

3D MONOCULAR RESTITUTION APPLIED TO SMALL FORMAT DIGITAL AIRPHOTO AND LASER SCANNER DATA

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WG III/1 Sensor Pose Estimation

KEY WORDS: 3D Monocular Restitution, Laser Scanner, Low Cost Digital Camera and Vector Mapping.

ABSTRACT:

The utilization of the low cost digital small format camera for the obtainment of space information of the terrestrial surface tends to increase in the current days. This is due to the increase of the resolution, low cost and good geometric stability for mathematical parameters that define the interior geometry. The data set point, with height surface information, derived from the laser scanner, has improved the accuracy. Also, the development of this new technique has improved the existent methods applied to obtainment of the space information for several engineering applications. The development of new photogrammetric procedures applied to obtainment of information of the terrestrial surface that present facility, less qualified operational dependence and low cost in the productive process, is being more and more requested in the current. This paper shows the development of the methodology used and the results obtained from 3D photogrammetric vector mapping using the monocular restitution; digital aerial images obtained from low cost small format camera and data set height points deriving from laser scanner system. The digital aerial images were provided by an aerial survey performed with digital small format Sony camera, model DSC-F717, resolution of 5.2 Mbytes, CCD dimension of the 2560 x 1920 "pixel". The air survey was performed in an approximate height flight of the 750 meters. The pixel resolution in terrain is approximately 25 centimeters. The height data set points were derived from laser scanner air survey with 1000,00 meters of the height flight. The resolution of the pixel size in terrain is approximately 50 centimeters. The System used is OPTECH/INS GPS APPLANIX, property of the Technology Institute for the Development – LACTEC – UFPR. This paper presents the height interpolation procedures and mathematical algorithms and techniques development used for both with and without height features extraction. The procedures were implemented in the computational program (Digital Monoplotting) and it was developed in the Graduation Program Course in Geodesic Sciences in the UFPR. Control points were used to determinate the exterior orientation of the images and the compatibility of the height data set points. The three-dimensional coordinates of points of the entities were compared. The points were derived from the vector mapping produced by 3D monocular restitution and the conventional 3D stereo restitution performed in the Zeiss Planicomp with conventional metric photos (camera WILD RC-10 and scale of 1/6000). The paper presents the results performed in the comparisons.

1. INTRODUCTION

Small format digital cameras have currently become popular instruments, with spatial resolutions similar to traditional cameras operating with photographic film. The utilization of this sensor in engineering projects that employ terrestrial or aerial images to obtain metric information tends to increase in photogrammetric applications. This is due to the continuous increase of the resolution of the sensor element based on CCD (Charged Coupled Device) or CMOS (Complementary Metal Oxide Semiconductor), along with the low cost and higher geometric stability of the image. One also notices the constant development of analytical photogrammetric procedures based on digital images, thus causing the practice of Photogrammetry to be more utilized.

The utilization of non-conventional digital cameras in photogrammetric applications demands accurate camera calibration procedures so as to determine the defining parameters of the projective geometry (HABIB et al. 2003).

Altimetric information of the terrestrial surface obtained from laser scanning has improved the accuracy of the digital model of the surface (DMS) and it has brought development and improvement of new photogrammetric techniques to obtain

spatial information of the terrestrial surface (See Ackermann 1996; Baltsavias 1999). Presently, the development of photogrammetric procedures to obtain information about terrestrial surface presenting easy features, less qualified operational dependence and low cost in the productive process, is being more and more required

This paper presents the development of methodology and results obtained from the vector tri-dimensional photogrammetric mapping supported by 3D Monorestitution and from digital aerial images obtained with small-format cameras and altimetric data from laser scanning system. A digital image proceeding from an aerial covering performed with a small-format digital camera, Sony DSC-F717 model, 5.2 Mbytes resolution, CCD of 2560 x 1920 Pixels, was utilized. The aerial coverage was conducted in an approximate flying height of 750 meters, resulting in pixel with approximate resolution on the terrain of 25 centimetres.

