GRASS GIS for the distinction of vegetation from buildings using LiDAR altimetric data.

R. Antolín Sánchez[(1)] *y M. A. Brovelli*[(1)]

[(1)] Laboratorio di Geomatica, Politecnico di Milano – DIIAR – Polo Regionale di Como. Via Valleggio 11, 22100 Como, Italia. (roberto.antolin, maria.brovelli)@polimi.it

RESUMEN

La tecnología LiDAR (Light Detection and Ranging), basada en el escaneado del territorio por un telémetro láser aerotransportado, permite la construcción de Modelos Digitales de Superficie (DSM) mediante una simple interpolación, así como de Modelos Digitales del Terreno (DTM) mediante la identificación y eliminación de los objetos existentes en el terreno (edificios, puentes o árboles). El Laboratorio de Geomática del Politécnico de Milán – Campus de Como- desarrolló un algoritmo de filtrado de datos LiDAR basado en la interpolación con splines bilineares y bicúbicas con una regularización de Tychonov en una aproximación de mínimos cuadrados. Sin embargo, en muchos casos son todavía necesarios modelos más refinados y complejos en los cuales se hace obligatorio la diferenciación entre edificios y vegetación. Este puede ser el caso de algunos modelos de prevención de riesgos hidrológicos, donde la vegetación no es necesaria; o la modelización tridimensional de centros urbanos, donde la vegetación es factor problemático.

Con este propósito, nuestro grupo ha revisado el algoritmo de filtrado y ha llevado a cabo nuevas actualizaciones para posibilitar la clasificación de forma automática de edificios y vegetación. El algoritmo utiliza como única información datos altimétricos de campañas LiDAR y se beneficia de las diferencias en altura entre el primer y último impulso presentes en dicho tipo de datos. El primer paso es aplicar el filtro ya existente a dichas diferencias. Posteriormente, se realiza una vectorización automática considerando agrupamientos de puntos clasificados como doble impulso. La vegetación se obtiene discriminando el tamaño y la forma de los polígonos obtenidos en la vectorización.

El filtro se ha integrado como parte de las herramientas LiDAR del programa libre y de código abierto GRASS GIS 6.2 bajo licencia GPL (General Public License). De este modo, se tiene una herramienta adecuada para la importación, la visualización y el procesamiento de datos LiDAR dentro del mundo del software libre.

Palabras clave: *SIG, software libre, GRASS, LiDAR, vegetación.*

ABSTRACT

The LiDAR (Light Detection and Ranging) technology, based on the scanning of the territory by airborne laser telemeters, allows the construction of Digital Surface Models (DSM) by a simple data interpolation, and Digital Terrain Models (DTM) by the identification and removal of attached and detached object (such as buildings, bridges, power lines or trees). For this purpose, the Laboratory of Geomatica of the Politecnico di Milano - Campus of Como – developed a filter algorithm based on bilinear or bicubic spline interpolation with Tychonov regularization in a least squares approach. However, in many cases it is still necessary a more accurate and complex DEM in which a distinction between buildings and vegetation is needed, like in some hydrological hazard prevention models, where only vegetation has to be removed, or in automatic 3D city modeling where vegetation is problematic because it interferes with the vectorization of the building models.

Therefore the filter was revised and further improvements were carried out in order to allow an automatic classification between buildings and vegetation. The procedure uses LiDAR altimetric data as unique information and takes advantage of the differences in height between first and last LiDAR pulses. Firstly, the old filter (consisting in an edge detection, a region growing and a correction algorithms) is applied to these differences. Then, a vectorization is made by considering clustered points classified as 'double pulse'. Vegetation is obtain by discriminating the shape and size of the polygons obtained in the vectorization.

The filter has been developed into the free and open source GRASS 6.2 GIS software (under general public license GPL) as part of the LiDAR tools, in such a way to have an integrated environment suitable to enter, visualize and process the data.

