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Automatic analysis of terrestrial laser data: The application to a rock cliffs instability in the Dolomites (Eastern Alps- Italy)

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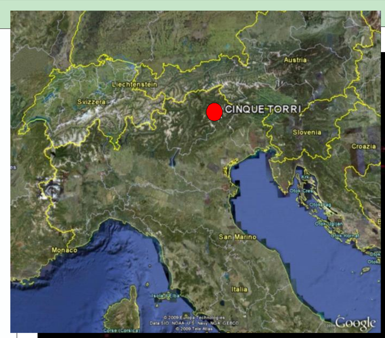
Introduction

Terrestrial laser scanner (TLS) techniques are nowadays a powerful tool to acquire accurate geometrical models of discontinuous rock masses and to detect relative displacements of unstable zones through the use of multi-temporal images. The acquired data are represented by a point cloud, made up by millions of points, each characterized by x, y, z values and by intensity scalars or mapped RGB colourization via photo coupling.

This study concerns the analysis of the geomechanical behaviour of the instable rock cliffs formed by the Cinque Torri group in the Dolomites (Italy).
The applied methodology is based on TLS data processing by means of the experimental software **Point Cloud Mapper (PCM), (Vosselman, 2004)**, that allowed automated structural discontinuity analysis of the Torre Inglese.

Case study : the Torre Inglese (Cinque Torri group)

The geomorphology of the area is strongly influenced by the tectonic structures that resulted from the Alpine orogenesis and the geotechnical contrast between lithologies. Several rock cliffs collapses occurred in the area. The most recent one is the fall of the Torre Trephor that happened in June 2004. Among the various pinnacles, the most hazardous is represented by the Torre Inglese, an unstable rock tower of about 7800 m3 made up by Dolomia Principale, which reaches up to an altitude of about 2275 m a.s.l.



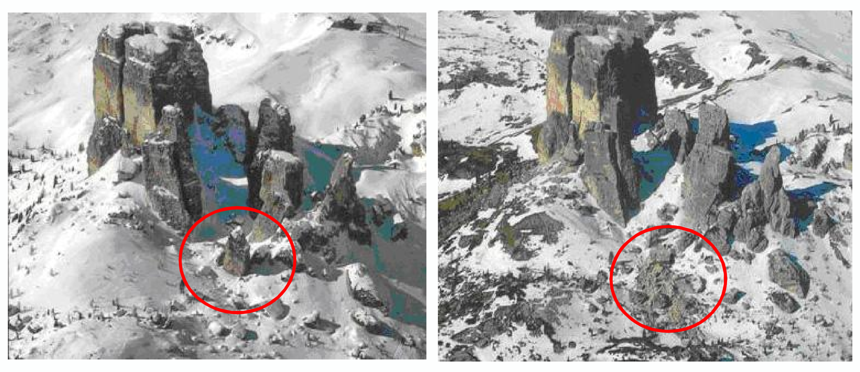


Figure 1. The collapse of the Torre Trephor on June 2004

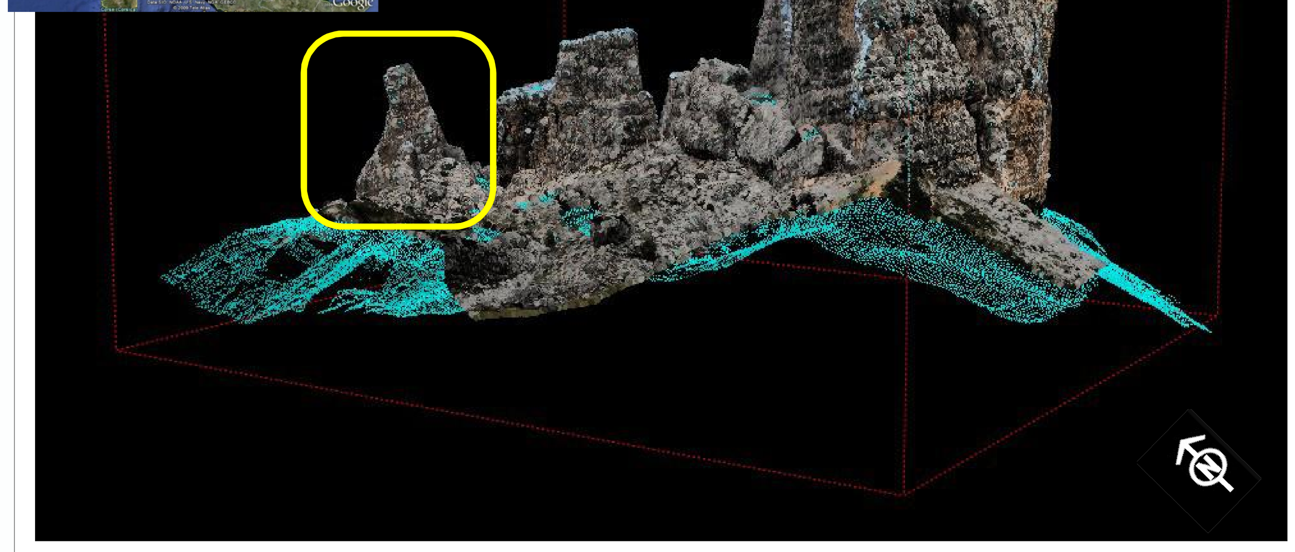


Figure 2. The point cloud data set with the associated RGB values of Cinque Torri (Dolomites-Eastern Alps, Italy). The Torre Inglese pinnacle is the external one on the left.

