DEM Generation based on UAV Photogrammetry Data in Critical Areas

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Keywords: UAV Photogrammetry, DEM, DSM, GIS, Filtering, Landscape Heritage.

Abstract: Many Geomatics technologies based on the use of terrestrial and aerial sensor offer a significant support and new potentialities in term of quickness, multi-scale precision, cost-cutting, and in short, sustainability. The 3D data and mapping products, above all the large-scale ones derived from aerial acquisitions (e.g. Unmanned Aerial Vehicles, UAV) can be gradually adopted even when the context is not enough accessible or standard airborne data does not fulfill the requested resolution and accuracy.

Starting from the availability of large scale UAV data, the paper is mostly purposed to examine the use of tools aimed to generate DEM (Digital elevation model) from DSM (digital surface model) obtained from UAV flights. In literatures many application concern the point cloud data generation from aerial photogrammetry or airborne laser scanner. Several different filtering approaches and algorithms (filtering point along density, direction, slope) are used to derive bare-Earth, but in the test case, the high level of detail of objects, together with the complexity of high slope of ground impose some adaptation.

The test is included in a decision-making processes concerning the promotion of Alpine landscape leaded through a project of sustainable mobility. Therefore the DEM generation is used to foresee a possible and sustainable path of the railway rack, achieved by a simple multi-criteria analysis performed by Geographic Information Systems (GIS) tools. In the end an important aspect of the test is the use of open source GIS tools employed in the experience.

1 INTRODUCTION

Nowadays the documentation technologies based of advanced Geomatics tools offer a significant support in maps updating, in term of quickness, precision, cost-cutting, and in short, sustainability.

The use of Unmanned Aerial Vehicles (UAV) offers almost new potentialities with high detail value, and related applications truly become progressively affordable, even where the context is not enough accessible for traditional terrestrial survey techniques. (Aicardi et al., 2014)

A project of sustainable mobility in mountain framework (a rack railway) have been analysed and improved through the setting up of an integrated project of 3D landscape documentation and modelling. This has been achieved using aerial photogrammetry by drone and 3D data treatment and spatial analysis in GIS. In landscape documentation, the use of UAV and integrated sensors, together with the application of more traditional Lidar terrestrial and aerial techniques, perform very interesting results in the context of large-scale mapping and in terms and effectiveness.

In case of complex documentation applied at specific valuable zones of the built and natural heritage, that are located often in arduous areas very scarcely accessible, the previous issues lead us to choose specific survey tools able to reach great detail and at the same time, a relatively large area of coverage. (Boccardo et al., 2015).

2 DEM FROM UAV

The UAV approach can be useful to produce spatial-temporal high-resolution models, in competitive period and resources, that providing useful 3D data for many GIS monitoring applications, as georeferenced information at large-scale derived from orthoimages and DSM (Yastıklı et al., 2013).

The main application of UAV survey producing spatial data for GIS modelling and analysis are the territorial, geological, urbanistic, agricultural and forestry ones (Perko et al., 2015; Höfle et al., 2013; Susaki, 2012; Grenzdörffer et al., 2008). Even in the architectural and archaeological contexts the use of UAV become increasingly important and common, adding to essential to achieve accurate metric documentation, integrate

Sammartano, G. and Spanò, A.
DEM Generation based on UAV Photogrammetry Data in Critical Areas.
In *Proceedings of the 2nd International Conference on Geographical Information Systems Theory, Applications and Management (GISTAM 2016)*, pages 92-98
ISBN: 978-989-758-188-5

different source geospatial data, as well as categorize and store spatial-temporal information. (Themistocleous et al., 2015; Rinaudo et al., 2012)

For investigation purposes about land forms the use of UAV acquisitions enables to obtain high detailed morphological data of the area, that can be processed in order to generate a DSM, comparable to the Lidar ones; with these results we can proceed in many cases to update effectively traditional cartography and numerical data. However, the 3D information regarding the earth surface need to be processed for the derivation of a useful DEM, without the interference caused by vegetation cover and buildings. In literatures many application in these direction concern point cloud data from aerial photogrammetry or airborne laser scanning and different filtering approaches and algorithms. (Hosseini et al., 2014; Korzeniowska et al., 2011, Chen et al., 2007; Masaharua et.al., 2002).