The digital surface model (DSM) originated from a survey carried out by laser scanning system, in flying height of 1000 meters, with approximate resolution of 0.5 meters, obtained from OPTECH/INS GPS APPLANIX System, belonging to the Institute of Technology for Development – LACTEC – UFPR.

An aerial dataset carried out with a WILD RC-10 conventional camera in the scale of 1/6000 was also employed, in order to obtain control points and verify the accuracy obtained in the proposed methodology.

2. TEST AREA

A digital image covering the region of the Centro Politécnico of the Federal University of Paraná was utilized in this research (See picture 01). This image is part of the aerial covering carried out by AGRITEC Agrimensura e Aerofotogrametria S.A. in July 2003. A small-format Sony DSC-F 717 digital camera was employed, with resolution of 5.2 Mbytes, CCD of 2520 x 1960 pixels. The aerial covering was done in a flying height of approximately 750 meters, resulting in pixel with spatial resolution on the terrain of 25 centimetres.

Taking into account the characteristics of the buildings, one can divide the image into two distinct regions. The first, on the left side, has part of a residential neighborhood where the buildings are smaller and close to one another. The second, in the central part and right side, has bigger buildings and more space separating them. This sub-division of the image into two main regions will be discussed in the next chapters. It was done simply to analyze the accuracy obtained in the experiment carried out.



Figure 1: Aerial image taken with Sony camera employed in this research.

3. GEOMETRICAL PARAMETERS OF THE DIGITAL CAMERA

The parameters of interior orientation of the Sony DSC-F717 digital camera were determined with three calibrations utilizing information of three different dates. The same operational conditions and techniques were employed for the taking of pictures of the test field existing at Federal University of Paraná – Centro Politécnico. Stability conditions were analyzed to determine these parameters for a certain period of time in the utilization of the camera. The values employed in this research are presented in table 01. Other information about calibrations performed and stability of the parameters of interior orientation may be found in MACHADO et al., 2003, HABIB et al., 2003 and HABIB et al., 2002.

Interior Orientation Parameters	
Parameters	Determined values
c'	10.082 mm
x_o	-0.253 mm
y_o	-0.151 mm
k_1	$-2.18915186e-03 \text{ mm}^{-3}$
k_2	$2.75934941e-05 \text{ mm}^{-6}$
k_3	0.000
P_1	$-1.47185370e-04 \text{ mm}^{-2}$
P_2	$-1.42394475e-05 \text{ mm}^{-2}$

Table 1: Geometric parameters of the camera.

4. LASER SCANNER DATA

A laser scanner survey of Centro Politécnico region covering an area of approximately 7.2 km² was conducted in flying height of 1000 meters, with resolution of approximately 0.5 meters, obtained through OPTECH/INS GPS APPLANIX System, property of the Institute of Technology for Development – LACTEC – UFPR.

This work utilized a cloud of points with coordinates X, Y, Z, originated from the last echo. Only the area covered by the digital image was delimited, resulting in a group of approximately 800,000 points. The processing of these points was carried out with the purpose of selecting only those identifying the borders of edifications contained in the image. The mathematical algorithm developed performed the processing in two stages. In the first, all the points belonging to a scanning laser strip were filtered utilizing the technique of simplification of polygonal based on the algorithm of Douglas-Peucker, as shown in DOUGLAS 7 PEUCKER, 1973. In the second, each of the points obtained in a profile was analyzed with the purpose of selecting only those that presented a height difference bigger than a threshold furnished, relating to the former or latter point, as presented in AXELSSON, 1998.

Figure 2: Shows the results obtained with the application of the methodology suggested in region of big constructions. One can verify that the mathematical algorithm proposed managed to evidence satisfactorily the laser points existing on the borders of main buildings. Therefore, it has the disadvantage of not excluding defining border points of the main trees existing in the image.

Picture 03 shows the results of application of methodology in the small buildings residential area. In this case, one can see the low performance of the algorithm proposed, for due to the little space separating one building from the other and the laser system resolution, the algorithm fails to present some borders points desired. On the other hand, by diminishing the threshold, other borders not desired are selected.



