# PHOTOGRAMMETRIC CONTROL POINTS FROM AIRBORNE LASER SCANNER DATA

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**Résumé**

Cet article présente une méthodologie d'extraction semi-automatique de points d'appui pour la phototriangulation à partir d'images d'intensité laser. Les points d'appui sont déterminés par l'intersection de facettes planes reconstruites à partir des points d'un levé laser aéroporté. L'objectif est de vérifier la possibilité de substituer les points ainsi obtenus à des points qui seraient mesurés directement sur le terrain, par exemple au moyen d'un récepteur GPS. Les points laser sont traités de manière à permettre la reconstrtruction des facettes places correspondant aux toits des maisons, édifices et autres constructions, par une méthode semi-automatique. L'identification et l'extraction de cette facettes se sont appuyées sur une triangulation de Delaunay et sur l'analyse des vecteurs normaux des triangles qui la constituent. Pour tester cette méthode, on a réalisé une photo-triangulation avec une compensation par faisceaux basée sur les points issus du relevé laser, des points mesurész sur le terrain par GPS servant de points de contrôle. Un bloc photogrammétrique constitué de 6 images acquises par une caméra non métrique a été utilisé pour ces tests. L'analyse et la comparaison des résultats permettent de recommander cette méthode.

**Mots clés** : points de contrôle photogrammétriques, données laser aéroportée, LIDAR.

***Abstract***

*This paper offers a methodology for the semi-automatic extraction of control points for phototriangulation by using laser intensity images. The control points are determined by the intersection of three or more plane features which make up the roof of houses or building or constructions in general. The features under study are selected visually in aerial photos of constructions in which there are three or more sloped roofs presenting concurrent plane features. These constructions are identified in laser intensity image, and the plane features which define their roofs are extracted and individually adjusted from a group of points which result from the survey undertaken with airborne laser scanner. Control points are determined through the intersection of roof planes of each construction previously adjusted. By using this technique, it is possible to use the points obtained from plane feature intersection in a computational routine, thus replacing the ones obtained in the field. The airborne points were processed in a semi-automated way to rebuild the plane features of building roofs. Thus, they were identified in laser intensity image and extracted from Delaunay´s triangulation. Finally, the analysis of normal vectors of the generated triangulation is realized. The methodology was tested by phototriangulation with bundle adjustment and supported by the points obtained from laser scanner and by checking points the ones pre-signalized and which where obtained from the field with GPS help. A photogrammetric block formed by six aerial photos obtained by non-metric digital camera was used for tests. The results were analysed and compared, and the methodology used was recommended.*

***Keywords*** *: Photogrammetric control points, Airborne laser scanner data, LiDAR.*

***Resumo***

*Este trabalho apresenta uma metodológica para a extração semi-automática de pontos de apoio para a fototriangulação. Os pontos de apoio foram determinados a partir da reconstrução, ajustamento e interseção de planos, gerados a partir de um conjunto de pontos oriundos de um levantamento realizado com o sistema laser scanner aerotransportado. O objetivo foi de verificar a possibilidade da utilização de pontos obtidos pela interseção de planos em uma rotina computacional, em substituição aos pontos levantados diretamente em campo com, por exemplo, o emprego de rastreadores GPS. Os pontos do laser scanner aerotransportado foram processados de forma a possibilitar a reconstrução das feições planas formadoras das coberturas de edificações, através da aplicação de um método semi-automático. As feições planas procuram reproduzir as existentes nas coberturas de casas, edifícios ou construções em geral A identificação e extração desta feições planas, foi realizada mediante o emprego da triangulação de Delaunay analisando os vetores normais dos triângulos gerados que as constituem. Para testar a metodologia realizou-se uma fototriangulação com ajustamento simultâneo por feixes de raios apoiada com os pontos obtidos do laser scanner e utilizaram-se como pontos de verificação, pontos pré-sinalizados levantados em campo com GPS. Um bloco fotogramétrico formado por 6 imagens obtidas com câmara digital não métrica serviu de base para os testes. Os resultados foram analisados e comparados, concluindo-se pela recomendação da metodologia.*

