TOPOGRAPHIC SURVEY OF THE CONTROL POINTS FOR PHOTOGRAMMETRIC RECORD

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ABSTRACT

The accomplishment of a photogrammetric recording of historical monuments it is important that be done a topographical survey, with the purpose of determine some control points in the building structure, for posterior orientation of the photographs. This paper shows the experience of the topographical survey made in the "Solar do Rosário", historical monument of Curitiba – Paraná - Brazil. The used method was the spatial intersection and the points configuration of the base (until to three points) had their location defined conciliating the available space and the rigidity. The redundant observations provided least squares adjustment. The final results and the respective accuracy of the adjustment allowed their comparison with the obtained solution using simpler methods, indicating the more viable in spend time and accuracy. The survey was done with a total station whose angular accuracy is of 1" and linear of 1 mm + 1 ppm. It was also tried to test the viability in executing the survey with equipment of smaller cost, in the case a theodolite electronic of angular accuracy of 10".

1 INTRODUCTION

This work is one steps of the photogrammetric recording of architectural facades that is being accomplished in the " Solar do Rosário ", construction that belongs to the historical collections of Curitiba - Brazil. The work is being developed at the Post-Graduate Program in Geodesic Sciences of the Federal University of Paraná (UFPR), and this step had the support of the Calibration and Geodetic Instrumentation Laboratory of UFPR.

As well as in the conventional photogrammetric (aerial), the terrestrial photogrammetric is base on control points to photos orientation, as well as to represent the object in a projection system. The determination of these points coordinates, in this work, were calculated by different methods using topographical observations that were obtained in two field surveying: in the first, a total station was used, and in the second an electronic theodolite.

2 EQUIPMENT AND PROCEDURES

2.1 Equipment

In the directions observation two equipment were used in different surveying, nevertheless occupying the same base stations: a total station Leica TC 2002, with a prism in the base measure and an Leica electronic theodolite (T100), with a tape measure for the base determination. The specifications of both instruments are shown in the table 1.

TC – 2002		T – 100	
Telescope Magnification	32x	Telescope Magnification	30x
Effective Aperture	42mm	Effective Aperture	45mm
Shortest Focus Distance	1.7m	Shortest Focus Distance	0.85m
Multiplication Factor	100	Multiplication Factor	100
Additive Constant	0	Additive Constant	0
Angle measurement Type	Incremental	Angle measurement Type	Incremental
Minimal Display	0.5”/0.15mgom	Minimal Display	20”/10” /50cc/20cc
Accuracy DIN 18723	1”	Accuracy DIN 18723	10”

Table 1 – Technical data

2.2 Procedures

The topographical method used in this work is based on horizontal and vertical angular observations. The determination of the angles consists in the directions measurements in the two positions allowed by the telescope theodolite or total station: direct position and inverted position, starting from a certain direction denominated origin. For the horizontal angles obtaining a origin direction was determined as 0º in the first iteration. The directions of the points were determined in the facade of the monument. More two iterations were observed: one of 45º and to another of 90º.

3 SPATIAL AVAILABILITY

For spatial availability two fundamental items were considered: the first is related to the available of physical space in the place and the possibility of interdiction of the streets, because in some cases this interdiction can cause upset to the traffic of vehicles; the second item tells respect to the base shape geometry, because a poor geometry causes damage in the positioned point precision. In the execution of this work both cases were observed and the details are described in the sequence.

3.1 Dimensions and location of the monument

The “*Solar do Rosário*” is part of the historical heritage of Curitiba city. This is located in the Nestor de Castro passageway, on the corner of Rosário street. Both the street have a vehicles and of pedestrian intense traffic. The monument was built in two floors, with a total height of approximately 10 meters. The figure 1 shows in a schematic situation plant of the referred construction. The front monument facade it was used as object study in this work.