Picture 02 – Shows the laser scanner points selected in the region with big buildings

Of the 800,000 points originated from the laser scanning and existing in the region contained in the image, approximately 10% of defining points of the borders of the buildings were selected.



Figure 3: Shows the laser scanner points selected in the region of small buildings.

5. DETERMINATION OF CONTROL AND VERIFICATION POINTS

Fifteen control points and seventy verification points in form of point image were identifiable in aero photos taken with an aerophotogrammetric camera. Its coordinates, in geodesical referential, were determined from observations conducted in photogrammetric models previously oriented in the analytic photogrammetric Zeiss Planiacomp C-100, property of the Graduate Program in Geodetic Sciences at UFPR.

The aerophotogrammetric covering was conducted in July 2000 in a scale of 1/6000. A metric camera, WILD RC-10, with focal nominal distance equal to 153.000mm was employed. The models possess artificial photogrammetric points (PUG). The coordinates were determined by bundle adjustment aerotriangulation. This paper took into consideration the fact that the coordinates of support points and verification points proceeding from the reading of photogrammetric models are exempt from error, to be taken as the base for verification of work conducted with the integration of laser scanner data and small format digital aerophotos.

6. TRANSFORMATIONS BETWEEN PHOTOGRAMMETRIC AND GEODETIC SYSTEM

The vectorial file containing the contours of the buildings is obtained through monocular digitalization of the image utilizing the CAD MicroStation PC system (computer aided design). Applying the mathematical transformations between the photogrammetric and geodetic systems involved, one proceeds to the rectification of the vector file generated in the digitalization. The fundamental mathematical model performs the transformation of photogrammetric coordinates (x_p, y_p) of points observed in the image, for the local tri-dimensional, Cartesian, geodetic system (X_L, Y_L, Z_L) , utilizing inverse collinear equations. More details on this transformation may be seen in MAKAROVIC, (1973) and MITISHITA, (1997).

$$X_L = X_o + (Z_L - Z_o) \frac{m_{11}x_p + m_{21}y_p + m_{31}c}{m_{13}x_p + m_{23}y_p + m_{33}c} \quad (1)$$

$$Y_L = Y_o + (Z_L - Z_o) \frac{m_{12}x_p + m_{22}y_p + m_{32}c}{m_{13}x_p + m_{23}y_p + m_{33}c} \quad (2)$$

$$x_f = a.x_g + b.y_g + e \quad (3)$$

$$y_f = c.x_g + d.y_g + f \quad (4)$$

$$x_p = x_f - x_o - \Delta r(x_f - x_o) - \Delta dx \quad (5)$$

$$y_p = y_f - y_o - \Delta r(y_f - y_o) - \Delta dy \quad (6)$$

$$\Delta r = (k_1 r^2 + k_2 r^4 + k_3 r^6) \quad (7)$$

$$\Delta dx = P_1 (r^2 + 2(x_f - x_o)^2) + 2P_2 (x_f - x_o)(y_f - y_o) \quad (8)$$

$$\Delta dy = 2P_1 (x_f - x_o)(y_f - y_o) + P_2 (r^2 + 2(y_f - y_o)^2) \quad (9)$$

$$r^2 = (x_f - x_o)^2 + (y_f - y_o)^2 \quad (10)$$

$(x_g, y_g)^T$ = Coordinates in the graphic system;

$(x_f, y_f)^T$ = Coordinates in the image system;

$(x_p, y_p)^T$ = Coordinates in the photogrammetric system;

(a, b, c, d, e, f) = Affine transformation parameters;

(k_1, k_2, k_3) = Radial distortion parameters;

(P_1, P_2) = De-centering distortion parameters;

(x_o, y_o) = Coordinates of principal point in the image system;

c = Focal length;

$(X_o, Y_o, Z_o)^T$ = Coordinates of exposure station;

$[X_L, Y_L, Z_L]^T$ = Coordinates in the local geodetic system;

m_{ij} = Elements of rotation matrix $(R(\chi).R(\phi).R(\omega))$.

In this paper, the origin of the image referential was utilized as being the center of the image.

