TERRAIN MODELING IN AN EXTREMELY STEEP MOUNTAIN: A COMBINATION OF AIRBORNE AND TERRESTRIAL LIDAR

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ABSTRACT:

A combination of airborne and terrestrial LIDAR data has been used to model extremely steep mountains that are crossed by the Núria cog railway. This cog train is the only terrestrial transportation resort to reach the Núria Valley in the Spanish Pyrenees. The purpose of this Digital Elevations Model (DEM) is the modeling of rocks that fall over the railway track in order to implement protection measures to mitigate this risk.

The airborne LIDAR system was an Optech ALTM 3025. Special parameter settings were selected to improve the coverage of the area but as the mountains contain many overhangs and vertical walls some occlusions appeared in the airborne LIDAR data. A terrestrial survey was also carried out in order to improve the terrain modeling. The terrestrial campaign consisted of 5 scenes observed with a Riegl LMS-Z210 mounted on a tripod in 5 static positions in front of the problematic vertical areas. Terrestrial laser scenes were oriented identifying previously surveyed reflectors.

The poster presents the methodology applied to integrate data from both LIDAR sensors and shows the obtained results.

1. INTRODUCTION

In this paper it is described the procedure that was used to build a 3D terrain model of an extremely steep terrain. The surveyed area comprises 71 Ha in the mountains crossed by a railway track in its path to the Núria Valley in the Spanish Pyrenees. The generated terrain model was required to analyze the risk and to implement protection measures against the hazard of rock falling over the railway track.

2. DATA AND METHODOLOGY

The data was captured with two different instruments owned by the Institut Cartographic de Catalunya (ICC), an Optech ALTM 3025 airborne lidar and a Riegl LMS-Z210 terrestrial lidar. The second instrument has been used in static positions and in dynamic mode (Talaya et al., 2004), however, the measurements done in dynamic mode had not been used to generate the final terrain model.

The data processing and terrain model computation has been done using different programs, some of them commercial and some of them developed at the ICC, with successive approximations in a rather tricky way that is explained in the paper.

2.1 Airborne lidar data

The airborne lidar flight was done on July 28th, 2003 and consisted of seven parallel strips with 20% overlap that fully covered the area of interest. These strips had a half scan angle of 7º (setting A in table 1). The almost vertical pointing of view reduced the probability of occlusions due to the mountains at the bottom of the canyon. Two additional strips were flown one over each side of the canyon with the purpose of getting more points distributed on the vertical walls of the mountains. These additional two strips had a half scan angle of 20º, the maximum allowed by the instrument (setting B).

	Setting	
	A	B
Velocity (knots)	120	120
Half Scan angle (degrees)	7	20
Scan frequency (Hz)	35	20
Pulse repetition (Hz)	25,000	25,000
Height above ground (m)	1300	1300
Strip overlap (%)	20	-
Ray divergence (mrad)	0.2	0.2
Point distance along (m)	0.88	1.54
Point distance across (m)	0.89	1.51
Footprint (m)	0.260	0.260

Table 1. Flight parameter settings.

Finally, a cross strip was flown over the rest of the strips and also over a control field in a flat area. A set of 48 points was measured with GPS-RTK on the control field with an estimated accuracy of 3 cm (1 sigma) to be used as ground control.

Systematic errors in elevation for each strip were reduced using the strip adjustment procedure that is routinely applied to airborne lidar data at the ICC (Kornus and Ruiz, 2003). Corrections between –1.3 and 13.6 cm were applied to the elevations in each strip. Applying this approach accuracies in the order of 10-15 cm in elevation are usually obtained for lidar points in flat areas measured from 2300 m altitude above ground.

Last echo airborne lidar points were classified into ground and non-ground points with the help of TerraScan software

(Terrasolid, 2004a). As a first approach to the terrain model, a triangulated irregular network (TIN) was computed taking into account only the ground points with TerraModeler (Terrasolid, 2004b), from the same company. As most of the computer programs usually used in terrain modelling TerraModeler builds 2.5D surface models. The name 2.5D is applied in computer graphics to those special kinds of surfaces were each point in the horizontal domain has only one corresponding elevation. Therefore, the elevation in these surfaces is a function of the planimetric coordinates (x,y).

