# THREE DIMENSIONAL CALIBRATION ROOM DESIGN AND APPLICATION FOR ARCHITECTURAL DOCUMENTATION METHODS

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**ABSTRACT:**

Three-dimensional documentation and visualization studies are frequently used in the architectural cultural heritage works, with considerably detailed metric properties of the models. The digital 3D reconstruction for the purposes of documentation of cultural heritage can be done with multiple techniques. Thus, different kinds of measurement and modelling techniques, such as photogrammetry and laser scanning, were combined in our applications. In this case, the metric accuracy and factuality of the models became important in the process of data integration of such techniques. The accuracy of the integration was obvious before the applications. Surveying results had to meet certain specifications in order to provide sufficient accuracy standards for a certain application. On the other hand, if extra instruments and methods would have been used, it would yield a non-functional accuracy far above the needed standards.

## 1. INTRODUCTION

The first step towards establishing a geodetic network is the design of the photogrammetric network study. Conceptually, the purpose of the network design is to produce an optimum geodetic network configuration and an optimum observation plan that will satisfy the pre-set quality for calibration area. The importance of network design in close-range photogrammetry has been recognized since the 1970s and investigations into methods for close-range photogrammetric network design have been under development since then. (Marzan, Karara, 1976) Presented preliminary studies about integration were associated with network design. The network design of the calibration room has been extended with pipe construction on the ceiling for laser scanning studies especially.

The precision of object space coordinates of points have been calculated with adjustment for certain network (Schneider, Schwalbe, Maas, 2009). This network design method has the advantage of precise 3D geometry and simplicity with laser scanning and close-range photogrammetry integrated studies. The concept has entirely convenient for architectural close-range photogrammetric applications with or without laser scanning integration. The similar calibration rooms had been constructed in TU Dresden and ETH Zurich for integrated studies of photogrammetry. Some of the studies for calibration networks have been applied successfully for close-range photogrammetry networks for instance camera calibration studies (Fraser, 1984, 1992, 1996). Initial studies discussed the network design problem in close-range photogrammetry, and performed first order design using with an analytical methods in hardware and software integrated applications (Fritsch, Crosilla, 1990). This paper is organized as follows: After the introduction, section 2 gives a description of the geodetic survey of the calibration room. Section 3 presents the accuracy and statistical analysis of survey data in the study site. Section 4 points out the results of the study and a discussion of these results are made.

## 2. GEODETIC STUDY

The geometric surveying task comprised not only the derivation of the relative positions of points, but also an estimation of the

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accuracy of the results. This was not only a subsidiary property of the application before working in the field, but also a method for testing the new documentation techniques and instrumentations, such as panoramic video documentation. By designing three dimensional calibration rooms, with reliable geodetic network study; different measurement and modelling, techniques were processed for the data integration from different sources. In this study, a calibration room of an area of 12mx9mx4m was established, in order to integrate the photogrammetric and laser scanning data. This calibration room can be used for all documentation purposes in order to get reliable data using photogrammetric and laser scanner methods.

The geometry of the network has been established for all three-dimensional surfaces and pipes also. The floor, ceiling and walls have been used for signalizing in the room. 43 target points on the floor, 79 target points on the walls and 78 target points on the ceiling have been signalized. Totally 200 target points have been established for calibration room with different three-dimensional surfaces. The network design has been established especially for close-range photogrammetry and laser scanning integration studies. The panoramic image of calibration network has shown in figure 1. Centering on a landmark was the other major error source especially when geodetic measurements were considered. It directly was sub-millimetre positional errors that try to achieve sub-millimetre positional accuracy. However, in that case there was a chance to remove central error without having central procedure. In affect, no central process has been done during measurements.

Figure 1: Calibration room network

As the geodetic observations, theodolite T 2002 (Wild) was used for angle measurements with $0.5^{cc}$ precision in the network of the calibration room. Four station points have been setup for all angle and distance measurements. The measurement setup has shown in figure 2. Topcon GTS 701 was used for the distance measurement from the polygon points to targets with laser distance measurement with 2mm+2 ppm precision. Angle measurements have been repeated four sets of vertical and horizontal angles. Distance measurements from all polygons to targets have been done also four times. This measurement algorithm has been determined the bundle arrays for all target points and polygons also. This method has given the scale and rotational advantage for adjustment of coordinates in local datum (Çelik, Yalın, Ergün, 2001).