In conventional monorestitution applications with the utilization of inverse collinear equations, the value of the

coordinate Z_L is obtained using an iterative process supported by a digital terrain model (DTM). In this application where the objective is the mapping of buildings with the integration of laser scanner data, a new procedure to obtain this coordinate was implemented. The points originated from the laser scanner survey that define the borders of buildings are projected on the image space with the collinear direct equations, as presented in figure 02 and 03. A group of (n) points with coordinates on the hybrid system (photogrammetric and geodetic) $(x_{pi}, y_{pi}, Z_{Li}) i = 1, n$ is generated. The photogrammetric point of a corner of a building is observed on the referential of the image. After simple mathematical transformations, the coordinates on the photogrammetric referential are determined. To determine the local geodetic coordinates $[X_L Y_L]$ with the application of inverse collinear equations, the value of the coordinate Z_L must be determined. Utilizing the nearest neighbor interpolation technique, the value Z_L of the point to be rectified is determined in the files of coordinates of transformed laser scanner points $(x_{pi}, y_{pi}, Z_{Li}) i = 1, n$.

The proposed methodology was implemented in the 3D MONOPLOTTER computational program (See Fig. 04) developed at the Graduate Program in Geodetic Sciences, UFPR.

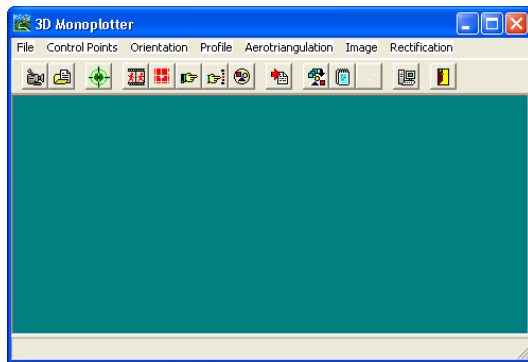


Figure 4: Main page of 3D Monoplotter program.

7. RESULTS OBTAINED IN THE MONORESTITUTION OF BUILDINGS

7.1 Exterior Orientation

Employing collinear equations in direct form and MMQ adjustment (Least Squares), the parameters of exterior orientation of the image were determined. To conduct the adjustment, eight control points distributed all over the image were observed. Coordinates of these points in the photogrammetric system were obtained from observation conducted in the digital image with the CAD MicroStation PC system and the coordinates in the local geodetic system obtained from the observation of photogrammetric models in the analytical photogrammetric ZEISS PLANICOMP C-100, as described in item 5.0 of this paper. The main results obtained in the adjustment are:

Kappa (χ) = 1.9651533575 $\sigma_{(\chi)}$ = 0.0005451726
 Phi (ϕ) = 0.0064097357 $\sigma_{(\phi)}$ = 0.0027718695
 Omega (ω) = -0.0158918124 $\sigma_{(\omega)}$ = 0.0030046261
 Xo(m) = 108.621222420 $\sigma_{(Xo)}$ = 2.1647013270
 Yo(m) = -76.2077762045 $\sigma_{(Yo)}$ = 2.3494253375
 Zo(m) = 1652.6215413585 $\sigma_{(Zo)}$ = 0.4449289549

Standard deviation of the residues in the photogrammetric coordinates: $(\sigma_{(x)} = 0.003 \text{ mm} ; \sigma_{(y)} = 0.003 \text{ mm})$
 Standard deviation of the residues in the local geodesical coordinates: $(\sigma_{(X)} = 0.221 \text{ m} ; \sigma_{(Y)} = 0.191 \text{ m} ; \sigma_{(Z)} = 0.063 \text{ m})$

7.2 Tridimensional Monoplotting

Utilizing the 3D Monoplotter Program, the digital vector file was rectified according to the methodology presented in item 6.0. The tridimensional coordinates of some corners of the buildings (X,Y and Z) were obtained in the vector rectified file. The planimetric (X, Y) coordinates were determined with the application of inverse collinear equations and the altimetric coordinates of the interpolation performed with the laser scanner data. The values obtained from the rectified vector file were compared with the coordinates determined with the reading of photogrammetric models in the ZEISS PLANICOMP C-100 System, as described in item 5.0 of this paper. To verify the accuracy of the 3D monorestitution proposed in this research, it was considered that the tridimensional coordinates of the corners of the buildings obtained in the PLANICOMP C-100 are correct, exempt from error of observation and others connected with the photogrammetric process utilized.