***Palavras-chave*** *Pontos de controle fotogramétricos, Dados de varredura laser aerotransportado, LiDAR.*

## 1. Introduction

Points of photogrammetric support are traditionally collected in the field by means of geodetic surveys, like, for example, the Global Positioning System. New techniques and methodologies have been developed to determine the exterior orientation of photographs (Xo, Yo, Zo. k, Φ, ω) in such a way that they do not depend on the control obtained in the field. Among them there is the flight supported with GPS complemented by INS (Inertial Navigation System) which would minimize the quantity of control points in the block.

At present, other methodologies have also been developed by the indirect acquisition of photogrammetric support, using airborne laser scanner. The system scans the surface and registers a dense cloud of tridimensional points, but without a morphological definition of the objects to be punctually identified in an aerial photograph, and this is the reason why they cannot be used directly as photogrammetric control points. On the other hand, the processing of features from a 3D point cloud allows the extraction of points, straight lines, polygons and planes which have been treated to obtain photogrammetric support.

Some researchers have worked aiming at the automation of the feature extractions to generate photogrammetric support. Delara et al. (2004) presented a methodology to perform the bundle block adjustment using non-conventional aerial images and Laser Scanner data. Habib et al. (2004) showed two alternative approaches for utilizing linear features derived from LIDAR data as control information for aligning the photogrammetric model relative to the LIDAR reference frame. The first approach incorporates LIDAR lines as control information directly in a photogrammetric triangulation. The second approach starts by generating a photogrammetric model through a photogrammetric triangulation using an arbitrary datum. Dalmolin et al. (2005) developed methodologies for the extraction and the use of line features. Vosselman (1999) presented an approach based on the detection and outlining of planar faces in dense height data. To avoid loss of information due to interpolation, all operations are performed on the Delaunay triangulation of the original height points. The planes of the faces are determined by clustering of the points. The outlines of the faces are determined by a connected component analysis on the triangles of the Delaunay triangulation.

Lee and Schenk (2001) and Rottensteiner and Briese (2003) worked with the extraction of planar surfaces, though these were not used as support.

This paper presents a methodology to obtain a block of photogrammetric points, generated from the intersection of plane features, extracted semi–automatically from a survey made by airborne laser scanner.

## 2. Methodology

The first step of the proposed methodology is the identification of a point in the laser scanner intensity image, corresponding to constructive elements which have, at least, the intersection of three or more planes. In urban regions, building roofs present this characteristic, which can be visually determined in an aerial photography, and its approximate coordinate manually obtained in the laser scanner intensity image (Figure 1).

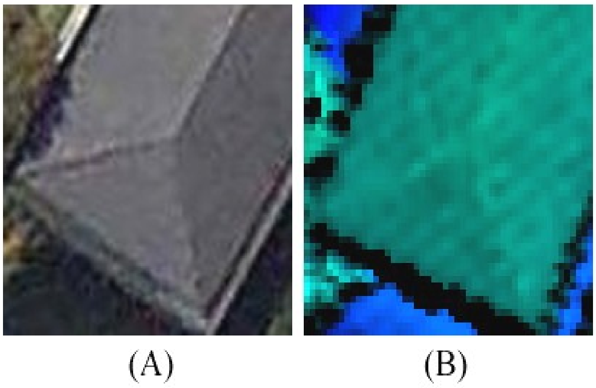



**Figure 1:** Building roof present in **(A)** aerial photography, and **(B)** in the laser scanner intensity image.

The approximate points of the sloped roof will be used to extract from a point cloud the ones which belong to the roof. The data will be processed for the automatic extraction of planar features. A Delaunay triangulation of the hard data will be done, and a filter will be applied to remove the points which are not wanted. The filter is based on the acquisition dihedral of angle (*θ*) which makes up each Delaunay triangle of a hypothetical horizontal plane (Figure 2), eliminating all those triangles which have and angle (*θ*) out of the 4°< θ<30° interval. According to (Camargo and Boulos, 2005), the angle between two planes may be obtained by the relationship between their normal vectors according to Equation (1):

$$\cos(\theta) = \frac{\vec{n}_H \cdot \vec{n}_D}{\|\vec{n}_H\| \cdot \|\vec{n}_D\|} \qquad (1)$$

where :

