 | 6.23 |
| 12 | 30.1 | 2.55 | 2.39 | 4.36 | 5.59 |

### 3.6 Effect of Using Additional Parameters

Since a non-metric camera was used in this study, additional parameters were necessary to be taken into consideration to obtain better adjustment results. Additional parameters were used to correct for systematic distortions of the camera model. The parameters are two for radial distortion (a1,a2) , two for decentering distortion (a3,a4) and two for affine deformation (a5,a6). These six parameters were chosen according to Novak (1991) using the following relation.

$$\Delta X = a_1 ( r^2 - 1) x + a_2 ( r^4 - 1 ) x + a_3 (r^2 + 2x^2 ) + a_4 xy - a_5 x + a_6 y$$
$$\Delta Y = a_1 (r^2 - 1 ) y + a_2 ( r^4 - 1 ) y + a_4 ( r^2 + 2y^2 ) + a_3 xy + a_5 y \tag{5}$$

To study the effect of additional parameters on the accuracy, a test using six stereo pairs with base of 2.05m and different object to camera distances were adjusted with and without using the mentioned additional parameters. Table 5 shows the results of the six models. From the table it can be seen that the percentages of improvements in accuracy for the stereo pairs are about 33%, 24% and 42% in X, Y and Z directions respectively when using the additional parameters.

### 3.7 Effect of Using Side Photography

In establishing a GIS for a highway, the usual case is photographing in the direction of the van movements. Sometimes, targets of special importance can be located at one side of the road. Then it is possible to photograph the object points with the base of the two cameras parallel to the van motion. The advantages are the ability to increase the length of the base and also one may obtain the smaller object to van distances. Four stereo pairs were taken. The first was the usual case with base line of 2.05m and 35 m average object to camera distance. The other three pairs were using side photographs and same number of control and check points. The second pair had base line of 2.05m but with 25 m object to camera distance. The third had base line and object to camera distance of 2.50m and 25m respectively. The last pair has base line of 2.75m and same camera to object distance. Table 6 shows the average error for check points for the four models. From the table it is clear that the accuracy have been improved. The percentage of improvements for the fourth model compared with the first are 30%, 32% and 42% in X, Y and Z respectively.

Table (5) Average Errors for Check Points With and Without Additional Parameters.

| Pair | Av. Objects | With | | | | Without | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Distance m | SX | SY | SZ | ST | SX | SY | SZ | ST |
| 1 | 55 | 4.30 | 3.70 | 8.20 | 9.97 | 6.45 | 4.90 | 15.13 | 17.16 |
| 2 | 50 | 3.92 | 3.51 | 7.76 | 9.38 | 6.00 | 4.58 | 14.32 | 16.19 |
| 3 | 45 | 3.63 | 3.32 | 7.31 | 8.81 | 5.55 | 4.34 | 13.49 | 15.22 |
| 4 | 40 | 3.54 | 3.24 | 6.95 | 8.45 | 5.21 | 4.24 | 12.83 | 14.48 |
| 5 | 35 | 3.33 | 3.13 | 6.63 | 8.05 | 5.04 | 4.14 | 12.24 | 13.87 |
| 6 | 30 | 2.87 | 2.71 | 6.26 | 7.40 | 4.24 | 3.76 | 11.55 | 12.87 |

Table (6) Average Errors for Check Points for Side Photography Case Study.

| Case of Study | Length of Base Line (m) | Average Objects Distance (m) | Average Error (cm) | | | |
|---|---|---|---|---|---|---|
| | | | SX | SY | SZ | ST |
| Normal | 2.05 | 35 | 3.54 | 3.57 | 5.64 | 7.56 |
| Suggested | 2.05 | 25 | 2.41 | 2.55 | 3.50 | 4.96 |
| Suggested | 2.50 | 25 | 1.90 | 2.09 | 3.10 | 4.19 |
| Suggested | 2.75 | 25 | 1.65 | 1.90 | 2.70 | 3.69 |

### 3.8 Effect of Increasing the Number of Camera Stations.

To estimate the effect of increasing the number of camera stations, tests have been carried out using two, three, four, five and six camera stations. The first pair was the usual case. For the second test, one camera station was added in the middle and its elevation is 0.50m above the other two cameras. For the third test one more cameras station was added with its elevation 0.5m higher than the first two.. The fourth test a fifth camera with its elevation 0.75m higher than the first two cameras was added in the middle. The fifth test a sixth camera station was added with its elevation similar to fifth camera station. Fig. 2 shows the arrangement of the cameras for the five tests.

Table 7 shows the results of the test. From the table it can be seen that increasing the number of camera stations improves the accuracy. When six cameras were used the accuracy is improved compared with the case of two cameras by 31%, 60% and 28% in X, Y and Z respectively.