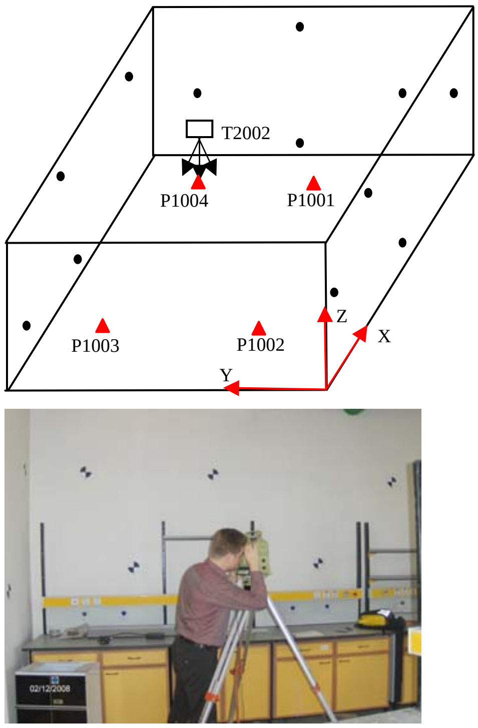


Figure 2: Observation setup

### 3. ADJUSTMENT OF THE NETWORK

Geodetic data have been produced using the departmental adjustment software at GIT. This software has also outlier detection process that helps to remove outliers if exist. At first, angle measurements of the network have been adjusted for X-Y coordinates individually processed and their adjusted coordinates have been obtained in local coordinate system. Second, the trigonometric levelling data have been adjusted with functional method. Thereafter these coordinates have been accepted as approximate coordinates of the network for the following works done. It was previously mentioned that only horizontal direction observation and vertical angles have been measured during the adjustment process. Absolute distance measurements have been made for scaling the network. Therefore, the adjustment software has been used to handle these direction observations and angle measurements. The direction observations were much more precise then absolute distance measurements for this network.

The conventional adjustment process of the observations has used the equation (1).

$$\begin{aligned} N &= A^T W A \\ n &= A^T W l \\ x &= \theta_{xx} n \\ V &= Ax - l \end{aligned} \tag{1}$$

where N = normal matrix
A = design matrix
W = diagonal weight matrix
x = unknown vectors
n = cofactor matrix
V = residual vector

Weights of observations have been calculated with the standard deviation of unit weight which shown in the equation (2) for independent observations.

$$s_0 = \sqrt{\frac{V^T W V}{n-u}} \tag{2}$$

where $s_0$ = standard deviation of unit weight
n = observation number
u = unknown number

The matrix of the cofactor for corrections have calculated with equation (3)

$$\begin{aligned} \bar{\theta}_{ii} &= A\theta_{XX} A^T \\ \theta_{vv} &= W^{-1} - \bar{\theta}_{ii} \end{aligned} \tag{3}$$

where $\bar{\theta}_{ii}$ =weight co-efficient matrix of adjusted observation

$\theta_{vv}$ = co-factor matrix of corrections

The statistical reliability of the observation network has been calculated the equation (4) for Pope Test.

$$\bar{V}_i = \frac{|V_i|}{s_0 \sqrt{\theta_{vivi}}} \tag{4}$$

The parameters of error ellipses of the all control points have been calculated with the equation (5) as shown below.

$$\begin{aligned} \theta &= \frac{1}{2} \arctan \frac{2\theta_{xy}}{\theta_{xx} - \theta_{yy}} \\ w &= \sqrt{(\theta_{xx} - \theta_{yy})^2 + 4\theta_{xy}^2} \\ A &= s_0 \sqrt{\frac{\theta_{xx} + \theta_{yy} + w}{2}} \\ B &= s_0 \sqrt{\frac{\theta_{xx} + \theta_{yy} - w}{2}} \end{aligned} \tag{5}$$

where $\theta$ = theta angle of ellipse
$w$ = hypotenuse form of co-factors
$\theta_{xx}$ = standard deviation of X direction
$\theta_{yy}$ = standard deviation of Y direction
$\theta_{xy}$ = co-variance of X, Y direction