Table 2 shows the accuracy results obtained in the 3D monorestitution in the region of large buildings. The acronyms DX, DY and DZ are discrepancies in meters in the three tridimensional coordinates of the point and Dpla is the planimetric discrepancy existing.

Figure 5 shows the spatial distribution of the planimetric discrepancies presented in Table 2. One can verify that the planimetric discrepancies are well distributed around the origin 0.0 and 90% of the points tested present planimetric accuracy of up to 0.5 of the meter. The results obtained for the 3D monorestitution of big buildings are equivalent to conventional stereophotogrammetric restitution in the scale of 1/2000.

In table 3 and figure 6, the accuracy obtained with the 3D monorestitution in the region of small buildings is presented. In this case, the accuracy obtained in the determination of the tri-dimensional coordinates is inferior if compared with the former case. One can verify that 90% of the points tested present planimetric precision of up to 0.70 of the meter. This smaller precision is related to two main deficiencies. The first is linked to higher degree of difficulty to define the points that represent the borders of the buildings in the group of points proceeding from the laser scanning, as mentioned in item 4.0, and the second, the difficulty to identify the corners of edifications in the digital image, due to the resolution of the image.

One can verify in figure 5 a small tendency of systematic spacing in the determined planimetric discrepancies, of

approximately a “pixel” in the terrain. This spreading is related to the determination of parameters of exterior orientation. The inaccuracies existing in the identification and reading of the control points in the image, due to the resolution of the image, influence the determination of parameters of exterior orientation. Other systematic spacings, with the same level of significance, were found in orientations conducted and not shown in this paper. In the orientations, different groups of control points read in the image were employed. It was verified that this type of spacing may occur in any of the regions tested, depending on the orientations parameters determined. However, the systematic spacings found in the tests performed were always at one “pixel” significance level.

Point	DX(m)	DY(m)	DZ(m)	Dpla(m)
1	.314	-.147	.077	.347
2	.069	.145	-.068	.161
3	-.135	.005	.339	.135
4	.080	.494	.077	.500
5	.007	.418	-.361	.418
6	.141	.485	-.371	.505
7	.224	.334	-.467	.402
8	.114	.597	-.525	.608
9	-.324	.360	.106	.484
10	-.011	.135	-1.127	.135
11	-.051	.251	.145	.256
12	-.587	.185	-.282	.615
13	.261	-.103	-.001	.281
14	-.229	-.007	.160	.229
15	-.043	.018	.102	.047
16	.252	-.054	.377	.258
17	-.207	-.010	-.003	.207
18	.011	.204	-.161	.204
19	.236	-.035	-.139	.239
20	.195	.288	-.042	.348
21	-.206	-.275	-.792	.344
22	.322	.473	-.011	.572
23	.035	-.005	-.271	.035
24	-.238	.481	-.049	.537
25	-.113	.251	-.223	.275
26	-.382	.038	-.218	.384
27	-.243	.032	-.098	.245
28	-.058	.240	-.509	.247
29	.394	-.244	-.220	.463
30	-.149	-.133	.223	.200
31	.069	-.179	.483	.192
32	.138	.261	-.148	.295
33	-.152	-.157	-.269	.219
34	.109	-.480	.577	.492
35	.099	.362	-.281	.375
Mean	-.002	.121	-.113	.322
S. dev.	.221	.258	.341	.154

Table 2: Accuracy obtained in the 3D monorestitution in the region of large buildings.