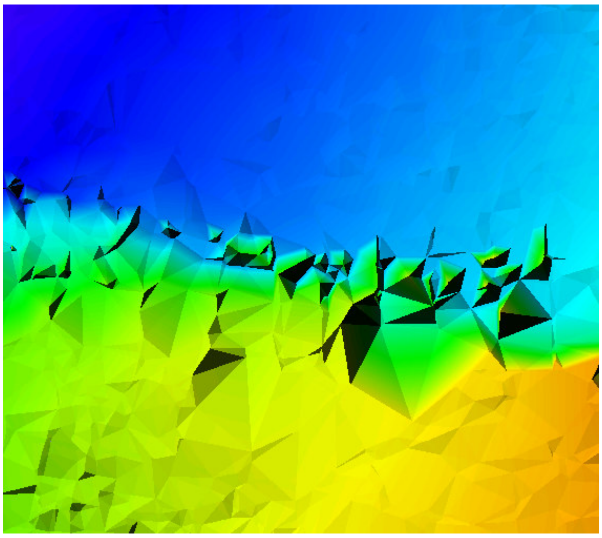

Figure 1. Spike artefacts in an overhang area

This surface model is not appropriate to represent overhang areas where a single (x,y) point can have three corresponding elevation values and in these regions characteristic spike artefacts appeared (Fig. 1).

Usually, after automatic classification some editing is required to remove residual vegetation that the automatic classification has wrongly classified and that has been included in the terrain model. The classification algorithm employed by this program is based in a combination of the opening filter from mathematical morphology (Serra, 1982) and a filter similar to the slope filter (Vosselmann, 2000). The presence of vegetation in this very steep terrain confused the program very often and an intensive editing work was required. The tops of many hills had also to be checked during the editing phase (all those hills with a width smaller than the kernel size of the opening filter).

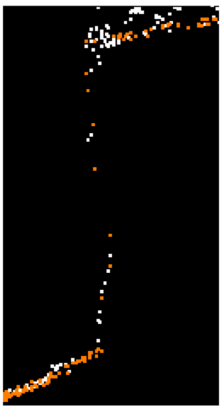

Figure 2. Lidar points in an overhang

With the 2.5D model an approximation to the real surface was done replacing the overhang areas with almost vertical walls.

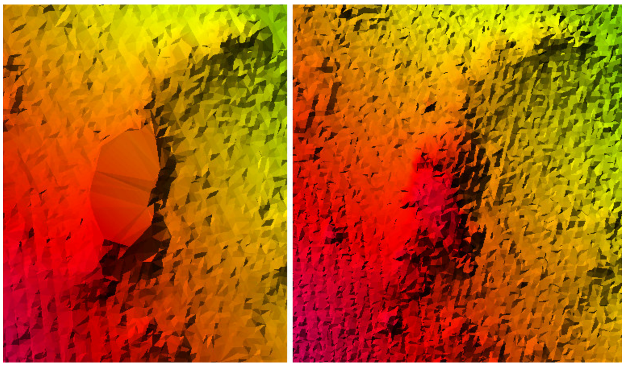

Figure 3. Editing of the hills.

The surface was edited to remove the spikes that appeared in that areas (Fig. 1 and 2). The editing operations do not remove any point from the data set, only the class labels of the points involved in the editing operation are changed from one class to another and the total number of points remains unchanged. The editing process continued until the resulting 2.5D model was considered to be an acceptable representation of the bare earth surface (without vegetation), within the limitations of 2.5D surface models. This intermediate surface (Fig. 4) was employed for two different purposes: The first one was to detect the areas where the density of aerial data was too low or where data gaps appeared due to occlusions (Fig. 5). A terrestrial lidar survey campaign was carried out to cover these areas. The second use of the intermediate 2.5D surface was to improve the orientation of the terrestrial lidar data.

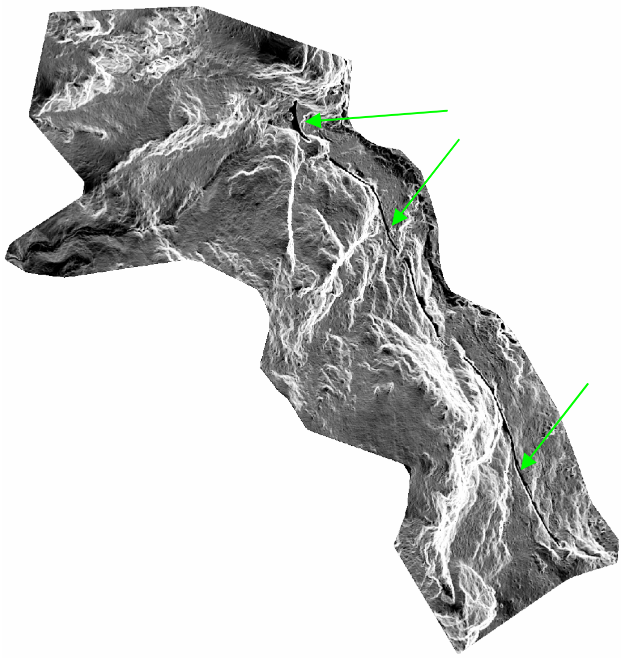

Figure 4. Slope map of the 2.5D surface model. The arrows show the location of the railway track.

