

FUSION AND OPTIMIZATION OF LIDAR AND PHOTOGRAMMETRIC TECHNOLOGIES AND METHODOLOGIES FOR CARTOGRAPHIC PRODUCTION

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ABSTRACT:

The main objectives of this work include the combination of data acquired by photogrammetric techniques and LIDAR. It also considers the development of some classification algorithm based on the use of spectral variables and spatial relationships aimed to obtain the required elements for digital mapping and digital elevation model products. At the same time, the different errors associated to the different cartographic stages are quantified. All these studies will be the basis to set up the technical requirement paper to be considered in any LIDAR project.

1. INTRODUCTION

The emergence of different airborne sensors for geospatial data capture has allowed working with different methodologies in cartographic production. For this reason, it is necessary to study the feasibility of the modern technologies and their operative development in order to achieve the optimized integration of geospatial data.

Every technological advance is an essential step to fulfil the needs of society, at the same time being important that the technicians responsible indicate the means of improving results in consideration of the different user capabilities. In this process the national cartographic institutions must give their professional advice and establish the working patterns normalizing the cartographic production criteria, so as to honour the purpose demanded by society.

The current potential in cartographic production for information registration depends on the choice of passive sensors such as analogical cameras and matrix or linear array digital cameras; active sensors such as LIDAR and RADAR; information sources such as RGB, Panchromatic, near IR, intensity level, position (x, y) and height first echo ... last echo); sensor orientation through INS/GPS and/or aerotriangulation; advantage out of the information (cartography, DTM, DSM, etc.) through photogrammetric techniques, LIDAR or RADAR.

In short, the production framework will depend on the available means and on the technical specifications set up for carrying out the work. We should take into account that the above-mentioned options – in addition to the traditional ones – allow the integration of information from the different sensors and its subsequent management in order to achieve the intended objective. This will be the subject of this paper along with decision taking and the pertinent quality control, as well as the exploitation of the information through the detection of changes and vectorization.

2. PHOTOGRAMMETRY VS LIDAR

Much has been written about photogrammetric techniques and LIDAR [see Schenk (2001) and Habib et al (2004)] and about their integration [see P. Ronnholm et al (2007)]. The following table is a concise comparative table of both techniques (Photogrammetry mapping: EM 1110-1-1000, 2002):

	LIDAR	Photogrammetry
Energy source	Active	Passive
Geometry	Polar	Perspective
Sensor type	Punctual	Matrix or linear
Measurement of points	Direct without redundancy. Accuracy of information only depends on calibration of system components	Indirect with redundancy. Images with overlay provide the intersection of the homologous rays (HR)
Information type	Punctual. Reconstructed surface (type of material and observed structure) difficult to assess	May be punctual, lineal or superficial. Easy to interpret reconstructed model due to info source: the image
Sampling	Individual points	Full areas
Associated image	None or monochromatic image	High geometric and radiometric quality
Horizontal accuracy	2-5 x less than vertical accuracy	1-3 x better than vertical accuracy
Vertical accuracy	10-15 cm (~ 10 cm per 1,000 m on heights of 2,500 m)	Depends on flight altitude and focal length of the camera
Flight plan	More complete. Small passes,	Needs consideration of

	higher potential for data	longitudinal and transverse coverage
Flight constraints	Less impact of time, daylight, night, season clouds	Daylight flying, clean atmosphere necessary
Production range	May be automated, thus a greater production	Higher need of editing control
Budget	25%-33% of budget: photogrammetric compilation	
Production	Software: depends on qualified commercial & technical people	Software for the end-user: slow process of identification and manual extraction. Not reliable if automated, implies editing, especially at large scales
Data acquisition limited by a largely contrasted area	Data can be acquired. Successfully used in coastal cartographic production	Difficult and expensive
Processing	Groups	Correlation
Feature extraction	Definition of zones or areas	Edge limits 2-D
Results	Edges or limits 3-D	Edges and zones 3-D