θ: angle between Delaunay triangle and the hypothetical horizontal plane;

$\vec{n}_H$ : normal vector to the hypothetical horizontal plane, and

$\vec{n}_D$ : normal vector to Delaunay plane triangle.

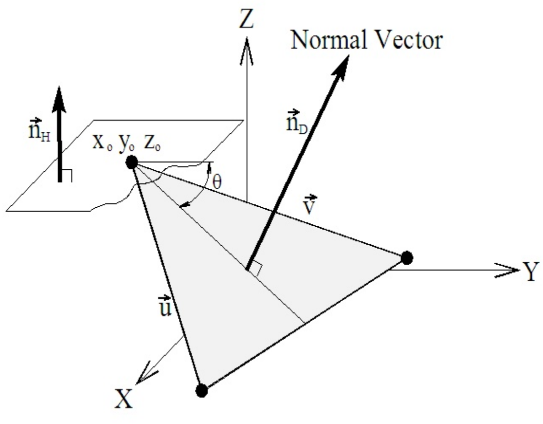



**Figure 2:** Delaunay triangle of a hypothetical horizontal plane.

The treatment of Delaunay triangles aims at eliminating points which do not belong to the sloped roof and removing the coplanarity condition of the triangle set (Figure 3).

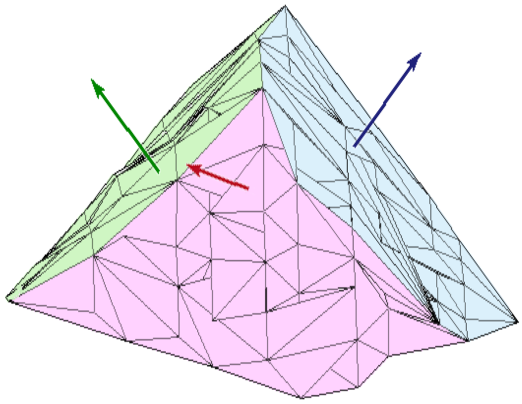


**Figure 3**: Delaunay triangulation which represents different sloped roofs.

The selection of points for the detection of each roof or better saying sloped roof side is based on the direction of normal vectors which have Delaunay triangles. The sloped roof sides are identified, adjusted through the Least Squares Method iteratively by using the plane equation as a functional mathematical model (see Equation 2) and the implicit stochastic adjustment method (Equation 3). In the adjustment, all the points which do not belong to the sloped roof according to a pre-established threshold are eliminated (Figure 4).

$$aX_T + bY_T + cZ_T + d = 0 \qquad (2)$$

where :

- a,b,c,d : plane parameters to be adjusted ;
- $X_T$, $Y_T$, $Z_T$ : geodetic coordinates of the points which belong to each sloped roof.

$$F(\Delta,f) = 0 \qquad (3)$$

where :

- Δ : vector of adjusted parameters which define the plane;
- *F:* vector of adjusted observations.