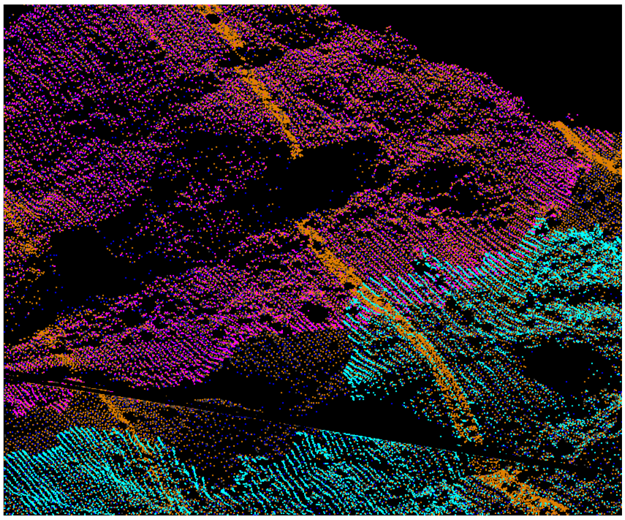

Figure 5. Gaps in aerial lidar data. (colors according strip number).

2.2 Terrestrial lidar data

A local network was measured consisting of 13 points linked to Fontalba GPS point (290079002). This point was measured from Puig d'Estremera geodetic point (288080001) and Llívia GPS permanent station (284074001).

Five sites were selected to station the terrestrial scanner in front of the areas showing important gaps in airborne data. The terrestrial lidar survey was done during two days, on September 8th and 9th, 2003. Target reflectors were installed and their coordinates were measured with GPS and total station. The known coordinates of the targets allowed for a first approximation to the point cloud orientation of each scan but, as they were closer than the area to measure, the angular accuracy of this orientation was poor. In order to improve this preliminary orientation, surface matching was employed. A grid surface was computed for each terrestrial scan scene and another was computed from the aerial points classified as ground in the 2.5D model. This last surface was considered as the reference surface. The orientation of each terrestrial scan scene was adjusted to match the reference surface obtained from the airborne lidar points. For each terrestrial lidar point cloud a translation and a rotation were computed to minimise the distance between the corresponding grid and reference surfaces. This process was done with Polyworks software from the company Innovmetric.

Once the orientation of the terrestrial points had been refined they had to be classified but the available software was not able to process data in almost vertical walls. The slope filter assumes that the terrain slope is not too high and those points that increase the surface slope over a certain threshold are supposed to belong to the vegetation. This assumption failed completely in this area. To circumvent this limitation a global rotation was applied to all the lidar points to reduce the average slope of the terrain. The point cloud was rotated by 30º around an axis approximately parallel to the railway track. After that, it was possible to add points to the previous set of ground points by a fast editing procedure using the standard tools available in TerraScan. The amount of available ground points in areas with data gaps increased and the model improved (Fig. 4). After editing, the inverse rotation was applied and all the points that had been classified as ground were used to build a 3D triangulated surface model.

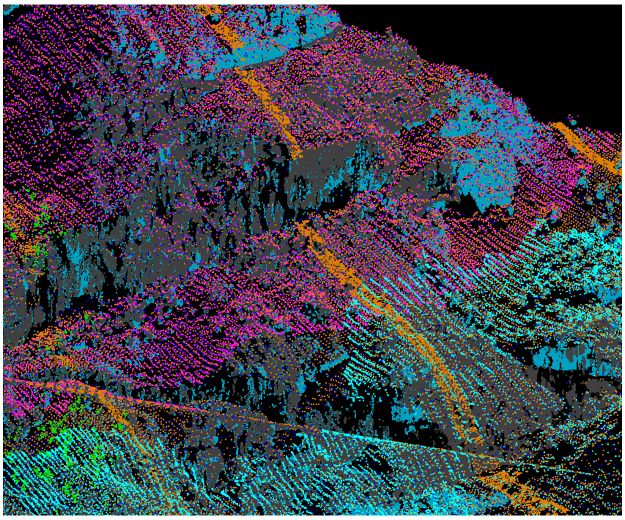

Figure 6. Gaps covered with terrestrial lidar data.