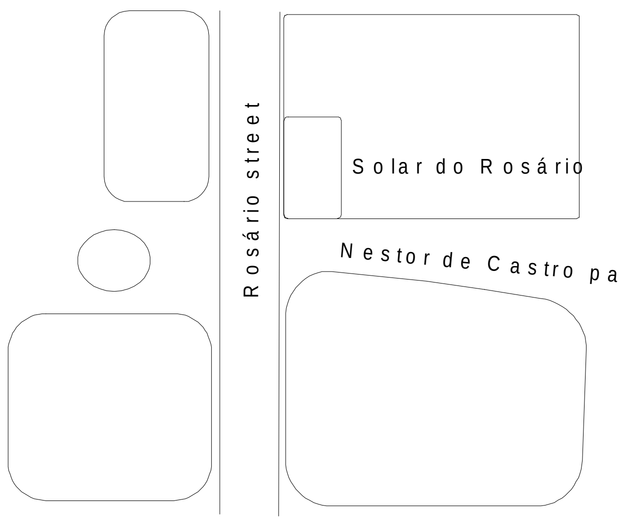

Figure 1. Schematic plant of “Solar do Rosário”

3.2 Preliminary analysis of precision in the topographical surveying

As mentioned in the section 2 of this paper, the used equipment were a total station and an electronic theodolite. For the preliminary precision analysis, for the control points in the facade, was used the intersection method to calculate the coordinates, as function of its simplicity, once it has on principle the plane triangles resolution.

Of the errors theory, it's known that is smaller the errors observational propagation, if an equilateral triangle was formed. In a practical surveying it is not possible to form equilateral triangles, as it could be observed in the case shown in the "Solar do Rosário".

The figure 2 shows the configuration of the two worse points (with poor geometry). The size of the base B and the distance of this to the facade were determined in agreement with the available space of the place.

It was used in this work a local coordinates system, the Cartesian origin of X, Y, Z was established in the instrument optic center, in the E point. The X axis was defined by the ED direction, the Z axis coincident with the vertical of the station E and the Y axis was determined forming a dextrogery system.

The measured angles from the E station were called just for $\hat{E}$, the angles from the D station were called $\hat{D}$, and the vertical angles were called $\hat{Z}$. The following expressions were used calculate the coordinates:

$$x = B\sin\hat{D}\ \cos\hat{E}\ \cos\sec(180^\circ - \hat{E} - \hat{D}) \qquad (3.2.1)$$

$$y = B\sin\hat{D}\ \sin\hat{E}\ \cos\sec(180^\circ - \hat{E} - \hat{D}) \qquad (3.2.2)$$

$$z = B\sin\hat{D}\ \cot g\hat{Z}\ \cos\sec(180^\circ - \hat{E} - \hat{D}) \qquad (3.2.3)$$

The covariance matrix ($\sum L_b$) of the observed angles and of the base is known and the propagation of the covariance law (exp. 3.2.5) provides the covariance matrix of the coordinates (x, y, z) of the points.

$$\sum_{x,y,z} = D \sum_{Lb} D^T \qquad (3.2.5)$$

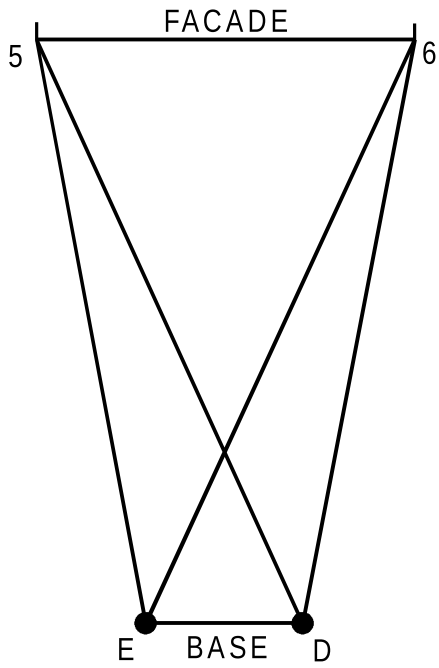

Figure 2. – Triangle configuration of the processing points

where:

