Environmental Risk Monitoring by Satellite, LiDAR, Topographic and UAV Photogrammetric Survey Techniques

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Keywords: DSM, LiDAR, GNSS, Photogrammetry, UAV

SUMMARY

In this work, several survey techniques and methodologies applied in a limestone quarry have been compared in order to describe the obtained accuracies, precisions, taken precautions, operative difficulties and costs.

According to the Apulia regional mining and quarrying planning rules (Piano Regionale Attività Estrattive, PRAE) every year the quarries owners have to update the Quarry Cadastre Geographic Information System. To do this, some statistical schedules and topographic surveys are required for the PRAE Control and Management Office.

Several surveys techniques have been applied using low cost instruments (Total Station and GNSS receiver) and other less cheaper ones that are a LiDAR and UAV photogrammetric surveys. For each method different algorithms have been used in order to build the Digital Terrain Models (DTM) which eventually have been compared. This analysis shows that these DTM obtained are almost perfectly comparable.
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1. INTRODUCTION

The study area is a quarry located in the rural area of the city of Turi (BA) characterized by Mesozoic carbonate rocks, which are locally covered with some alluvial-eluvial red soil deposits. The quarry is being used by more than 50 years; it has some sub-vertical walls on the east side and no vegetation. In similar study cases, it is not convenient doing LiDAR or photogrammetric surveys, that are complex and expensive, and then it is interesting to evaluate the use of low-cost methodologies. Taking into account the environmental peculiarities, such as low vegetation, sharp breaklines, etc., the results as well as the modeling procedures will be analyzed and validated in order to estimate the extracted volumes and those to be removed.

Fig.1 Topographic survey

2. REGULATIONS

The Apulia Regional Quarry Cadastre is a dynamic tool linked to the mining evolution and it records some information like historical trend, current and prospective productivity. From this point, the spot height map is an element able to support the Quarry Cadastre, because it meets the needs of geographical component information update. The geo-referenced spot height maps (in a UTM33 or WGS84 projection) must return the quarry volumetric shape and the 3D morphological features in a single and quick way.
Mining Activities Service has set some guidelines and standardized procedures to support technicians for the spot height map correct processing.

3. TOPOGRAPHIC SURVEY

The survey operations have been done on 23rd and 29th March 2014; the first step was the relief of 10 fiducial marks coordinates, which are located along the quarry perimeter. These are then used as support points for the others kind of surveys, as indicated in the rules. The spot height map was obtained using a Leica TPS 1200 total station and simultaneously a Leica GS14 GNSS satellite receiver. The relief done by using the total station consists on nine station points and about 600 points, while the one done by using GNSS receiver in RTK mode counts about 200 points. The latter was made by referring to the Apulia region permanent stations network and it was processed with Leica Geo Office software.

![Fig.2 Topographic report](image)

3.1 Interpolation Methods

It is possible to build a regular grid elevation model starting from the spot height map using different interpolation algorithms. In this work “3D Analyst” ArcGIS tool has been used, but other algorithms can be used in relation to the needed result precision.

Basically, there are two kind of methods: the first is a deterministic one, which smooths the model in a certain neighborhood according to different mathematical functions (Inverse Distance Weighting, Natural neighbors, Trend, Spline, etc.) starting from the points height values; the second method is a geo-statistical one which provides a prediction surface that through the autocorrelation expresses the estimate uncertainty or accuracy (Kriging, Topo to Raster).

In order to take in account obstacles, breaklines and abrupt changes in slopes in the survey it is necessary to hand-draw the braklines (or barriers), which establish a discontinuity on the
interpolations. This is the best approach, otherwise the only other disadvantageous option is to increase significantly the points to be measured.

The Inverse Distance Weighting method (IDW) calculates the heights matrix cell value by using the values of the points in the neighborhood. This method is based on the concept of similarity for which points that are very close tend to have the same features (such as height). The Spline method interpolates the feature values building an area of minimum curvature which passes exactly through the input points, adapting to them as a thin layer of rubber. The Natural neighbor method uses an algorithm similar to the IDW and Kriging ones. It allows to know the elevation of a point identifying the nearest height points values and applying a weight such as the "Voronoi polygons" areas associated with them. In a first phase, the Voronoi diagram is made up of polygons associated with each input point. A new polygon is created around the point to be interpolated whose area, compared to the initial ones, is used as a weight in the interpolation.

The Kriging is a geo-statistical interpolation method based on a statistical analysis which has resulted a prediction surface as well as the autocorrelation between points. The latter is a parameter that expresses the prediction accuracy.

Finally, the Topo to Raster method uses an iterative finite differences interpolation technique. It is optimized to have the local interpolation methods computational efficiency, such as Inverse Distance Weighting (IDW), without losing the surface continuity obtained from the global interpolation methods, such as Kriging and Spline.

In this paper, all the models obtained from the several illustrated algorithms are compared. Volume, area (Area_3D) and horizontal surface projection with the reference plane at ellipsoidal height of 318 m (2D Area) were calculated from the extracted patterns with raster cell size of 1 m.

4. LIDAR SURVEY

The LiDAR survey has been done by SIT Company srl, Noci (BA), on 10th May 2014 with the REIGL-LMS-Q680 I sensor on board of the aircraft. The latter has flight at 950 m AGL altitude for more than 980 meters, detecting 4-5 point per square meter for a total of 16’284’743 points.

![Fig.3 LIDAR Survey](image-url)
5. UAV PHOTOGRAMMETRIC SURVEY

The UAV survey was executed on 22th January 2015 in collaboration with SAL Engineering of Modena which has done three flights at about 70 m of altitude with a copter equipped with a brushless electric motor and a GNSS satellite positioning system, that is necessary to determine the photogrammetric lens centers and IMU inertial system for the flight attitude. Nearly 800 nadiral and inclined images were taken with CANON EOS 550D calibrated camera with 18 mpx APS-C sensor. A framework of 15 Ground Control Point (GCP) has been set on the study area and other 3 check points were collected with dual frequency Trimble GPS receivers for error checking.