A dynamic survey was also carried out with the terrestrial laser to acquire some additional information about the rail path. Data was captured with the terrestrial LIDAR instrument integrated in the GeoMòbil, a Land Based Mobile Mapping System (Talaya et al. 2004a and Talaya et al. 2004b). The GeoMòbil was mounted in a train platform that was driven by the train. In order to collect different parts of the track various paths were completed with the scanner mounted in different orientations. The GeoMòbil system includes GPS/IMU sensors for the direct orientation of the terrestrial laser scanner and of two digital frame cameras. As the static laser campaign proved to be enough to fill the data gaps, the dynamic laser survey was not used in this project.

3. RESULTS AND CONCLUSSIONS.

Aerial and terrestrial lidar have been complementary in this project. Aerial lidar data has a high precision in height on flat areas and it is expected that its precision will decrease with slope due to the worse precision of angular measurements and footprint size. The usually achieved accuracy in elevation in flat areas is around 10 cm. In contrast, the standard deviation of the points in Easting and Northing was expected to be around 65 cm. This figure was computed from the relation σ=H/2000 were H is the height above ground according to system specifications from Optech. The footprint has a diameter of approximately 26 cm from 1300 m above ground (Baltsavias, 1999). The largest error source for the terrestrial lidar is the footprint size. At a distance of 300 m, the beam divergence of 3 mrad corresponds to a footprint diameter of 90 cm. Angular errors are less important. The elevation angle is measured with a resolution of 0.036º and the azimuth with 0.018º. At this distance, the precision in elevation is 9 cm while in azimuth it is twice that value. Precision in range is 2.5 cm. Both lidar systems had a better precision in the laser direction. The almost vertical mountain walls were scanned from sites in front of them. It is expected a high accuracy of terrestrial lidar because the laser ray direction was close to the surface normal. Combining aerial and terrestrial lidar it has been possible to obtain a product of better quality than achievable using only one of these techniques.

Horizontal cross sections with 1-meter interval were computed from the 3D surface model. The cross sections surface representation is simpler to manage and render with standard CAD software.

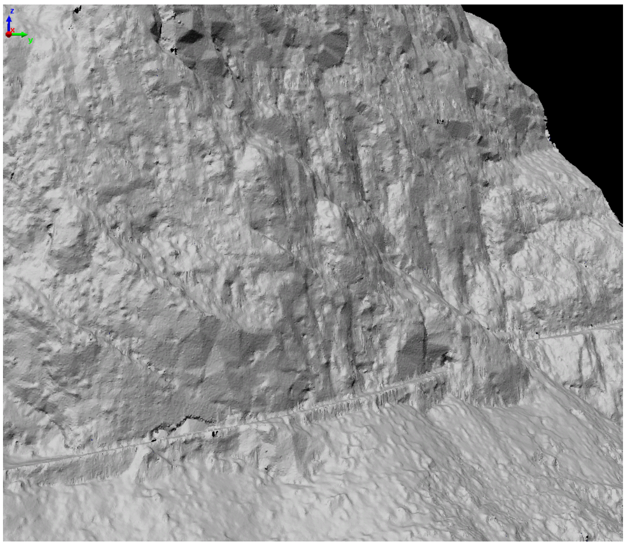

Figure 1. Perspective view of the 3D surface model (detail).

Figure 2. Photograph of the tunnel in Fig. 6.

As an attempt to evaluate the quality of the model, the points from the local network were compared with the model. Only 6 of the 13 points fell inside this study area. They are too few points to consider the results significative and they are also poorly distributed: Points 4000-4002 are very close one of each other.

Number	Easting	Northing	Known H	Laser H	ΔH
2001	431226.611	4691455.977	1501.910	1500.986	-0.924
2002	431239.628	4691461.193	1499.961	1494.111	-5.850
4000	431555.676	4690889.853	1458.325	1458.053	-0.272
4001	431567.400	4690893.977	1459.470	1459.192	-0.278
4002	431572.284	4690888.450	1460.905	1460.510	-0.395
6000	431522.593	4690889.032	1506.640	1506.695	+0.055

Table 2. Differences between final DTM and GPS network points

Point 2002 was measured on a bridge and in the model this construction was removed. Without considering point 2002 the statistics of the results are:

Number of points:	4
Average of the errors:	-0.223 m
Standard deviation:	0.193 m
RMS:	0.279 m

An independent survey to evaluate the quality of the model is pending at the time of writing this paper.

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