Table 1. Comparison of photogrammetry vs punctual LIDAR

From the tests and trials carried out in the Photogrammetry Laboratory of the Technical School of Surveying, Geodesy and Cartography of the Technical University of Madrid (Spain) with both techniques and information, provided by the National Geographic Institute (IGN) of Spain, from the same zone (Segovia) flown over with Vexcel Ultracam D digital camera and LIDAR sensor, processed with DIGI3D/MDTop photogrammetric software for LIDAR GTBiberica (Inpho DTMaster) information, we have come to the following conclusions:

- The classical photogrammetric technique is very dependable and accurate but the production process is time-consuming, very specialized, and thus costly.
- If we consider semi-automation processes, i.e. automatic correlation with breakline drawing by operator, production times are going to be improved and even the HR will be less specialized, however the software and even the quality of the images make this methodology slow since it involves much editing of the correlated points. On the other hand, if we want to decrease the number of correlated points (a greater interval) we should increase the number of breaklines, so we would go back to the above-mentioned case regarding production times.
- Full automation implies a large amount of correlated points. The automatic extraction of the breaklines provided by the current software is still the cause of many inaccuracies which force a revision, and adding that information in the

classical way by restitution. Therefore, the time spared is lost in a stereoscopic revision.

- Maybe the aspect that stands out is the actual information source, the image, a metric document, of high geometric resolution and increasingly better radiometric resolution. Besides, sensors allow ever-increasing information in the spectral range.
- Regarding the LIDAR techniques, they appear satisfactory as far as the number of points (density/sq meter) and precision (it is necessary to eliminate systematic errors, calibration, etc.) However we have to use very specific software and at times the filtering and classification processes are long and intricate. In any case, a metric verification of the information supplied appears to be convenient.

The use of one technique or another will depend on parameters such as **cost**, **time** and **quality**, independently, two at a time or all together, as we shall see below (decision triangle).

3. CARRYING OUT THE INTEGRATION OF INFORMATION

To the extent in which the resolution of the LIDAR sensors has been progressively increasing with time and in view of the possibility that these sensors could collect spectral information in other bands and not only the information provided by the LIDAR, researchers have been developing procedures and techniques of classification based on the fusion of information provided by the LIDAR with the information provided by the regular photogrammetric cameras. Haala and Brenner (1997) reconstructed 3-D models of cities and vegetation using a combination of LIDAR data with another data source.

The ML (Maximum Likelihood) classifier is appropriate in our case to solve the problem by using several bands of spectral information and other attributes simultaneously [TSO and Mather (2001)]. The initial hypothesis of this method is that the classes we want to obtain are distributed with the same likelihood in the image considered; although this is not always the case, the method is improved and extended in the well known Bayesian decision method which assigns a different likelihood of occurrence to each class [Swain and Davis (1978), Strahler (1980), Hutchinson (1982), Mather (1985), Maselli et al (1995)].

In our case we carry out the classification of the LIDAR scatter plot by turning the RGB image into HIS, so as to get the colour information through the H and S attributes encoded to 8 bits. In addition we have the information of the panchromatic camera that provides us the channel I with an encoding of 16 bits.

To this spectral information we add the R component of the infrared camera, encoded to 8 bits, linearly independent of the previous attributes, the LIDAR intensity level encoded to 8 bits, and finally the Z increment of the point, i.e. the Z difference between the first and the last pulse. In all, we carry out the classification of the LIDAR points with 6 independent attributes in order to improve the results of the classification that would be obtained by using only part of the attributes.

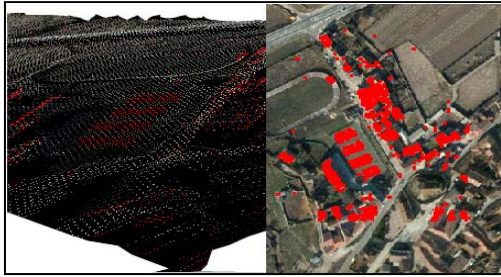


Figure 1. Example of classification through ML classifier

When combining the information provided by the traditional sensors with the one supplied by the LIDAR sensor, an additional issue comes up: the origin of the HIS and infrared attributes are digital images with regularly distributed pixels generally forming rectangular grids that may have different resolutions among them and they may range over ground areas not necessarily coinciding among themselves; in addition, the LIDAR scatter plot containing the information about the intensity level and the Z increment are irregular grids as a consequence of the way in which the points were obtained.