Key words: *GIS, free software, GRASS, LiDAR, vegetation.*

INTRODUCTION

Airborne Laser Scanning

The Airborne Laser Scanning (ALS) technology is based on the ground survey from an airborne laser telemeter. The telemeter measures the distance between the emission point and the echoing point which is a generic ground point hit by the laser ray. Thus, the laser telemeter measures two time the distance between the instrument and the echoing surface. The final data from a LiDAR survey is a great amount of planimetric coordinates, sorted by the point retrieved instant, and the corresponding ellipsoidal heights. Since LiDAR is often able to measure the intensity echo, this kind of signal attribute is also archived.

Some of the most important laser scanning capabilities are a high accurate measurements, a high point resolution and a high velocity survey. Due to two basic characteristics of LiDAR technology (monoscopy and almost-nadirality), laser rays are able to reach the ground or the studied object surface, also through very narrow passages in highly vegetated zones.

Filter and segmentation algorithms

Nowadays, ALS applications are very wide and go beyond the unique use of LiDAR technique for Digital Elevation Models production and object modeling. Topics in LiDAR publications go from terrain elevations and digital terrain modeling to 3D building [1] and man-made structures modeling [2], forestry and vegetation mapping, power lines, engineering applications (i.e. volume computations), coastal engineering, hydrology, geology, etc.

From LiDAR data, it is easy enough to develop a Digital Surface Model (DSM) as a simple raw data interpolation. DSM just represents the trend of the terrain and of the objects over it. However, the principal aim is to develop a Digital Terrain Model (DTM) or a Digital Building Model (DBM). Considering the height coordinates and using their geometry, the idea is to automatically classify the data. This process is named *filtering*, and the classification depends on each process. In Sithole [3] it was showed a picture of the different filters and their performances. In general, the classification consists of two different feature types: terrain and object. Thus, filtering LiDAR data needs some algorithms to determine the points belonging to the terrain or to each single object. Those "object" points are removed before the DTM calculation. Moreover, the most extended classification consists in differencing between terrain and off-terrain points, although algorithms dividing point clouds in more categories have been also implemented.

Vegetation

It is also possible the computation of other types of products from ALS point clouds. For 3D building modeling, forestry [4], [5] or hydrological purposes it should be possible to compute DEMs where only vegetation is present, thus buildings have been filtered, or on the opposite, where vegetation has been removed and buildings have been left. Therefore, points should be labeled, at least, as bare earth, building or vegetation during filtering. This differentiation is essential, for example, in hydrological projects, where the volume of vegetation represented by this type of DSM (canopy), is not the same as the volume that actually obstructs the water flow (stem).

Commonly, filters aim to separate between terrain and off-terrain points. However, some filters make further classification and go beyond the simplest labeling into object and bare earth and are also able to classify objects as vegetation or buildings. Since the scientific community has realized the importance of this kind of classification, this distinction has become more common and it is easily found in many of the filters of the last years. Furthermore, modern sensors, which are able to record the full waveform of the backscattered echo, make possible new algorithms dealing with this kind of data.

There are many techniques used in vegetation filters. Hug and Wehr [6], and Tovari [7] use normalized DSM (nDSM=DSM-DTM) with a height threshold in order to reject small objects. Both authors make use of further features such as gradients, height texture, segments size and shape, intensities, etc. for a classification improvement. Forlani [8] applies a region growing based segmentation where the height between a pixel and its neighbors has to stay below a threshold. The relation to neighboring segments and shape descriptors are used for the classification by a set of rules. Tarsha [9] use exclusively first echo data and height differences of all points within one raster cell as well as morphological operations. Matikainen [10] makes a first segment classification as terrain and off-terrain and then, with a statistical classification tree method, buildings and vegetation are filtered. Training segments are used, where attributes were derived from both the last and first pulse DSMs and aerial color ortho images.

METHOD

From the first beginning and due to educative purposes, our filtering algorithms were thought to be developed as free and open source software. Thus, the GRASS (Geographic Resources Analysis Support System) project [11] was chosen to publish our packages in. There were some reasons for this. First of all, GRASS is one of the most powerful analysis GIS of the “open” community, so there are many available software built in libraries that make easier the implementation. Secondly, it is widely spread and this makes the algorithm to be available to many people. This is, of course, also an advantage, because it is possible to use the community resources. Helpful backtracking has been carried out during the last two years, and also some ideas for the interpolation command improvement were suggested.