$$D = \begin{bmatrix} \frac{\partial x}{\partial B} & \frac{\partial x}{\partial \hat{E}} & \frac{\partial x}{\partial \hat{D}} & \frac{\partial x}{\partial \hat{Z}} \\ \frac{\partial y}{\partial B} & \frac{\partial y}{\partial \hat{E}} & \frac{\partial y}{\partial \hat{D}} & \frac{\partial y}{\partial \hat{Z}} \\ \frac{\partial z}{\partial B} & \frac{\partial z}{\partial \hat{E}} & \frac{\partial z}{\partial \hat{D}} & \frac{\partial z}{\partial \hat{Z}} \end{bmatrix}$$

Considering the standard deviation as:

$$\sigma_B = 0{,}001m \quad \text{and} \quad \sigma_E = \sigma_D = \sigma_Z = 4{,}84813681109 \times 10^{-6}\,\text{rad}$$

The obtained deviations for the coordinates points 5 and 6 were:

Point 5	Point 6
σ_X= 0.00241 mm	σ_X= 0.00062 mm
σ_y= 0.01391 mm	σ_y= 0.01359 mm
σ_z= 0.00159 mm	σz = 0.00160 mm

The deviations above are estimate of the errors for the points positioning in the facade, and they are inside of an acceptable precision. This fact confirms that used configuration to the surveying was appropriate.

4 COORDINATES PROCESSING

The coordinates processing was made using three different methodologies: intersection; analytical spatial intersection; and least squares method.

4.1 Intersection

This method consists in the resolution of plane triangles, to obtain the plane coordinates (x, y), as well as, the coordinate (z). Being E and D two observation stations and P the point of coordinates to be determine, the figure 3 shows the procedure.

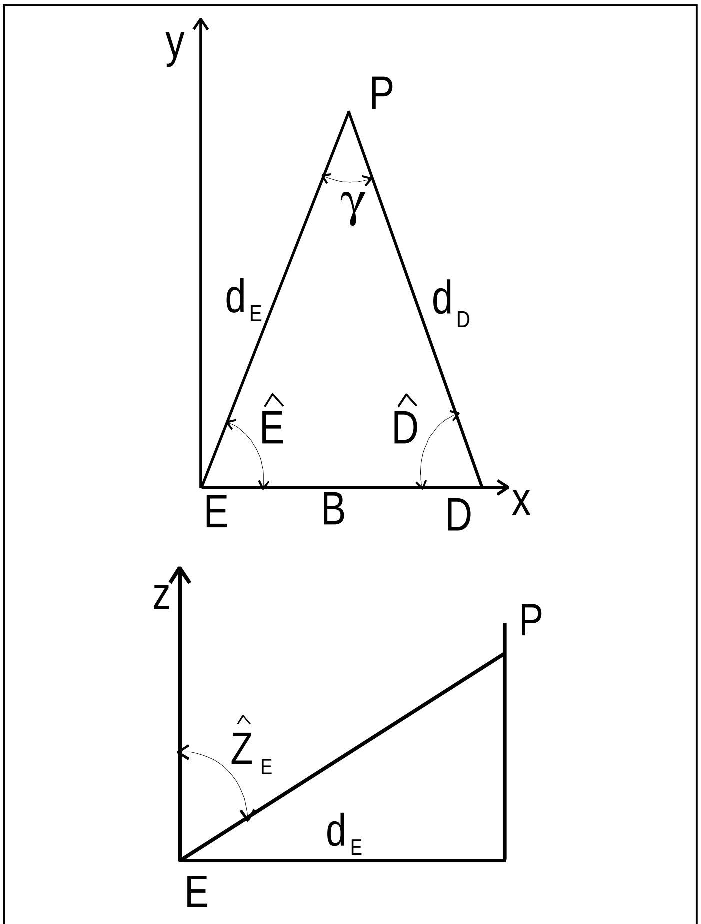

Figure 3 – Intersection Method

In the survey were observed the horizontal angles ($\hat{E}$ and $\hat{D}$), the base B and the vertical angle (Z) for each stations. The angle γ was determined through relationship among internal angles of the plane triangle:

$$\gamma = 180° - (\hat{E} + \hat{D}) \quad (4.1.1)$$

The distances d_E and d_D were calculated applying the sinus law:

$$d_E = \frac{B \,\text{sen}\, \hat{D}}{\text{sen}\, \gamma} \quad (4.1.2)$$

$$d_D = \frac{B \,\text{sen}\, \hat{E}}{\text{sen}\, \gamma} \quad (4.1.3)$$

The plane coordinates (x, y) were calculated using the following expressions:

$$x_P = x_E + d_E \cos \hat{E} \quad \text{or} \quad x_P = x_D + d_D \cos \hat{D} \quad (4.1.4)$$

$$y_P = y_E + d_E \sin \hat{E} \quad \text{or} \quad y_P = y_D + d_D \sin \hat{D} \quad (4.1.5)$$

The value of the coordinate Z is calculated from:

$$z_P = z_E + d_E \tan \hat{Z}_E \quad \text{or}$$

$$z_P = z_D + d_D \tan \hat{Z}_D \quad (4.1.6)$$

If more than two stations had be used to process the coordinates, they should be obtained by the average of the solutions, combined two by two. The table 2 shows the obtained coordinates of the topographical surveying with the total station and the table 3 shows the coordinates with the electronic theodolite.

Point	X(m)	Y(m)	Z(m)
1	-0,618	16,949	6,787
2	4,290	17,042	6,776
3	7,138	17,062	5,782
4	-3,537	16,858	5,794
5	-0,705	16,220	4,844
6	4,404	16,325	4,827
7	6,606	17,101	2,552
8	1,066	16,994	2,549
9	-3,575	16,846	2,722
10	-1,841	16,863	-0,707
11	3,985	17,006	-0,711
12	2,612	16,997	0,782

Table 2. Points coordinates with Total Station - Intersections method

Point	X(m)	Y(m)	Z(m)
1	-0,616	16,947	6,789
2	4,286	17,036	6,772
3	7,130	17,060	5,779
4	-3,525	16,863	5,793
5	-0,701	16,214	4,845
6	4,400	16,319	4,827
7	6,598	17,094	2,556
8	0,623	16,978	2,549
9	-3,570	16,848	2,719
10	-1,840	16,884	-0,702
11	5,929	17,046	-0,705
12	2,412	17,024	0,366

Table 3. Points coordinates with Electronic Theodolite -Intersections method

4.2 Analytical Spatial Intersection

The determination of the coordinates of a point can be obtained through angular observations accomplished in two stations (or more) of known coordinates. As the observations are subject to errors, the two directions probably will be not intercepted in the space, and could exist infinite positions where the point can locate. The method of analytical spatial intersection minimizes the positioning area of this point for the theory that the smallest distance among two reverse line is the perpendicular common among them. If the observations be still considered with the same precision, the medium point of the perpendicular segment will be the solution of the problem. (Ibiapina, 1993)

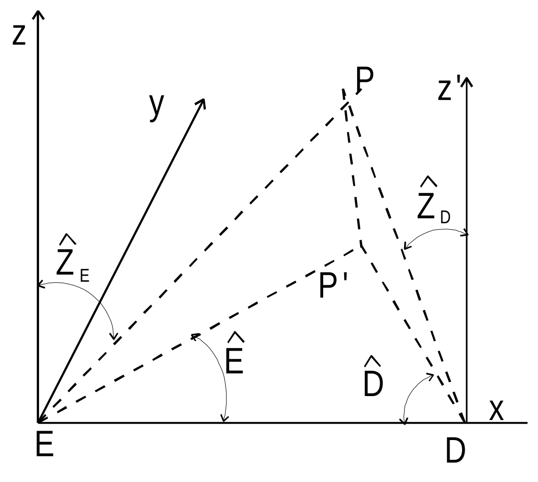

Figura 04 – Interseção espacial analítica

Considering two observation stations with kwon coordinates named E and D, the observations of the vertical and the horizontal angles, as illustrates the figure 4. The vector v and u are the directions from E and D to P point, given by:

$$v = (\sin\hat{Z}_E \sin\hat{E}, \sin\hat{Z}_E \cos\hat{E}, \cos\hat{Z}_E) \qquad (4.2.1)$$

$$u = (\sin\hat{Z}_D \sin\hat{D}, \sin\hat{Z}_D \cos\hat{D}, \cos\hat{Z}_D) \qquad (4.2.2)$$

The perpendicular vector simultaneously to the two versores above is supplied by the vectorial product of both:

$$n_E = v \times u \quad \text{or} \quad n_D = v \times u = -n_E \qquad (4.2.3)$$

Vectors v and n_E form the vectorial base of a plan, denominated π_E and vectors u and n_D form a base plan π_D. Of this way, the vectors w_D and w_E can be written as a linear combination of its respective bases. Introducing the stations coordinates E and D, represented by the vectors x_E and x_D (application point), we have:

$$w_E = s_E v + t_E n_E + x_E \qquad (4.2.4)$$

$$w_D = s_D u + t_D n_D + x_D \qquad (4.2.5)$$

being s_E and t_E the vector base parameters of the plan π_E. s_D and t_D are the vector base parameters of the plan π_D.

The vectors which possess the same direction of the versores v and u, with application points in E and D, are respectively given for:

$$r_E = \lambda_E v + x_E \qquad (4.2.6)$$

$$r_D = \lambda_D u + x_D \qquad (4.2.7)$$

The point P (see figure 4) is calculated by the intersection of the line (defined by the vector in 4.2.6) with the plan (defined in 4.2.5). Therefore, in the intersection, we have:

$$r_E = \lambda_E v + x_E = s_D u + t_D n_D + x_D = w_D \qquad (4.2.8)$$

that rearranging gives:

$$\lambda_E v + s_D u + t_D n_D = x_E - x_D \qquad (4.2.9)$$

The equations system above is constituted by three equations and three unknown variables and like vectorial v, u and n_D are linearly independent, the system admits only a solution. Substituting those values in the equation (4.2.4) or in the equation (4.2.5) we obtain the coordinates of the point P.

In a way similar can calculate the coordinates of P_D, equaling $r_D = w_E$ solving a new system of linear equations, with three equations by three unknown variables. The found values are substituted in the equation (4.2.4) or in the (4.2.7), supplying the coordinates of the point P. The coordinates of the point P is obtained finally of the average between the coordinates of P_E and P_D, that is:

$$P = \frac{P_E + P_D}{2} \qquad (4.2.10)$$

The next tables (table 4 and table 5) shows the found coordinates for the control points, for the observations with the total station and with the theodolite, respectively.

Point	X (m)	Y (m)	Z (m)
1	-0,618	16,959	6,812
2	4,301	17,111	6,824
3	7,152	17,114	5,820
4	-3,546	16,875	5,821
5	-0,709	16,230	4,868
6	4,327	16,062	4,770
7	6,573	17,032	2,562
8	1,063	16,997	2,570
9	-3,573	16,842	2,743
10	-1,835	16,850	-0,685
11	3,979	16,999	-0,690
12	2,609	16,997	0,803