Hence, in order to be able to carry out the classification using all the available information, the first step is to give attributes (HIS and infrared) to every point making up the scatter plot obtained with the LIDAR sensor; in order to do that, given the coordinates of a LIDAR point, we will locate the nearest pixel to it in every image and we will assign the attributes of the found pixel as attributes of the LIDAR point.

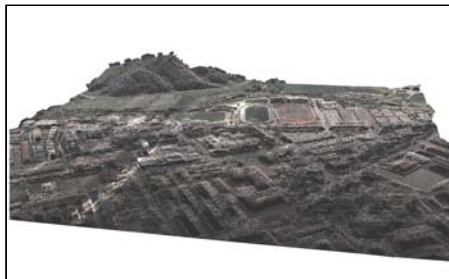


Figure 2. Detail of the LIDAR cloud combined with RGB

Inversely, given a particular pixel in any of the available images (HIS and infrared), its LIDAR attributes (intensity level and Z increment) will be searched for; the three LIDAR points nearest to the particular pixel are located through its coordinates; the attributes obtained from those points are interpolated using the Delaunay triangulation (Priego et al, 2004), and finally the result will be assigned to the pixel. With this procedure synthetic images may be created through the LIDAR attributes (among other applications).



Figure 3. Detail of a synthetic image

4. MULTI-CRITERION ANALYSIS

Presently there exist different techniques to obtain DEM's. This paper focuses on the study of two main methodologies, namely photogrammetry and LIDAR. Through the integration of these two basic technologies a third option comes forth sharing certain characteristics with the other two techniques. This third option stems from the integration of the points in the scatter plot from a LIDAR system, from the break lines fully outlining the irregularities of the terrain.

It has been empirically verified that DTM generation through airborne sensors has both advantages and inconveniences. The overabundance of points allows, through a series of algorithms, automating the classification of the points on the terrain and on no-terrain. However this overabundance does not entirely make up for the efficacy or quality of the end product that can be achieved by the involvement of an operator. In certain areas of the terrain, the lack of break lines defining it correctly will take a certain degree of accuracy away from the representation model automatically obtained by LIDAR sensors.

In this section a comparative study is made of the three already defined methodologies, which would allow choosing the most efficient one, the focal point being the three essential aspects in a typical process of cartographic production: time, cost and quality of the product. For that purpose a multi-criterion analysis is carried out, thereby assessing these three aspects in detail and leading into a general decision triangle which would enable anybody to choose the best option according to individual needs.

4.1 Indicators and independent analysis

In order to evaluate the three methodologies (photogrammetry (manually edited automatic correlation with break line integration), LIDAR (automated process of classification and filtering) and the integration of LIDAR with photogrammetric break lines, it is necessary to define a series of general indicators to be independently assessed in each case. These indicators allow assignment of an objective numerical value to different basic characteristics of a cartographic production process in relation to the three main aspects that allow choosing a technique.

The following table shows the indicators used in the analysis carried out for each methodology:

Altimetric accuracy	Planimetric accuracy
Resolution	Type of model (TIN, GRID, etc.)
Grid spacing	Realistic model
Full model	Production time
On-flight storage	Real cost of equipment
In-flight data processing	Preparation of human resources
In-flight losses	Condition for picture taking (orientation)
Calibration	Flight cost/difficulty
Terrain characteristics	Information about homogeneous surfaces
Information about break lines	Weather/time
Automatic 3D data acquisition	Measurement redundancy
Semantic information	RDI
Information source	

Table 2. List of indicators used in the analysis

After having established these indicators, the next step is their arrangement according to their importance in relation to the above-mentioned essential three aspects: cost, time and quality. For instance, the altimetric accuracy will be high on the list in relation to quality, although it will be less relevant in relation to time. While the preparation of the human resources is an essential aspect in relation to cost if a cheap product is desired, it would not be as important if the aim is a high quality product.