The first versions of our filtering algorithm are available in GRASS 5.4. They were tested in different times with good results [12], [13] and [14]. The same modules within the GRASS 6 vector architecture were presented in [15].

Detailed explanations of the filter can be found also in [12] and [13]. Mainly, our filter takes advantage of bilinear and bicubic spline interpolations with Tychonov regularization in a least-square adjustment approach. The regularization parameter serves to control the interpolation smoothness. The higher the parameter, the smoother the interpolation.

The LiDAR filtering procedure can be summarized as: i) outlier removal, ii) buildings and vegetation edge detection, iii) determination of the area inside these edges and iv) object removal and terrain surface reconstruction.

The execution of these steps is not carried out by an unique GRASS command able to filter a whole raw LiDAR data set. The GRASS commands implemented to carry out the procedure are, in order, *v.outlier*, *v.lidar.edgedetection*, *v.lidar.growing* and *v.lidar.correction*. This fact allows the user to verify the data filtering step by step. Thus, it permits to modify the parameter at a time for the best filter performance..

The final point classification has four categories; 1) *terrain single pulse*, 2) *terrain double pulse*, 3) *object single pulse* and 4) *object double pulse*. “Object double pulse” points generally mean edges, since the first pulse is the echo from the top of the object and the last pulse is the echo from its side. “Terrain double pulse” points can be considered as low and uniform vegetation zones in which the first and the last pulses are backscattered from the top of the vegetation and from the ground, respectively. If the last pulse returned height is almost the same as the first pulse returned height, then the point is considered as “single pulse”. Instead, if last pulse returned height differs from the first one, the point is considered as “double pulse”.

The procedure is able to identify all objects in the landscape, vegetation included. A procedure to distinguish between buildings and vegetation didn't exist till now.

Vegetation filter

As seen, detecting vegetation zones in ALS point clouds is an important task which has usually been faced at the same time that the filtering process. Authors that wanted to extract only vegetation or buildings from LiDAR datasets have developed their own algorithms instead of modify existing ones. Thus, vegetation filters have been thought to distinguish amongst bare earth, vegetation and buildings from their first version.

However, we have developed our vegetation classification from the filter algorithm described above. This was done for many reasons. First of all, our filter algorithm was designed to participate in the ISPRS filter test [3] where filters were only supposed to differentiate between bare earth and object. Only later [14] it was seen that it might be useful to distinguish amongst different types of objects such as buildings, vegetation, man-made structures, etc. Therefore, it was decided to improve our own filter because a) there already was a structure which could be used beyond its initial scope, and b) there would be an algorithm able to filter vegetation in the open GIS community.

Thus, a new GRASS command has been developed which is not published at the time this paper has been written. Henceforth, the new command will be named *v.lidar.vegetation*. This command starts from the last filter procedure, that is, *v.lidar.correction*. Unfortunately, the need of starting a new classification from an existing one leads to add further errors. That is, misclassified points in the first results might cause errors when buildings and vegetation are determined.

Basically, the new algorithm consists in a rasterization procedure in order to make computation easier and faster. Here, possible vegetation or building cells are identified. As in *v.lidar.growing*, both a region growing and a convex hull procedures are carried out. The area and the ratio between area and perimeter of the resultant sets are studied. Final classification will be obtained by checking, for each *v.lidar.correction* classification, whether points fall into these sets or not.

Rasterization

The first step consists in create a raster mask in which cells are assigned 1 or 0 values depending on whether points, falling into these cells, have been previously classified as *object single pulse* or *terrain double pulse*. *v.lidar.filter* allows us to look for vegetation or for buildings. Thus, an input parameter can be supply before starting the classification in order to flag those cells that contains *object double single* points if buildings are wanted or *terrain double pulse* points if vegetation is searched. In this way, if vegetation is wanted and at least one point within the cell has been classified as terrain double pulse, then this cell is flagged, otherwise, it is set to zero. On the other hand, if we are looking for buildings and at least one point is classified as object single pulse, then the cell is flagged, otherwise, it takes the zero value.

Rasterization is carried out to make easier the next region growing algorithm. Also it makes possible to assign more categories to points in order to allow further and more complex classifications.