Table 4. Points coordinates with Total Station – Analytical Spatial Intersection

Point	X (m)	Y (m)	Z (m)
1	-0,616	16,950	6,790
2	4,286	17,039	6,773
3	7,130	17,062	5,780
4	-3,525	16,866	5,794
5	-0,701	16,216	4,846
6	4,400	16,322	4,828
7	6,598	17,097	2,557
8	0,624	16,980	2,549
9	-3,570	16,850	2,719
10	-1,840	16,886	-0,701
11	5,930	17,048	-0,704
12	2,412	17,027	0,366

Table 5. Points coordinates with Electronic Theodolite – Analytical Spatial Intersection

4.3 LEAST SQUARES

To apply the Least Squares method in the adjustment is necessary to establish the mathematical model to be used. In this work each observation can be explicit as a function of unknown parameters, characterizing the parametric method of adjustment (Gemael, 1994).

For each observed point it is possible to form two observation equations: one for the horizontal angles and another for the vertical angles. If of the two different stations (E and D) observations, can be accomplished to a same point P and also if these two stations can be considered fixed, we will have 4 equations for 3 unknown. Can be applied the LSM to supply the solution. In the case of three observation stations we will have 6 equations for 3 unknown variables.

The observations adjustment has as objective, besides the estimate of only one value for the unknown of the problem, to estimate the precision of this unknown, and an eventual correlation among them. In the coordinates adjustment was obtained quadratic medium errors of the order of 1.8 mm, for the observations with the electronic theodolite, starting from two observation stations (E and D); 1.9 mm for the observations with the total station starting from the same observation stations and a errors of 1.5 mm for the observations with the total station, starting from the three observation stations (E, D and C). In the tables 6 and 7 the adjusted coordinates are shown, having as observations base the stations E and D, from the total station and the theodolite, respectively. The table 8 shows the adjusted coordinates for the accomplish observations with the total station for the base of three points (E, D and C).

Point	X(m)	Y(m)	Z(m)
1	-0,618	16,950	6,787
2	4,290	17,043	6,776
3	7,138	17,062	5,782
4	-3,538	16,862	5,794
5	-0,705	16,221	4,845
6	4,404	16,325	4,827
7	6,606	17,102	2,552
8	1,066	16,997	2,549
9	-3,575	16,848	2,723
10	-1,842	16,865	-0,707
11	3,985	17,006	-0,711
12	2,612	16,998	0,782

Table 6. Points coordinates with Total Station – Least Squares

Point	X(m)	Y(m)	Z(m)
1	-0,616	16,948	6,789
2	4,286	17,037	6,773
3	7,130	17,061	5,781
4	-3,527	16,867	5,793
5	-0,701	16,214	4,845
6	4,400	16,320	4,827
7	6,598	17,095	2,556
8	0,623	16,980	2,550
9	-3,570	16,849	2,716
10	-1,840	16,885	-0,701
11	5,929	17,046	-0,704
12	2,412	17,025	0,362

Table 7. Points coordinates with Electronic Theodolite – Least Squares

Point	X(m)	Y(m)	Z(m)
1	-0.619	16.976	6.795
2	4.292	17.054	6.778
3	7.141	17.076	5.784
4	-3.543	16.890	5.803
5	-0.705	16.241	4.849
6	4.405	16.332	4.828
7	6.607	17.106	2.551
8	1.068	17.006	2.549
9	-3.580	16.877	2.727
10	-1.842	16.892	-0.708
11	3.986	17.004	-0.712
12	2.615	16.998	0.781

Table 8 - Points coordinates with Total station for E, D and C base - Least Squares

5 CONCLUSIONS

With relationship to the equipment used for the angular information obtaining, to points without target, there is not difference in the coordinates calculated. The observations with electronic theodolite had the same result found in the observations with the total station.

For the observation stations number is important to accomplish tests with other base configurations. For the work, three stations were used forming a triangular base, that provided results different from the found to base formed for two stations, besides a larger standard deviation.

In relation to the three methods used in the coordinates calculation, everybody presented implement easy with satisfactory results, even so LSM just offers besides the points coordinates, its respective precision.

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