Next, weights are assigned to the indicators independently for each essential aspect (cost, time, quality). Thus three series of weights are obtained for each one of these main variables. At this point the different indicators for each technology are evaluated. A score of 1 to 10 is assigned to each indicator according to their importance in the three methodologies being studied. This numerical value is repeated thrice, one time to evaluate the time variable, another one for the cost variable and the third one for the quality variable. Thus triads of values are obtained for each indicator on the basis of the three main aspects and the methodologies. The last step consists of applying the previously assigned weights to the independent evaluations, multiplying each one of these by the weight of the indicator.

At last, the end evaluations for each technology on the basis of the three aspects are achieved. A decision matrix of size 4x3 is so generated, with each technology being represented in the columns and time, cost, quality and total being represented in the rows

	IMAGE MATCH + BREAKLINES	LIDAR	LIDAR + BREAKLINES
QUALITY	7171	7045	7900
TIME	5650	8170	7120
COST	7455	8920	7505
TOTAL	20.276	24.135	22.525

Table 3. Decision matrix.

4.2 Decision triangle

The results brought about by the previous analysis allow the design of a decision triangle. Since we are dealing with a graphic representation, it is possible to make a visual assessment of the results, consequently making it more efficient than a purely numerical representation. In addition, since the values appear represented jointly in relation to the three essential aspects, the choice of a methodology, taking into account more than one variable, becomes a simple, intuitive process.

The vertices of the triangle represent time, cost and quality and the bisectors of the angle are taken as axes. The centre of the triangle is considered to be the point for ideal work that would be reached by getting a score of 10 for all indicators in the three independent studies, while the vertices would get the worst possible score. Next the position for each methodology is placed over each axis using the final values appearing on the decision matrix. Joining the points corresponding to each methodology generates three internal triangles defining the general rank of the technologies.

Once the triangle has been fully designed, it is possible to carry out different studies depending on the desired number of variables.

Study with one variable

The study with just one variable is simple and direct. The variable is selected and the methodology which is closest to the centre is checked. The results of this multi-criterion analysis show that as far as time is concerned, the best option is the “pure” LIDAR. As far as quality is concerned the best option is the use of LIDAR along with break lines and as far as cost is concerned the best option is again the “pure” LIDAR.

Study with two variables

In order to select one of the three methodologies at the same time taking into account two variables, it is necessary to study the sides of the internal triangles formed for each technology. The nearer one side of an internal triangle is to the ideal working point, the better will the methodology be in relation to the two variables in consideration.

The middle point of each side of the big triangle is the one where the importance of the two variables is equal (50%-50%). If more importance wants to be given to one of the two variables, the point of study must be displaced along the side of the triangle toward the vertex corresponding to the predominating variable. This generates variations in the order of preference when choosing methodology.

Study with three variables

This third option allows verification of which methodology is the best in relation to the three variables jointly. For this purpose the centre of gravity of the internal triangles is calculated, the optimal methodology being the one having the centroid closest to the point of ideal work.