In many cases, the bare-Earth extraction can be obtained with algorithms of point clouds classification and segmentation, by filtering point along density, direction, slope, etc. (Pfeifer, 2008)

This takes moderately a large amount of time of human action in modelling systematic errors, filtering, feature extraction and thinning, up to 60%-80% of the processing time (Sithole, 2004).

This becomes more complex in the case of areas where the ground is not flat and common algorithm of analysis in high density urban, peri-urban or forestry areas (Perko, 2015. Susaki, 2012, Korzeniowska, 2011), that recognize objects according to their variation of high and density from ground, as an almost plane level do not work effectively. In past year, some procedures have been developed for slope land applications (Ismail, 2015. Hosseini, 2014), and adaptive algorithms where the threshold varies with respect to the slope of the terrain have been implemented (from the proposed one by Sithole, 2001).

3 THE EXPERIENCE ON ALPINE SLOPES

The overall experience of high scale mapping of the hamlets in the Castelmagno area (Piedmont, Italy) had numerous purposes, combining terrestrial scanning and low aerial acquisition with the aim to achieve multi-scale models. It's not objective of this paper the description of used instruments and techniques, since we are going to evaluate the use and processing of DSM derived from the UAV flights. The DSM and orthophoto generation have been accomplished by Structure from Motion (SfM) combining photogrammetry and computer vision methods. In spite of the availability of two flights, the first one from an hexacopter flying at the height of about 70 m. and a second by a fix wing Ebee drone flying at the height of 120m, we are going to consider only the second source. The next results are the starting point of the present work. Covered area: 2.43 Km^2, ground resolution: 0.11 m/pix, camera stations: 544, Tie-points: 1044668 GCPs residual: 2.5 pixel, CPs residual: 3 pixel

3.1 The Need of Large Scale Map Updating

The placement of a railway rack as a tool of local development has been designed to provide a large fruition, satisfying a tourist need and a private use.

The feasibility study expects that a path connecting three hamlets could promise a process of repopulation of the area in order to re-establish the main economic activity as desired.

So the railway rack has to cross in a transverse direction the hydro-geological basin of Valliera, which is a tributary of the Grana River. The departure station is designed to be placed in the Colletto village (1277 m above sea level), the path has to descend fast toward Croce (1179 m a.s.l) crossing the riverbed and climb the slope to Campofei (1542 m a.s.l.)

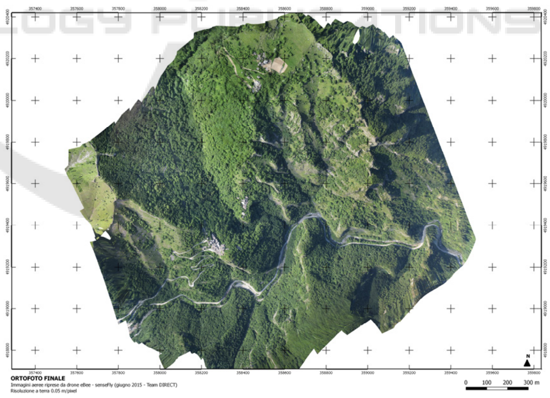

Figure 1: UAV orthophoto of the test area; the arrows show three villages to be connected by the railway rack.

First of all, the challenge to foresee a possible and sustainable path of the railway rack, need a very detailed DTM (Digital terrain Model), more accurate than the regional 1:10000 scale DTM. Next paragraphs are devoted to describe a DTM generation from UAV DSM, using open source techniques. Then a best routing search is presented in the last paragraph.

3.2 DSM to DEM Conversion

The aim of the first step of the test is the use of UAV data to obtain a morphological model of the project area, starting from the DSM, analysing and eliminating objects surfaces, and finally generating a DEM. The difficulties are attributed to the complex mountain context in with a forestry covering very diffuse was in many zones very thick. Furthermore, the steep gradient of the mountain slope added a robust bond to the raster analysis based on simple available algorithms distance range based.