Region growing and convex-hull

The idea in this step is to cluster the points with the same characteristics. Thus, for the first seed cell, which is chosen as the most southwestern and flagged cell, its eight neighbour cells are checked whether they are also flagged or not. In case that at least one of them has a value equal to 1, the region growing algorithm continues asking the next eight neighbours for each flagged cell. The region growing algorithm ends when no other flagged cell is found. At this time, the most southwestern and flagged cell, amongst those not checked, is considered as the new seed cell.

For each segment, a convex-hull set is computed in order to aid the calculus of the area and the ratio between 4π times the area and the square of the perimeter. This ratio gives an idea about the shape of the convex-hull results. Since for a circle, 4π times the area is $4\pi\cdot(\pi R^2)$ and the square of the perimeter is $(2\pi R)^2$, then the closer the ratio to 1, the closer the shape to a circle.

Thus, hulls with small areas or small ratio values are rejected and are not considered in the next steps. Segments with small areas are likely to be spare points and cannot be considered as buildings. On the other hand, they may be considered as vegetation in some cases if the area is big enough. For this reason, area is an input parameter, although a default value of 30 square units -usually meters- is suggested for standard cases. In the same way, very small ratios correspond to stretched shaped objects. Trees placed in a strait line reproduce these types of features, that is, long and narrow objects. On the other hand, buildings usually have almost square shapes that correspond to high ratio values. This is one parameter the user can supply too, being the default threshold equal to 0.5.

Final classification

For the final classification only those points with a former classification different from terrain single pulse are considered. Thus, points that were previously labeled as bare earth keep their classification. For each point, it is checked if it falls into one of the convex hulls.

From now on, let us call *vegetation* and *building hulls* those areas created when terrain double pulse and object single pulse seed cell were considered, respectively. In this way, double pulse points inside vegetation hulls will be classified as vegetation, otherwise, they will be classified as buildings. In addition, points that, in a first moment, were classified as objects and inside building hulls are labeled as buildings, otherwise terrain double pulse points will be considered as vegetation.

RESULTS

The new method has been tested with two of the eight datasets supplied for the ISPRS filtering test [3]: Csite3 and Csite4. In both datasets, last and first pulses are available. The basic features of interest within those datasets are data gaps, low density of terrain points (railway station), densely packed buildings with vegetation between them, open spaces with mixtures of high and low features, etc.

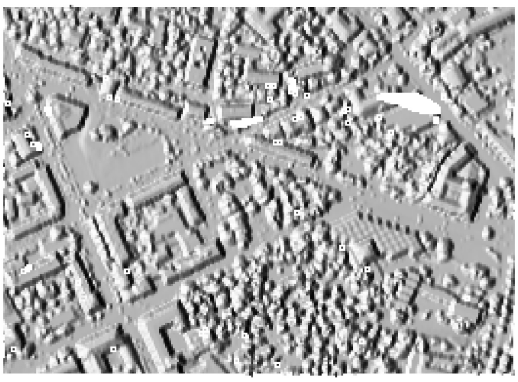

Figure 1: Shaded relief raster of Csite3 dataset

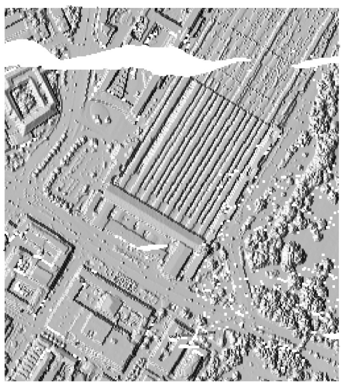

Figure 2: Shaded relief raster of Csite3 dataset

Csite3 is 204336 m^2 wide with 188514 points, thus, the resolution is 0,92 points/m^2. Its bounding box is N=5403504, S=5403117, W=512022 and E=512550 in (WGS84

UTM). On the other hand, Csite4 is 312639 m^2 wide with 258943 points, thus, the resolution is 0,82 points/m^2. Its bounding box is N=5403773, S=5403182, W=513110 and E=513639 in (WGS84 UTM). Shaded relief rasters created from last pulses raster maps for both datasets can be seen in Figures 1 and Figure 2.