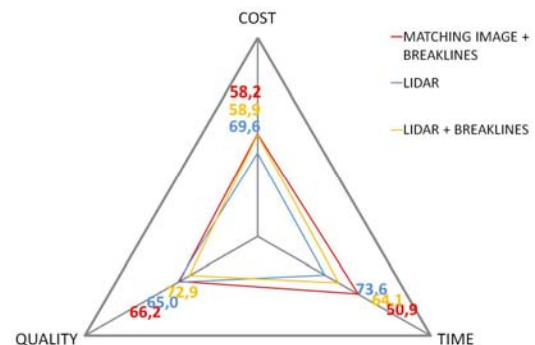


Figure 4. Triangle for the study with one variable

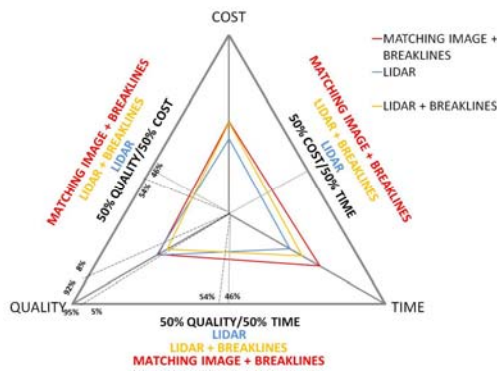


Figure 5. Triangle for the study with two variables

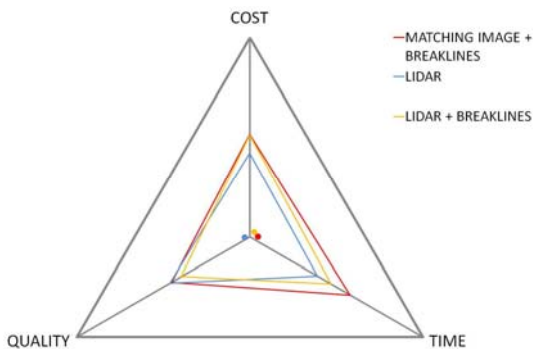


Figure 6. Triangle for the study with three variables

In this case, considering the three variables jointly, the best option is the “pure” LIDAR, closely followed by the LIDAR with break lines, the worst option being the correlation with break lines.

5. QUALITY CONTROL

Quality is defined as “a built-in property of something which allows comparison with any other thing of the same kind or nature and which fulfils certain requirements”. For our purpose, certain routine practices and controls have to be contributed ensuring the integrity, accuracy and completeness of the data, i.e. it must be verified that the desired quality has been achieved.

In the case of the information provided by the photogrammetric method, we are dealing with aspects concerning measurement redundancy – say observation redundancy. The results of photogrammetric triangulation provide quantitative measures of result precision.

- Variance component.
- Covariance matrix of calculated coordinates.
- Comparison of values with nominal data.

Independent measurements to verify precision through control point analysis.

- The coordinates of the photogrammetric points are compared to coordinates independently obtained (i.e. field GPS).

Regarding LIDAR information, the control is a procedure subsequent to the mission to ensure and check the quality of

registered data. The control may be made with two criteria. First, focusing on the “causes”, i.e. studying the behaviour of the elements defining the mathematical adjustment model, where “internal causes are considered (flight planning, external orientation and calibration) and external causes (flight conditions: direction of passes, flight altitude, etc. and type of terrain: height, vegetation type, etc.)”. See Habib, Advanced Photogrammetric Techniques:

$$\begin{bmatrix} x_{pl} \\ y_{pl} \\ z_{pl} \end{bmatrix} = \begin{bmatrix} X_0 \\ Y_0 \\ Z_0 \end{bmatrix} + R_{INS} \begin{bmatrix} \delta_x \\ \delta_y \\ \delta_z \end{bmatrix} + R_m R_s \begin{bmatrix} 0 \\ 0 \\ -\rho \end{bmatrix} + \begin{bmatrix} e_x \\ e_y \\ e_z \end{bmatrix}$$

where:

- x_{pl}, y_{pl}, z_{pl} coordinates of the laser track on the ground.
- X_0, Y_0, Z_0 phase centre coordinates of the GPS antenna.
- R_{INS} rotation matrix between terrain system and IMUs.
- $\delta_x, \delta_y, \delta_z$ displacement between laser unit and phase centre GPS antenna.
- R_m rotation matrix between IMUs and laser unit ($R_{\Delta\omega}, R_{\Delta\phi}, R_{\Delta\chi}$).
- R_s rotation matrix between laser unit and laser beam.
- ρ vector range of measurement of the laser system (laser beam).
- e_x, e_y, e_z random errors of components.

Second, focusing on the “effects”, studying the results provided by the scatter plot, where consideration is given to “relative internal effects (altimetric control, planimetric control) and absolute external effects (control points, difference between DTM and DSM, difference of intensity level, stereoscopic checking)”. In most cases the actual quality control of results is carried out with this second criterion, while possible corrections to those results are carried out on the elements of the equation chosen for adjustment.