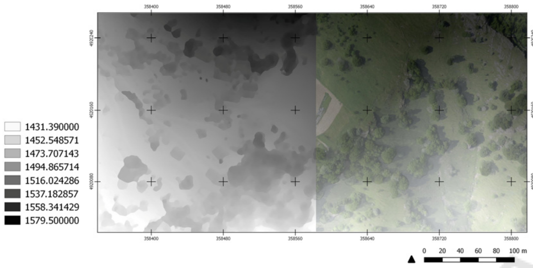

Figure 2: The DSM of the test area, compared with the orthoimage from the drone flight: it is distinct the assorted presence of vegetation cover in a very slope terrain.

3.2.1 Managing UAV Data in DSM Filtering: Different Approaches

The operational approach to derive a DEM from the DSM calculated from the UAV images was based on processing raster data by *filtering* algorithms.

The test was planned on the Open-Source platform QGIS (QGIS 2.10 Pisa, http://www.qgis.org/en).

The software offers many simplified and advanced processing tools, also with algorithms extension from GRASS Gis and SAGA Gis. In the test both of them have been used to setting up the DSM analysis.

The two raster approach proposed started from a base-objective, that is to recognise and eliminate non-coherent objects like buildings and wooden covering on the soil. It can be achieved with direct application of Raster filters, but not easily suitable because of the slope or, indirectly operating a multiple-step workflow of raster calculation and modelling (Cimmery, 2010)

DTM Filter Slope-based on SAGA GIS, allows recognizing object according to input data of search radius and terrain approx. slope. After several attempts, the best combination of values for the area have been: terrain slope: 30%. Search radius: 20. The output is a double divided raster data, with detection of *Bare Earth* (figure 3). This result is not enough appreciate, despite high input values, because of the internal area of *removed object* profiles that are still tree and building mass.

Morphological Filter on SAGA GIS, manages to smooth the raster DSM according to a search mode (circle or square) and according to 4 algorithms (dilation, erosion, closing, opening). The best fitting algorithm to model the area have been the erosion filter on circle mode with radius 50.

Gaussian Filter on SAGA GIS allows a filtering of the raster data according to the Gaussian histogram, imputing the Standard deviation.

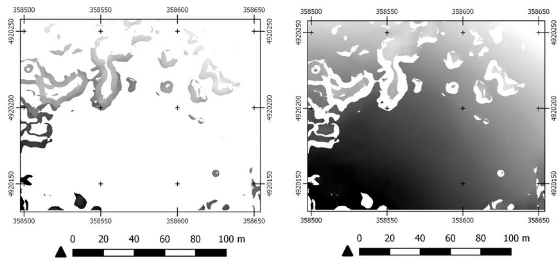

Figure 3: Example of Removed objects and Bare-Earth, the output from a DTM filter slope-based.

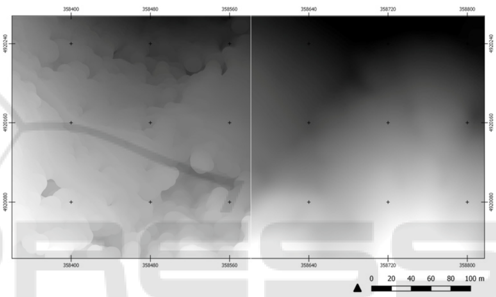

Figure 4: (Left) One of morphological filter outputs applied in test area with erosion 50 rad in circle searching mode (right) Gaussian filter STDEV 20, radius 70.

3.2.2 Helpful Approach for DEM Conversion

The proposed workflow tries to integrate some procedures of raster management in order to identify and remove trees and building, understood as discontinuity in the trend of mountainous terrain sloping. In this sense the Ruggedness Index have been applied to the threshold suitable to maximize the finding of objects on the area. Then a buffer area from 3 to 5 meters have been identified, that tries to include all the items to be deleted from the model.

Afterwards a cutting mask have been created to remove from the DSM incongruous elements. After this step, the following actions have been directed to fill hole after the cut and compare and assess the result of final DEM with the original DSM. (Fig.10). Even if some few residuals of final DEM points close to trees and buildings are still high, we can consider the valuable result of the surface interpolation and objects removing, taking into account the critical situation of the soil morphology.