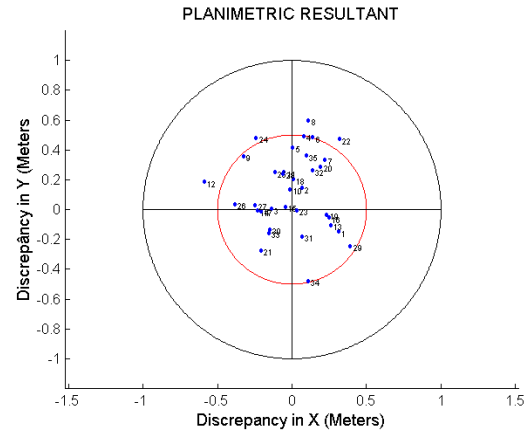


Figure 5: Special visualization of the planimetric discrepancies in the region of large buildings.

Point	DX(m)	DY(m)	DZ(m)	Dpla(m)
1	.421	.131	-1.842	.441
2	-.242	-.233	-.082	.336
3	.569	-.090	-.121	.576
4	.263	.250	.113	.363
5	.368	-.248	-.164	.444
6	.463	-.393	-.484	.607
7	.468	-.072	-.073	.474
8	.243	-.069	-.083	.253
9	-.100	-.003	.853	.100
10	.219	-.125	.324	.252
11	.495	-.026	.220	.496
12	.250	-.303	-.158	.393
13	-.134	-.173	-.197	.219
14	.503	.309	-.293	.590
15	.338	-.202	-.320	.394
16	.185	.138	.208	.231
17	.596	-.081	-.299	.601
18	.659	.114	-.381	.669
19	.554	.259	-.282	.612
20	.059	-.051	.284	.078
21	.557	-.539	-.369	.775
22	-.085	-.385	-.065	.394
23	.256	.408	-.196	.482
24	.218	.447	.062	.497
25	.256	.181	-.137	.314
26	.727	.211	-.473	.757
27	-.028	.441	-.391	.442
28	-.019	-.133	-.246	.134
29	.384	-.331	-.277	.507
30	.518	-.574	-1.132	.773
31	.523	.180	.185	.553
32	.453	-.286	-1.049	.536
33	.319	-.373	-.805	.491
Mean	.311	-.049	-.232	.448
S. Dev.	.248	.277	.477	.184

Table 3: Accuracy obtained in the 3D monorestitution in the region of small buildings.

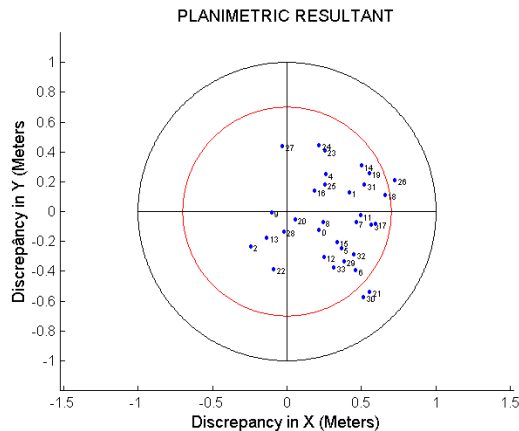


Figure 6: Special Visualization of planimetric discrepancies in the region of small buildings.

8. CONCLUSION AND RECOMENDATION

The results obtained in this research show that the methodology presented for the 3D monorestitution of buildings with the integration of laser scanner data and small-format digital images is viable and makes it possible to obtain the altimetric and planimetric accuracy needed to carry out tridimensional vector mappings in the scale of 1/2000. In the experiments conducted, 100% of the points tested presented planimetric discrepancies below 0.8 of the meter. The proposed methodology may be an alternative to obtain information about the terrestrial surface, considering the operational facility existing in the monorestitution and popularization of small-format digital cameras. Currently, the dependency on laser scanner survey may be seen as the main disadvantage to apply the proposed methodology. Research is being conducted aiming at automatizing the process by developing mathematical algorithms that improve the selection of scanner laser points defining the contours of the buildings. The utilization of low-cost and small-format digital cameras with higher resolution will increase the performance of the proposed methodology. The utilization of images with higher spatial qualities will lend more precision to the identification and reading of point details, thus increasing the accuracy of the proposed methodology. The dimension of the area covered by an image taken with a small-format camera is an important operational disadvantage, when compared with conventional photogrammetric cameras. In the future, this disadvantage will be eliminated with the development and utilization of sensors with higher resolution based on CMOS technology.

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