A working proposal must take into account the following elements: an appropriate mathematical model to calculate the LIDAR point coordinates; an algorithm of extraction of linear or surface features per flight pass; setting up reciprocal relationship between equivalent entities in overlapping zones (cross-coverage); an appropriate selection process in the linkage entities; applying a least square adjustment to the model. The ideal solution is based on a high degree of automation (minimal user interaction), use in standard flight missions, minimal requirement of additional flights (i.e. cross-passes) and a minimal number of ground control points.

6. CHANGE DETECTION

After having generated the orthophotography through the previous processes, cartographic exploitation comes next. Here we raise the possibility of obtaining, more or less automatically, linear cartographic objects and features that have changed between two images (orthophotos) taken on different dates, which is commonly known as change detection.

The automatic change detection may be carried out according to the technique based on the matching of an image pair or by extraction of linear features of an image of the current state of the area and subsequent comparison of this vector layer with the official vector file, thereby updating the existing cartography. Anyway, we are dealing with image processing, a set of operations that are applied to images in order to enhance or tone

down details such as edges, or to decrease or do away with noise patterns.



Figure 7. Detail of the original images

The algorithm we have created which we have named DETECAM is based on filtering in the frequency domain according to the Fast Fourier Transform. Thanks to its separability property, the complexity of calculations in bidimensional data (images) is reduced; two transforms for each image are carried out, one for the rows and another one for the columns (one-dimensional). When representing the transform spectrum, the highest frequencies occupy the corners, coinciding with image zones of high contrast. If these zones of the new image are substituted in the old image, by applying the inverse FFT, an image is obtained on which the edges of the changes appear lightly marked on the old image, having both been previously equalized.

The next step is to make a correlation between the old image and the new image, the latter having been modified by the previous step. In order to do this, we resort to a QuadTree algorithm with which we carry out the correlation of wide tiles, progressively subdividing them if changes are found until we reach the pixel level. The result of this correlation is a binary image with the changes undergone between both images in black over white background.

Evidently in this image-result there are salt-and-pepper type noises. In order to get rid of them, we resort to a filter we have named “direct occurrence filter”, on which a window size and a threshold are set. For each window obtained when the image is looked through, the number of white pixels is assessed; if this number is greater than the defined threshold, the central pixel will become white. In addition, if a white pixel is surrounded by black ones in the range of a pixel, it will become black. The image is then smoothed out by the application of a mode filter.

The next step consists of combining the binary image obtained with the modern image according to the following principle: if the pixel is black in the binary image, it will be replaced by the value of the RGB pixel of the modern image. If the pixel of the binary image is white, the resulting pixel will remain white. Finally, an image is obtained with the RGB attributes of the modern image, only at the points where changes were detected; roads, buildings ... appear.

Next a Mahalanobis classification is carried out. On the image obtained, a sample area is selected – e.g. a road – with ~10 points, and an image is obtained with just the changes resembling the established sample area, according to Mahalanobis distance. As in previous steps, the result is binarized, making black the pixels that statistically resemble those of the sample area and making the remainder white.



Figure 8. Detail of the DETECAM algorithm's workflow

In the end we get an image on which the road – or any other feature of interest – appears and also some noise that will be done away with by means of an inverse occurrence filter. In this case, a window size and a threshold are also set up, however if the window is superimposed on each pixel and the existing number of black pixels get over the threshold, the pixel is set up as black. As in the case of the direct occurrence filter, a 5x5 window mode filter is applied. The result is a noiseless binary image on which the changes in the two source images appear. This will be the image to be vectorized.

7. CONCLUSIONS

- The photogrammetric production may be improved concerning time and increase in correlated points if we have LIDAR software available for editing (tests have been carried out with good results).
- DTM geometry obtained from the LIDAR scatter plot is improved if breaklines from photogrammetry are included.
- Images provided with LIDAR intensity level do not have a good definition (images coming from the visualization of scatter plots!). In the making of orthoimages it is essential to start off from digital images. We are studying the generation of multi-layer images that could incorporate the LIDAR intensity as an additional channel (resampled image from the LIDAR intensity).
- The fusion of data coming from different sensors open new expectations in the filtering and classification of information, giving rise to possible new products.
- Photogrammetry appears to be a good tool for verification of data provided by LIDAR.

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