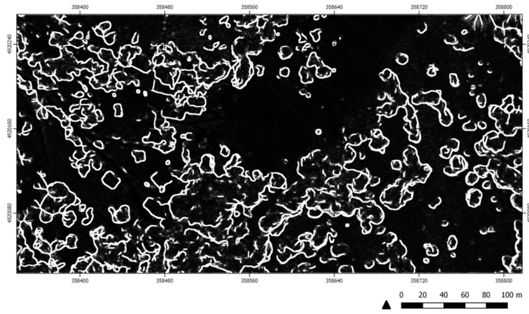

Figure 5: Applying the Terrain Ruggedness Index algorithm to de DSM: best-input value 0.05. Reclassification of the raster with binary values (0-1) to perform buffer analysis on a unique value.

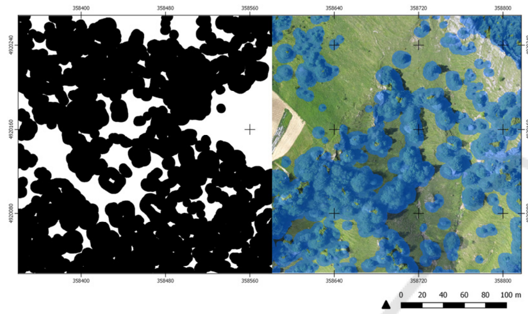

Figure 6: (Left) Creating a buffer area around objects by using the *Proximity* (Raster Distance) *analysis* tool. (Right) Identification of trees and buildings and vectorialization of raster in shape file layer.

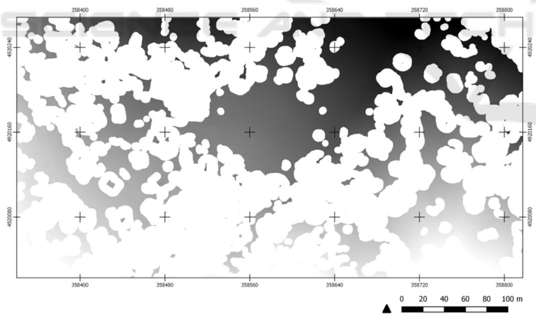

Figure 7: Recognized objects after **raster cut** on the DSM.

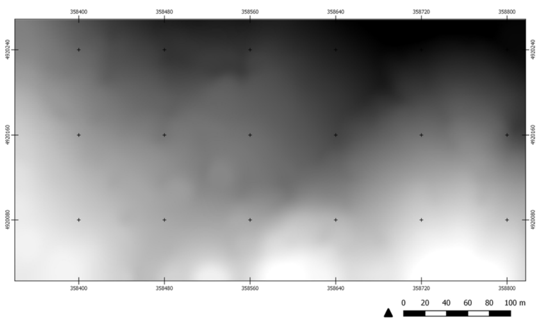

Figure 8: The closing gaps filters on SAGA GIS according to tension threshold 0.1.

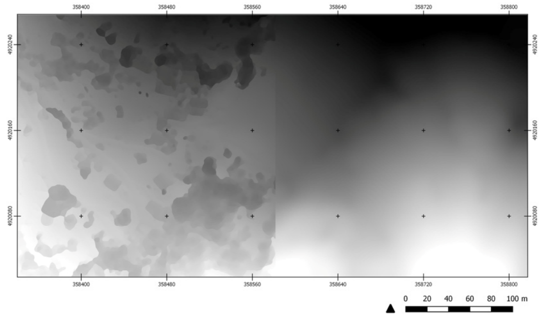

Figure 9: Comparison between the DSM generated from UAV image processing and the final DEM obtained from GIS raster analysis and filtering.

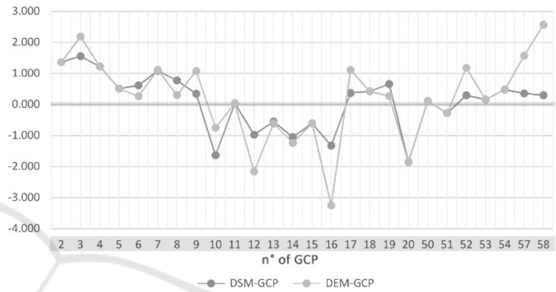

Figure 10: Residuals of DSM/DEM from GCP. The elaborated DEM, differs from DSM mainly on rich vegetation and built-up areas.