Fig. 4 GCP framework

The image processing was carried out with photogrammetric and Structure from Motion software (Agisoft PhotoScan) and as a result a cloud of more than a million points were calculated. In the following image the 2D and 3D different GIS DSM overlapping is shown.

Fig. 5 2D and 3D DSM
6. COMPARISONS

6.1 Comparison between Lidar and Topographic surveys

The following table shows the comparison between the survey results obtained from the LiDAR and the standard Topographic survey using the several interpolation methods.

<table>
<thead>
<tr>
<th>TIPO</th>
<th>Area_2D [m²]</th>
<th>Area_3D [m²]</th>
<th>Volume [m³]</th>
<th>Diff.Vol. [m³]</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lidar</td>
<td>64887</td>
<td>83492</td>
<td>1153409</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>IDW_49</td>
<td>65918</td>
<td>89277</td>
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<td>barriers radius 3pts</td>
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<td>IDW_50</td>
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<td>1182669</td>
<td>-29260</td>
<td>no barr. radius 3pts</td>
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<tr>
<td>Kriging_8</td>
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<td>1166399</td>
<td>-12990</td>
<td>radius 3 points</td>
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<tr>
<td>Kriging_9</td>
<td>69761</td>
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<td>1146699</td>
<td>6710</td>
<td>radius 12 points</td>
</tr>
<tr>
<td>Kriging_10</td>
<td>65580</td>
<td>78612</td>
<td>1150187</td>
<td>3222</td>
<td>radius 120 points</td>
</tr>
<tr>
<td>Natural_3</td>
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<td>79609</td>
<td>1118037</td>
<td>35372</td>
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</tr>
<tr>
<td>spline_barrier</td>
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<td>84157</td>
<td>1145817</td>
<td>7592</td>
<td>barriers</td>
</tr>
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<tr>
<td>TIN</td>
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<td>1116583</td>
<td>36826</td>
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<tr>
<td>topo to raster_1</td>
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<td>76189</td>
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<td>no barriers</td>
</tr>
<tr>
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<td>80815</td>
<td>1187234</td>
<td>-33825</td>
<td>barrier</td>
</tr>
</tbody>
</table>

6.2 Comparison between Lidar and UAV photogrammetric survey

The latter results have been compared also with the ones obtained from the UAV photogrammetric survey, that are shown as follows:

<table>
<thead>
<tr>
<th>TIPO</th>
<th>Area_2D [m²]</th>
<th>Area_3D [m²]</th>
<th>Volume [m³]</th>
<th>Diff.Vol. [m³]</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lidar</td>
<td>64887</td>
<td>83492</td>
<td>1153409</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>UAV n.1</td>
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<td>86968</td>
<td>1164151</td>
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</tr>
<tr>
<td>UAV n.2</td>
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<td>93789</td>
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<td>-29471</td>
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</tbody>
</table>

The DSMs extracted were also compared through profiles and cross sections getting an overlap and an almost coincident trend as shown in the following figure:
Fig. 6 Profiles comparison
7. CONCLUSIONS

The results highlighted in the first table show that the best result in terms of volumetric comparison between LiDAR and standard topographic surveys was obtained by the IDW method using breaklines and that the other algorithms, such as Spline and Kringing methods, produce satisfactory results anyway.

The difference between the calculated volume on the DSM extracted with IDW_49 and the volume of the LiDAR reference model is 2935 m$^3$ which represents an error of $0.25\%$. Therefore with appropriate precautions in the interpolation methods choice and in the breaklines drawing it is possible to build digital terrain models with low-cost topographic instruments (total station and GNSS receiver) with a significantly reduction of costs respect with a Lidar survey.

In the second table is shown that the photogrammetric DSM, thanks to the UAV and the new Structure from Motion algorithms achieves satisfactory results: the difference between the two volumes is 10742 m$^3$ with an error of $0.93\%$.

REFERENCES

BIOGRAPHICAL NOTES

MAURO CAPRIOLI is Full Professor in "Topography and Cartography" (ICAR-06) at the Department of Roads and Transportation of the Polytechnic of Bari, in which he is also Responsible for the "Topography and Cartography" Laboratory.
From 1997 he is President of the Degree Course in Engineering of Infrastructures, Polytechnic of Bari.
Since 1985 he is coordinator of the researches carried out from the local unit of “Topography and Cartography” of the Polytechnic of Bari.
He is responsible of conventions of research with public agencies (ASI) and private companies in the field of the land survey also by means of GPS (Global Position System), of Photogrammetry and Remote Sensing aimed to the production of Cartography and GIS projects, of special surveys for environment and territory.
He is advisor of Public Administrations (Regioni, Province, Comuni, etc.) for the provision of Standards and Norms in the field of Digital Cartography and Geographic Information Systems, the execution of ‘Cartography and ‘Civil Engineering Great Works’ tests and controls.
He is President of Bari Section of S.I.F.E.T. - Italian Society of Photogrammetry and Topography, of which he is fellow of the National Directive.
He is Member of A.I.T. - Italian Association of Remote Sensing.
He is Member of the editorial board of the national scientific review “Bollettino SIFET”.
He is Reference referee on behalf of the review ”Terra Nova - Blackwell Science”.
The scientific activity, testified from over 70 publications on national and international conferences and journals, has essentially been turned to the sectors: deformations control and monitoring, geodetic and navigational GPS, geodesy, treatment of the observations, applied photogrammetry, cartography, GIS and remote sensing.

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