Since no reference data was available for the building-vegetation comparison, a building manual digitalization had to be done. However, not only buildings but also other kinds of objects such as train platform shelters, trains or bridges were considered. The decision was taken assuming that those features likely behave as buildings rather than as vegetation. No orthophoto was supplied, thus, the digitalization was based on the last pulse rasters and a pre-classification carried out with the first filter. Doubtful cases were solved with colour images from internet (Google-Maps). This digitalization was considered as the truth, therefore, it will introduce further classification errors due to bad objects interpretation. Considering objects and no vegetation in the digitalization leads to biased results because it is only possible to check if points belong to buildings but it is not possible to know whether points actually lay on vegetation or not.

Table 1: Csite3 confusion matrix

		CLASSIFICATION		
		BUILDINGS	VEGETATION	TOTAL
TRUE	BUILDINGS	92,18%	7,82%	45025
	VEGETATION	15,28%	84,72%	71346
	TOTAL	52409	63962	**116371**

Table 2: Csite4 confusion matrix

		CLASSIFICATION		
		BUILDINGS	VEGETATION	TOTAL
TRUE	BUILDINGS	90,13%	9,87%	90402
	VEGETATION	14,33%	85,67%	62254
	TOTAL	90399	62257	**152656**

The quantitative analysis of the results has been performed by a confusion matrix shown in Table 1 and Table 2. The statistics are referred to those points classify by *v.lidar.correction* as not belonging to bare earth and that fall inside the buildings manually digitized. Hence, the number of points considered for statistics are 116371 and 152656 for Csite3 and Csite4 respectively. Results are presented as percentages but for the total number of both manually and automatically classified points.

Csite3 dataset has been filtered using object single pulse points in the region growing procedure. Instead, terrain double pulse points were used for Csite4. Both datasets have almost the same total error of 12,39% (Csite3) and 11,69% (Csite4). Type I errors (reject building points) range from 7,82% (Csite3) to 9,87%, while Type II errors (accept vegetation points as buildings) are 15,28% and 14,33% for Csite3 and Csite4 respectively. High values of Type II errors on both datasets are due to the former errors during the first filtering step -the one from v.lidar.edgedetection to v.lidar.correction. Moreover, Type II error is influenced by the fact that many points cannot be considered neither buildings nor vegetation, however in this case, the implementation of the algorithm classify them as buildings.

Figure 3 and Figure 4 show the qualitative classification for Csite3 and Csite4 respectively. Black colour represents building points and grey colour represents vegetation points.

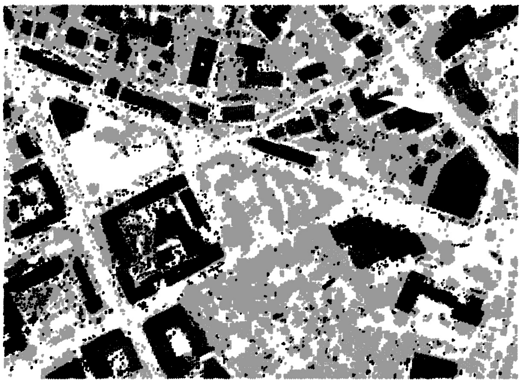

Figure 3: Csite3 classification. Black: building; Grey: vegetation

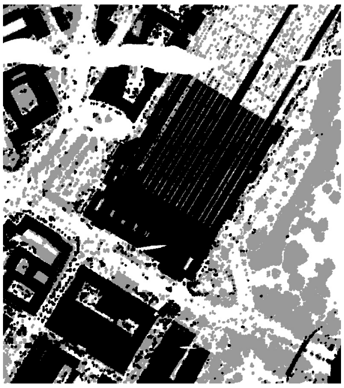

Figure 4: Csite4 classification. Black: building; Grey: vegetation

CONCLUSIONS AND FUTURE WORK

A new method for distinguish vegetation from buildings in ALS point clouds has been implemented. The algorithm developed was embedded into the free and open source software GRASS GIS. With it, the built-in lidar filtering tools available in GRASS can be considered as finished. It has been tested with two datasets with good results. However, further improvements should be done in order to obtain a more accurate classification. ALS datasets, with external cadastral information available are now being filtered. This will help to avoid final errors affected by digitalization and will show the real classification performances. In Csite3, where object single pulse points were used, Type I error is lower than in Csite4, where terrain double pulse points were used. Therefore, it seems that the fact of using object single pulse or terrain double pulse points might affect the final results. Further studies, using the other type of point classification for each case, should show if Type I and Type II errors could be minimize.