Having produced the coordinates of the control stations for the network, the direction observations and vertical angles measured on each face of the walls have been processed using the same departmental adjustment software to obtain the coordinates of geodetic control points that were selected as all photogrammetric control points in MATLAB 7.0 software. The

XYZ adjustment results, maximum and minimum accuracy of the points have shown in the table 1.

| ROOM DIMENSION | HORZ. (12m.) | VER. (9 m.) | HIGH (4m.) |
|---|---|---|---|
| Coordinate Accuracy After Adjustment | X (mm.) | Y (mm.) | Z (mm.) |
| Min. | 0,00478 | 0,00272 | 0,144143 |
| Max. | 1,66697 | 0,48859 | 1,16539 |
| Std. Dev. | 0,22777 | 0,06653 | 0,18498 |

Table 1. Coordinate accuracies after adjustment

However, this network has been scaled measuring only a distance since distance measurements are much less precise then the direction observation measurements. Therefore, distance measurements have been used for absolute scaling of the network. However, scaling error has been computed before last three-dimensional adjustment using triangulation measurements also. It has been seen that 0.3 mm. scaling error have occurred. The triangulation measurements have also proved that the interval accuracy is 0.1 mm. Both accuracy values also prove that sub-millimetre can be achieved using these instruments and measurements set up. These results have been detailed for survey on the network has been carried out at the same time (Demirel, 2003). The decision of four set of vertical and horizontal angles have been achieved with this method. Statistical results for geodetic three-dimensional network have shown in the Table 2.

| Statistical Analysis | Max. (mm.) | Min. (mm.) | Std. Dev. (mm.) |
|---|---|---|---|
| A parameter of error ellips | 0,84032 | 0,07446 | 0,13106 |
| B parameter of error ellips | 0,17961 | 0,02688 | 0,03592 |
| Test of Pope Points | Number of reliable points | Number of non_reliable points | |
| 200 | 196 | 4 | |
| Results | 98 % | 2% | |

Table 2. Statistical reliability of network

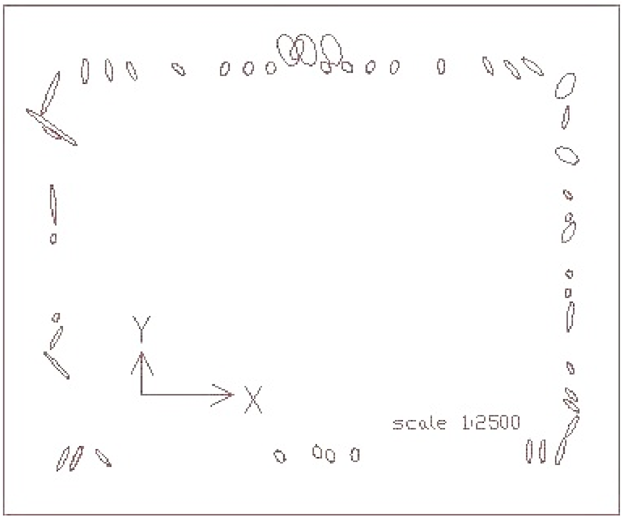


Figure 3. Error ellipses of the control points on the wall

The error ellipses of the network points have been shown in the Figure 3. The concept of reliability of geodetic networks originates from Baarda and refers to the ability of a network to detect and resist blunders in observations. In close range photogrammetry, precision and reliability considerations have been addressed by uniqe studies (Parian, 2007).

## 4. CONCLUSION

In consequence of this study, three-dimensional calibration room has been established for purposes of close-range photogrammetry and laser scanning integration. This room has 200 control points, which have precise coordinates. The geometry of these points have dispersed to all surfaces ($360^0$) of the room also. This property has advantage of the studies for panoramic imaging techniques especially. Therefore, the next step of the research is the use of panoramic cameras for object reconstruction and texture mapping, indoor environment applications for close-range photogrammetry and laser scanning integration also. This kind of calibration room can be used for different kind of measurement hardware integration. All of these concepts of documentation techniques have been interested in the cultural heritage documentation for the future.

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