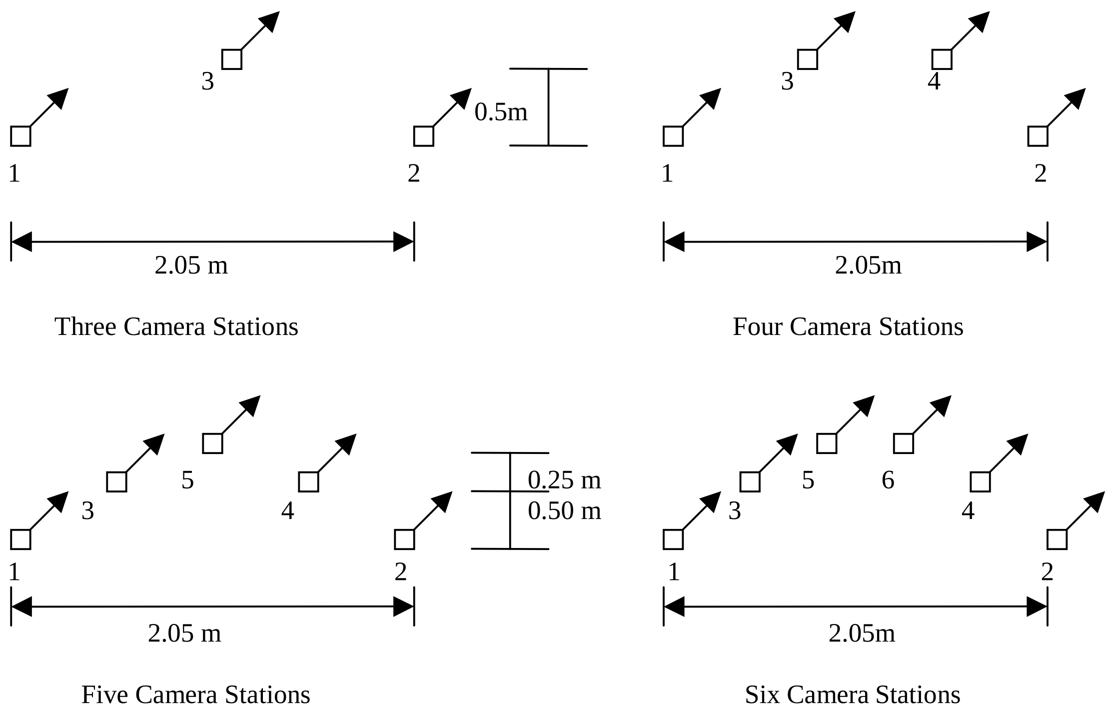


Fig. 2 - Arrangement of Camera Stations.

Table (7) Average Errors for Check Points Against Number of Camera Stations.

| Case of Study | Average Error (cm) | | | |
|---|---|---|---|---|
| | SX | SY | SZ | ST |
| Stereo – Pair | 3.33 | 3.13 | 6.63 | 8.05 |
| Three-Station | 3.11 | 2.42 | 6.11 | 7.27 |
| Four – Stations | 2.87 | 2.03 | 5.63 | 6.64 |
| Five – Stations | 2.51 | 1.69 | 5.19 | 6.01 |
| Six – Stations | 2.29 | 1.25 | 4.81 | 5.47 |

## 4- CONCLUSIONS

From the results of the research the following conclusions can be drawn

1- It is possible to obtain 10cm accuracy in position, for targets at 55m from the cameras, if close range photogrammetric system similar to one we used is utilized.

2- Increasing the base line length increase the accuracy significantly especially in Z direction, which could reach 40%. The authors suggest that, two sliding cantilevers can support the two cameras for a MMS. The length of these two cantilevers can be controlled automatically using a motor operated from inside the van according to the width of the road.

3- The distance between the objects and van has a great effect on the accuracy. Changing the distance from 53m to 30m increases the accuracy by 40% in Z.

4- Additional parameters when used improve the accuracy significantly which could reach 33%, 24% and 41% in X, Y and Z directions respectively.

5- Changing the direction of photography from that of van motion to the perpendicular direction improves the accuracy of the system in all direction than that obtained by the usual case. Side photography has the advantages of the ability to increase the base line length and have closest object to camera distances. The percentages of improvements in accuracy when using side photographs with 2.75m base line and 25m average object to camera distance than the case with base line of 2.05m and 35m average object to camera distance were 30%, 32% and 42% in X, Y and Z respectively.

6- Increasing the number of camera stations and using them at different heights improve the accuracy significantly especially in Y direction. The percentages of improvements when using six cameras were 31%, 60% and 28% in X, Y and Z respectively. While they were 14%, 35% and 15% in X, Y and Z respectively when four camera stations were used.

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