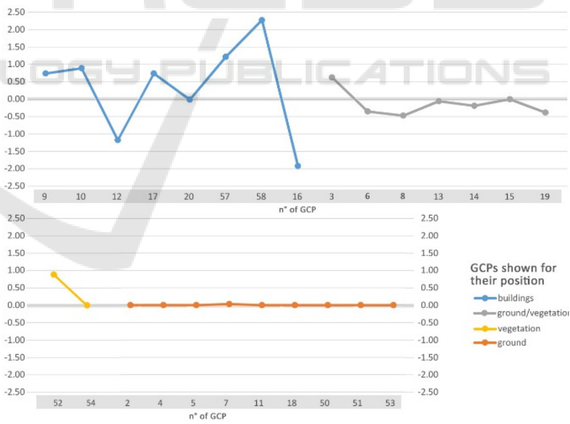

Figure 11: DEM residuals of on each GCP measured by GPS survey, clustered by their position in the area. Higher residuals between DEM and GCP are near buildings and vegetation.

3.3 Path Hypothesis

3.3.1 First Shortest Path Proposal

Based on an edited and evaluated DEM, the first aim of the has been the assessment of suitability of the shortest distance route, that correspond in a first approximation to the cheapest.

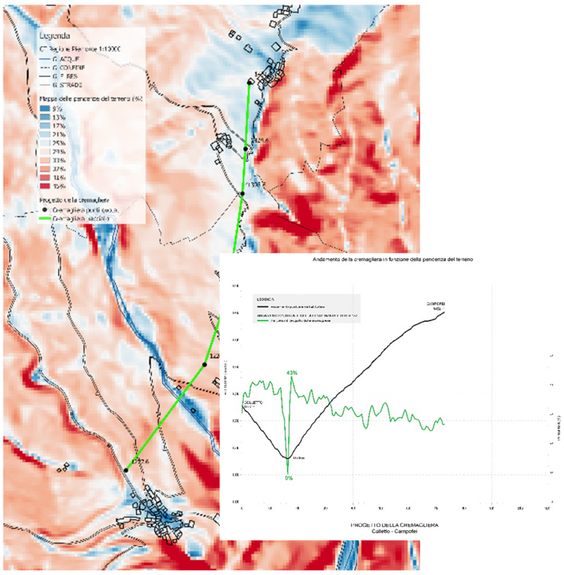

Figure 12: Slope map in red range color with firstly designed route of railway rack. (green). (right) Comparison of elevation differences (black) and slope values (green) of the straight path connecting the villages.

Safety first this straight path hypothesis has been compared with the regional map of landslide risk. Fortunately, the presence of a ridge submit to risk a face immediately next to slope of designed path, in the west direction.

The slope map generation, derived from the available high scale and accurate DEM, has brighten the presence of very precipitous slopes, in fact very often the hamlets have a medioeval or XVI- XVIIth foundation, so they are grasped to stone walls that are typical of the geo-morphological characterisation of the Valle Grana.

3.3.2 A Simple Multicriteria Analysis to Search a More Suitable Path

The abilities offered by the continuously expanding GIS technology and by the increasing availability of digital georeferenced data have been highly develop the use of multi-criteria spatial analysis to support land planning. (Botequilha-Leitão, Ahern, 2002).

Close to the riverbed, the slope reach to 43% and even worse many railway rack system are not able to divert the slope.

Indeed some innovative systems in use in alpine environment are able to reach very high slopes, even 40%. (Regis, 2015). The graph of figure 12, show the terrain profile highlighting the level differences among villages, contemporary with the slope values that reaches 43% close to the river.

Moreover, the GIS-Multi-criteria Decision Analysis is largely used to support best location analyses in very many fields of application. In this paper, we are going to use an example of a so called weighted overlay performed by raster grids, with the purpose of providing a test for the achieved UAV DEM.

Surely, the stronger constrain for searching a sustainable and best route is the slope, and we know that ordinary types of railway rack systems are able to face slopes around 20%, but some innovative types provide equipment with a successful power facing slopes higher than 40%. This last type will be taken into account for the best route assessment.

The slope raster map has been reclassified imposing four class of slope: from 0% to 20, from 21% to 35% , from 35% to 40%, and more than 40%. (fig. 13). The last class will be considered highly adverse.