BIBLIOGRAPHY

[1] Schwalbe, E., Maas H-G., and Seidel, F. (2001). "3D building model generation from airborne laser scanner data using 2D GIS data and orthogonal point cloud projections". *In ISPRS WG III/3, III/4, V/3 Workshop – Laser scanning 2005, pp. 209-214*.

[2] SITHOLE, G., and VOSSELMAN, G., (2006). "Bridge detection in airborne laser scanner data". *ISPRS Journal of Photogrammetry and Remote Sensing. Volume 61:33—46.*

[3] SITHOLE, G., and VOSSELMAN, G., (2004). "Experimental comparison of filter algorithms for bare earth extraction from airborne laser scanning point clouds". *ISPRS Journal of Photogrammetry and Remote Sensing, 59 (Issues 1-2):85—101.*

[4] STRAUB, B-M.(2003). "A Top-Down operator for the automatic extraction of trees – Concept and performance evaluation". *In ISPRS WG III/3 workshop – 3D reconstruction from airborne laserscanner and InSAR data. Volume XXXIV 3/W13, Dresden, Germany. October 8-10.*

[5] BRANDTBERG, T., (2007). "Classifying individual tree spieces under leaf-off and leaf-on conditions using airborne LiDAR". *ISPRS Journal of Photogrammetry and Remote Sensing. Volume 69:325—340.*

[6] HUG, C. and WEHR, A., (1997). "Detecting and identifying topographic objects in imaging laser altimetry data". *In International Archives of Photogrammetry and Remote Sensing. Volume XXXII/3-4W2.*

[7] TOVARI, D. and PFEIFER, N., (2005). "Segmentation based robust interpolation – a new approach to laser data filtering". *In ISPRS WG III/3, III/4, V/3 Workshop – Laser scanning, pp. 79—84.*

[8] FORLANI, G. and NARDINOCCHI, C., (2001). "Building detection and roof extraction in laser scanning data". *In International Archives of Photogrammetry and Remote Sensing. Volume XXXIV.*

[9] TARSHA-KURDI, F., LANDES, T., GRUSSENMEYER, P. and SMIGIEL, E., (2006). "New approach for automatic detection of buildings in airborne laser scanner data using first echo only". *In ISPRS Symposium of Commision III – Photogrammetric Computer Vision. Bonn, Germany. September, 20-22.*

[10]MATIKAINEN, L., KAARTINEN, H., and HYYPPA, J., (2007). "Classification tree based building detection from laser scanner and aerial image data". In ISPRS Workshop on Laser Scanning and SilviLaser, pp. 280—287.

[11]GRASS DEVELOPMENT TEAM, (2008). "GRASS 6.2 Users Manual". ITC-irst Trento, Italy. *Electronic document: http://grass.osgeo.org/grass62/manuals/html62_user/index.html.*

[12]BROVELLI M.A., CANNATA M.A., and LONGONI U.M., (2002). "Managing and processing LiDAR data within GRASS". *Proceedings of the Open Source GIS-GRASS users conference. 29 pages. Trento, Italy. September, 11- 13.*

[13]BROVELLI M.A., CANNATA M.A., and LONGONI U.M., (2004). "LiDAR data filtering and DTM interpolation within GRASS"*. Transaction in GIS, Blackwell Publishing Ltd.*

[14]ANTOLÍN, R., BROVELLI, M.A., FILIPPI, F., VISMARA, F., (2006). "Digital terrain models determination by LiDAR technology: Po Basin experimentation". *Bolletino di Geodesia e Scienze Affini, Anno LXV, n 2, pp. 69-89 .*

[15]ANTOLÍN, R. and BROVELLI, M.A., (2007). "LiDAR data filtering with GRASS GIS for the determination of Digital Terrain Models". *In "I* Jornadas de *SIG* libre*". Girona,* España. *March, 4-6.*