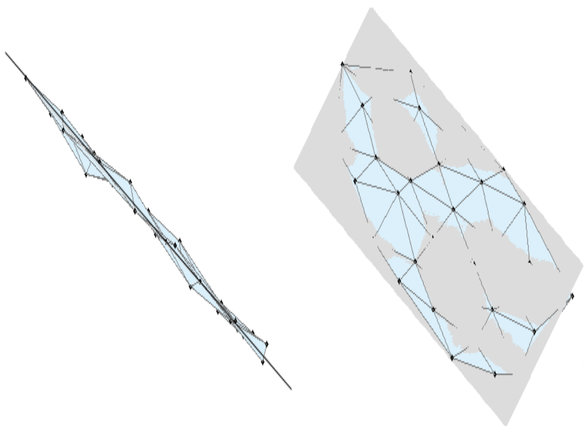


**Figure 4**: A roof plane adjusted.

The intersection of, at least, three concurrent planes (Figure 5), makes the system of equations homogeneous and it will provide the coordinates of a point, which will be used as photogrammetric support. In case of three or more planes, the non-homogeneous system becomes inconsistent, presenting more than one solution. In that case, the unique solution will be obtained by means of least squares adjustment with the use of parametric method (Mikhail, 1976).

$$(B'WB)\Delta = B'Wf \qquad (4)$$

where *B* is the matrix design and *W* is the weight matrix.

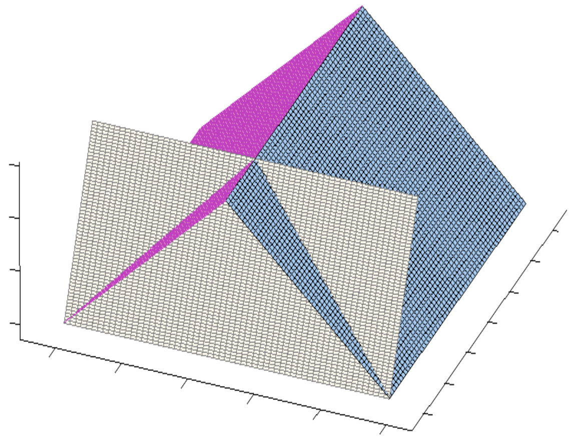


**Figure 5**: Intersection of three concurrent planes.

This system solution will provide the coordinate of a point of photogrammetric support, and it will take part in phototriangulation as a positioning constraint. The colinearity equation (Equation 5) was used as a mathematical functional model (Mikhail et al., 2001).

$$\begin{aligned} x_{fotc} - x_o &= -c \cdot \frac{m_{11}(X - Xo) + m_{12}(Y - Yo) + m_{13}(Z - Zo)}{m_{31}(X - Xo) + m_{32}(Y - Yo) + m_{33}(Z - Zo)} \\ y_{fotc} - y_o &= -c \cdot \frac{m_{21}(X - Xo) + m_{22}(Y - Yo) + m_{23}(Z - Zo)}{m_{31}(X - Xo) + m_{32}(Y - Yo) + m_{33}(Z - Zo)} \end{aligned} \qquad (5)$$

where :

- $x_{fotc}$, $y_{fotc}$ : photocoordinates observed in the aerial photograph;
- $x_0$, $y_0$ : principal point;
- c : calibrated focal length;
- $m_{ij}$: elements of rotation matrix which contains the angles (k, Φ, ω );
- Xo, Yo, Zo : coordinates of the perspective center,
- X,Y,Z : coordinates of the point in the object space obtained from laser scanning.

In Figure 6, a diagram of the steps of the methodological proposition is presented. It aims at the determination of photogrammetric control points, based on the extraction of plane features and the calculation of intersection points from the laser scanner data.

The algorithms were programmed in MatLab 7.0 software for the methodology development and the experiment achievement.