The shortest route cross the valley using almost the steepest path, and the change of slope direction close to the riverbed is particularly difficult. Another considered parameter is the inclination the railway rack route chasing contours direction; the DEM grid has been reclassified in four classes, selecting the breaks value in order to obtain an area near the river to be excluded, or considered as highly adverse area.

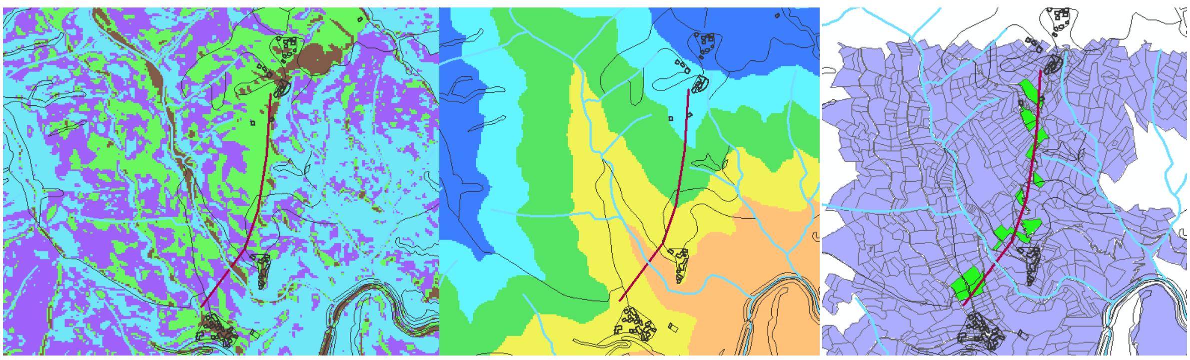

Figure 13: a. four classes of slopes grid map. b. five classes of elevation interval c. Parcel whose owner participate to the railway rack project.

(Orange in fig. 13b). The last parameter involved in the process are parcels whose owner has agreed and participated to the projects or not.

In the weighted overlay analysis, the three maps have been different level of influence. The slope classes had been an influence of 70%, the grid map connected with contours had a 20% influence, and the last one has been considered with low influence (since the administrative institution could give some benefits for the project acceptance).

The final result of weighted overlay is shown in figure 14, where *green* pixels show a highly suitable area to accommodate the railway rack, the *dark yellow* area are on average suitable, and the last class, in *red* pixel correspond to unfavorable area for the railway rack.

In Figure 14 the shortest and steepest path (*red*) has been compared with a manually traced route (*green*), avoiding unfavorable areas.

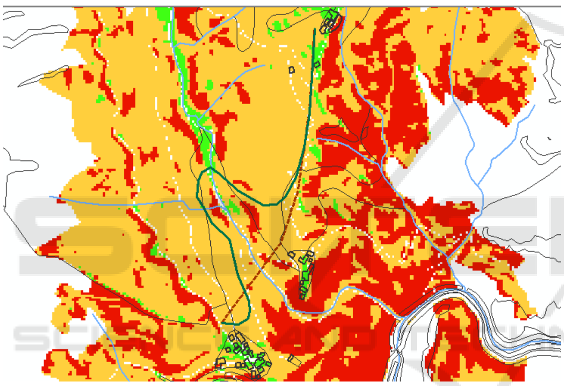

Figure 14: The grid maps visualize by different color the different suitability of areas to host the railway rack passage.

4 CONCLUSIONS

The increasingly studies as well as diversified applications of UAV photogrammetry survey make consider it a very suitable method for high scale quick and low cost mapping. Many processing techniques and platforms can manage today DSM derived from UAV processed images; and we are witnessing to a strong effort in order to adapt strengthened tools manage this kind of data in critical areas.

This paper is aimed to prove that the use open source tools to achieve the analyses and can be a significant step toward that knowledge circulation and sharing about geospatial data overall. Surely, some more enhancements need to be implemented in terms of big objects filtering tools. Some uses promise to offer further developments, especially in benefit that the GIS-based landscape modeling can offer to the analysis and decision-making phases in the ever more topical background of land use planning and heritage.

ACKNOWLEDGEMENTS

The UAV flights have been performed by the DiRecT Team (Disaster Recovery Team), involving Aicardi, I.. Chiabrando, F. Donadio, E. Lingua, A. Maschio, P. Noardo, G. Sammartano, F. Spanò.

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