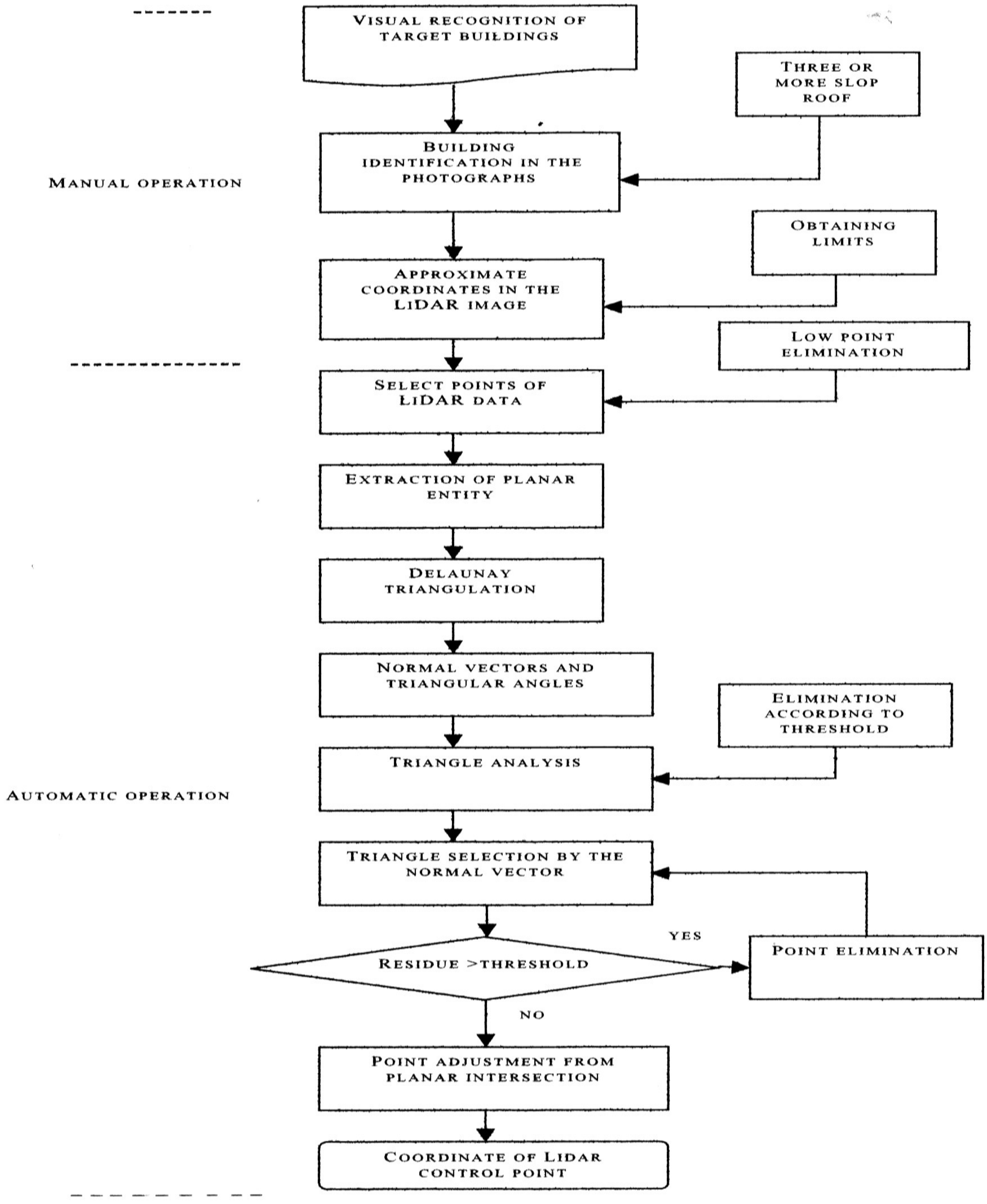


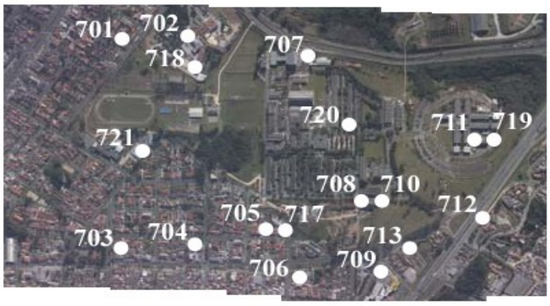

**Figure 6**: Pipeline of proposed method.

## 3. Results

The photographs used for the experiment development correspond to a block of six (6) images obtained in December 2004 with a non metric camera, Kodak model Pro DCS14n with a resolution of 3000 X 4500 pixels. The non metric camera was calibrated and the observations were done in the distortion free corrected image. The aerial photographs recover the Centro Politécnico Campus of the Federal University of Parana and surroundings. The average height of the flight was 1200 m and the pixel size equals 7.9 μm, equivalent to 0.20 m in the ground.

Figure 7 presents the photogrammetric block used and the distribution of GPS points pre-signaled for the result evaluation (A), and the distribution of control points obtained from laser scanning data (B).

(A)




(B)

**Figure 7**: Photogrammetric block and the distribution of GPS points pre-signaled (A) and the distribution of control points obtained from laser scanning data.

From the studied area, 18 buildings were chosen which supplied the condition for the choice of the control points. The identification of each sloped roof in the aerial photograph was done by means of visual recognition, and some of them presented more than three sloped roof units. The selected roofs correspond to residential buildings, which are kind of two or three-storey houses and other kinds of buildings located in the area of the Centro Politécnico campus of the Federal University of Parana. From the laser scanning intensity image, approximate coordinates of the chosen buildings were manually determined, at the geodetic referential system, as photogrammetric control points.

Figure 8 presents some of the selected roofs in the aerial photograph, and their homologues in the laser scanning intensity image, Delaunay triangulation calculated from the LIDAR data and the adjusted and filtered planes according to the proposed methodology.

It can be observed in Figure 8 that for points 707 and 717, the calculation process of normal vectors and plane adjustment made possible the elimination of points which did not belong to the sloped roof, and the identification of each sloped roof. In the case of points located at the building walls, point 718 in the Figure 8, the same process made their filtering possible as well.

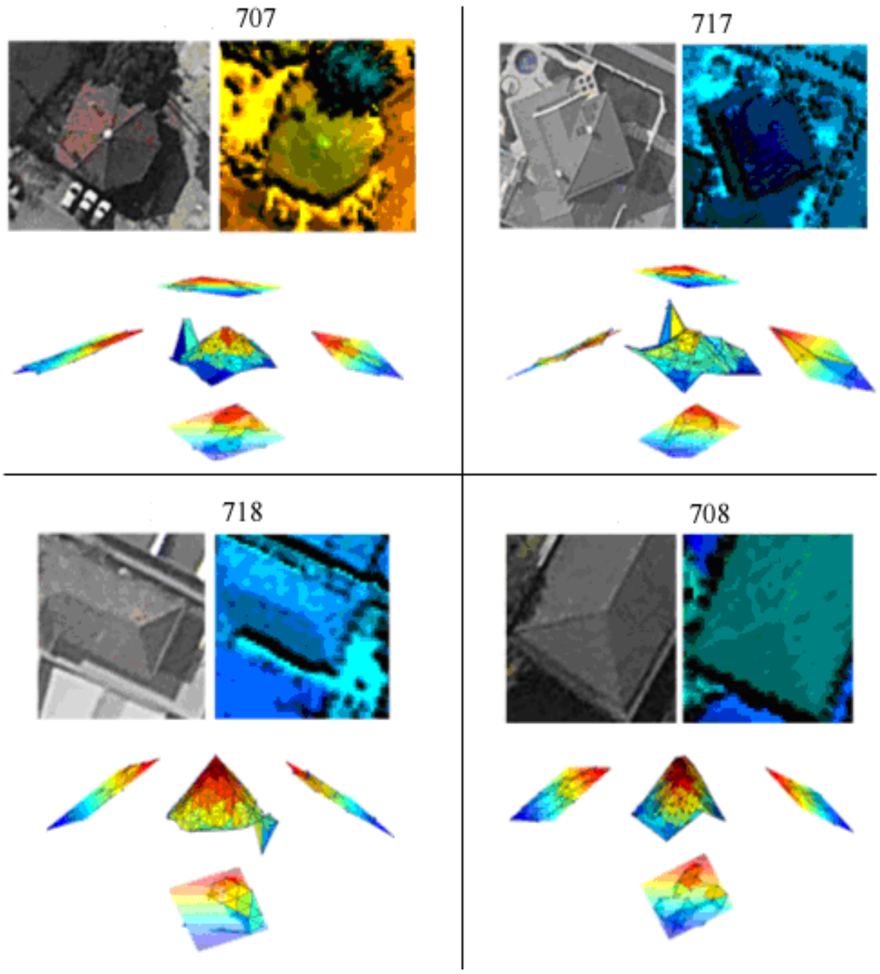



**Figure 8**: Sloped roofs extracted semi-automatically in aerial photograph, laser scanning intensity image and laser scanning hard data and adjusted planes.

The final product of the methodology and the developed algorithm correspond to an ASCii format file, which contains the block of points coordinates in the geodetic referential system.

## 4. Result analysis

In order to analyse the results, a phototriangulation was made, by using the block of points obtained by laser scanning as support ones and as checking points, 18 pre-signalized GPS ones (three of these points were not pre-signalized). The accuracy of these laser scanning points was determined according to Technical Specification of Optech about ALTM system for a flight height of 1000m, these precisions being about ±0.50 m for planimetry and about ±0.15 m for altimetry.

The phototriangulation procedure was comprised of three steps. The first one corresponded to the planning of photogrammetric points and the image observation. The second one was about the interior orientation and the correction of systematic errors. Finally, the third one corresponded to the phototriangulation by bundle adjustment with positioning constraint. The checkpoints were treated free of errors in the process of simultaneous adjustment.

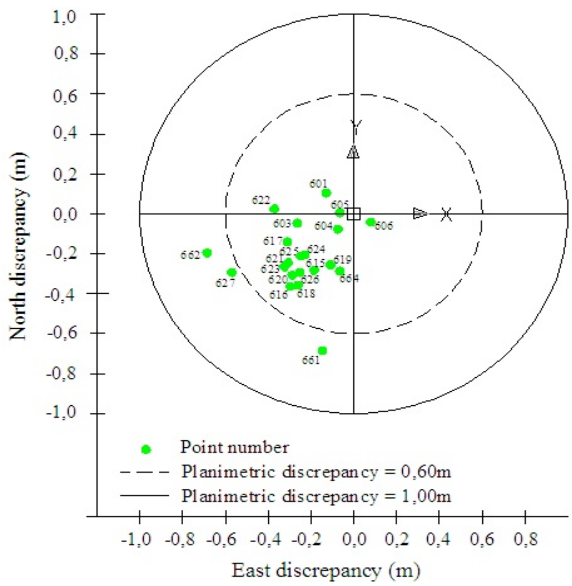



**Figure 9**: Planimetric discrepancy of GPS coordinate of pre-signalized points and the ones obtained from phototriangulation supported by laser scanning points.

It is noticed in Figure 9 that the discrepancies of GPS points 627, 662 and 661 present a greater deviation than other points, probably due to the difficulty presented in point observation in the aerial photograph, as points numbers 661 and 662 were not pre-signalized. Point number 627, in spite of being pre-signalized, also presented some observation difficulty as it was located in the image borders.

It is also observed that the planimetric discrepancies showed a tendency of systematic error type, as the deviation is similar among them. This tendency may cause displacement among all the reference systems of GPS data and the laser scanner data. In spite of the displacement, no point was beyond 1.0 m of discrepancy.

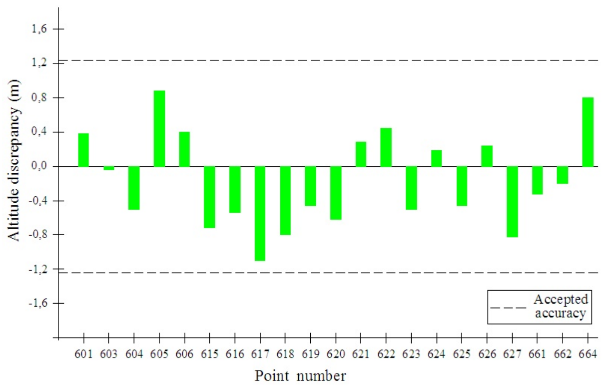



**Figure 10**: Altimetric discrepancy of the pre-signalized GPS points and the ones obtained from phototriangulation supported by laser scanning points.

According to the results, it is noticed in Figure 10 that the altimetric discrepancies do not make any displacement evident. These discrepancies remained within the expected accuracy, when compared to the accuracy obtained from the intersection of the rays (± 1.23 m), which was determined by the relationship between base and flight height.

Filliben´s test was applied to these differences, in order to check the sample normality and to eliminate errors. The “t-student” test and ‘χ-square” test were applied to evaluate accuracy, using 10% significance level in both cases.

The normal distribution (Figure 11) of planimetric and altimetric samples is confirmed in the analysis of Q.Q. Plot graphic. All the data are roughly distributed along a straight line.

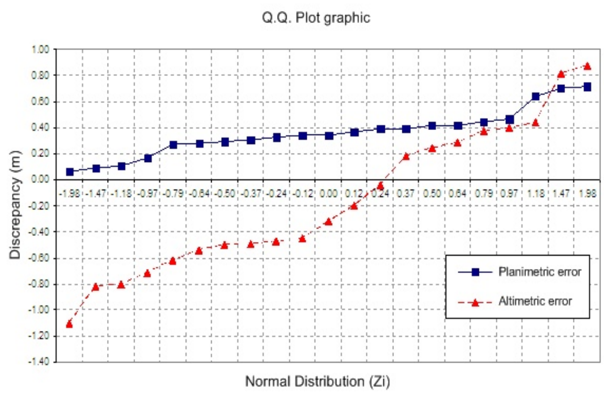



**Figure 11**: Q.Q. Plot graphic for the Filliben test in its planimetric and altimetric component.

As mentioned in a table for n = 21 and the level of significance of 10% (α = 0.1), the value of correlation coefficient r should be, at least, 0.961. The value of correlation coefficient for both straight lines was higher than the one in the table, as for the planimetric case the coefficient was 0.973, and for the altimetric one the value was 0.978.

Reaching the expected accuracy for a 1:2000 mapping, the results of “t-student” statistic test show that the populational discrepancy average is smaller or equal to 1.0 m for planimetry and altimetry. In the “χ-square” accuracy test, it is shown that the accuracy is better than ± 0.60 m in planimetry and ± 0.67 m in altimetry.

## 5. Conclusion

It is difficult to obtain photogrammetric control points from LiDAR data and the intensity image made by airborne laser scanner. As these data do not present any morphologic shape to be fully photo identified in an aerial photograph and to be used as supporting points, hence, they cannot be used in a previous treatment in studies which require accuracy.

Summing up, the proposed methodology for the treatment of planar features and to indirectly obtain the point coordinates which were not recorded by scanner laser works just like an interpolation method.

For the LIDAR data, the planar determination is one of the mathematical solutions, which allows an efficient performance, as the points largely present "semi-regular" distribution, thus presenting a highly redundant solution.

The control points extracted from LIDAR can replace the ones surveyed in the field, as it is possible to extract a "punctual" information which is photo identifiable. On the other hand, in order to obtain them, it is necessary to use techniques of digitally processed images and a mathematical modeling of the terrain.

## Acknowledgment

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