In June 2008 the pinnacle Torre Inglese was surveyed by a Riegl LMS Z420i terrestrial laser scanner, through six acquisitions of about 4 million of points each. The average spatial resolution related to the points of the cloud is in the order of 11 cm at 200 m distance.
The TLS point cloud enabled a structural characterization of the rock pinnacle using the PCM software

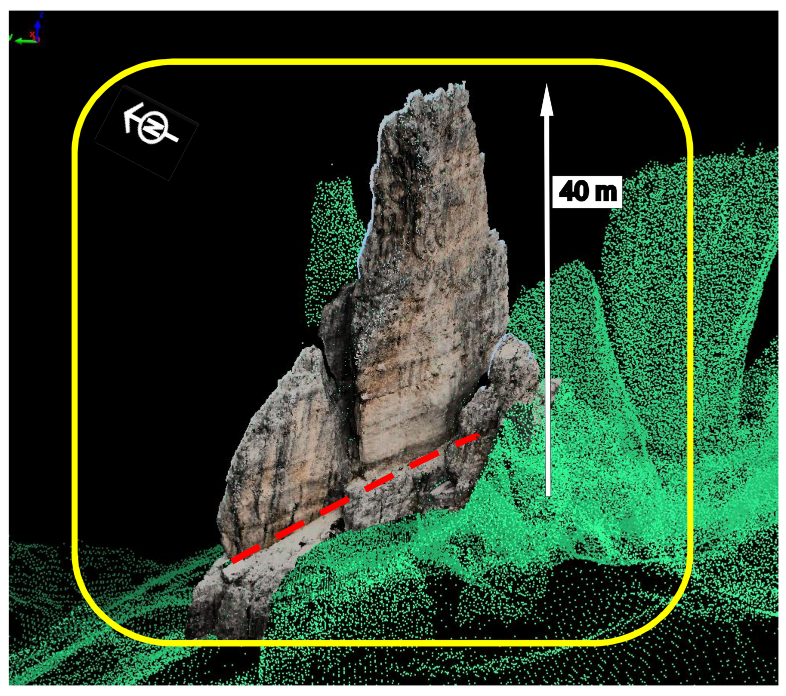


Figure 3. The point cloud of the Torre Inglese pinnacle (*PolyWorks package - Innovmetric*).This rock monolith has a volume of about 7800 m³ potentially unstable. Due to this critical situation a geodetic GPS antenna was installed on its top, while temperature and deformometer sensors were installed on main critical layering planes located in the lower part of the rock tower

Rock discontinuities evaluation

The method, as explained by Vosselmann (2004) and Slob (2005) has its mathematical basis in the 3D Hough Transform in combination with a Least-Squares evaluation. Its objective consist in the determination of the main geometrical properties of the rock discontinuities, the dip angle and the dip direction.

The steps of the REGION GROWING strategy to detect geometrical objects inside the unorganized point cloud:

SPATIAL ORGANIZATION OF THE POINT CLOUD **1**

The spatial organization of the original point cloud data is provided through a (Kd) tree-based structure which allows a quick spatial search in the point cloud and therefore the efficiency of the *direct segmentation approach*

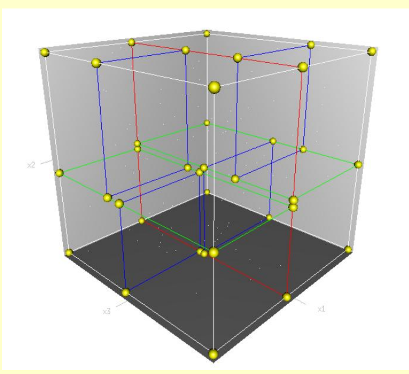


Illustration of the (3-D) K-D tree splitting tree (Tyner, 2007).

SELECTION OF THE SEED POINTS **2**

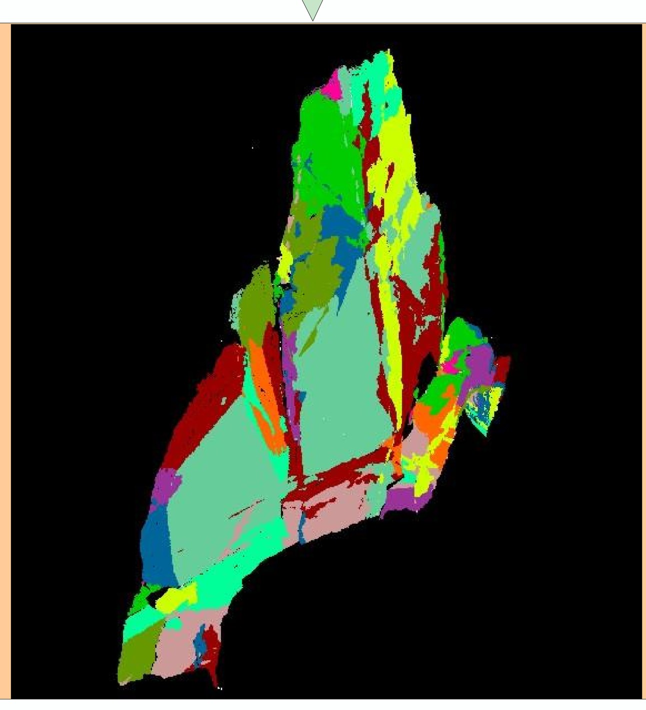
In PCM the **3-D Hough transform** is used to select a good set of seed points from the point cloud that forms part of the plane.
Seed points are random points around which, step-by-step, additional points are sought that fall on the same plane geometry.

DIRECT SEGMENTATION APPROACH

GROWTH OF THE SEED PLANES **3**

The seed plane is then "grown" interactively using a spatial search and then the new plane is every time optimized with Least Square (LS) estimation. The product of the segmentation process is a labelled point cloud, where points with the same label are part of the same discontinuity plane. The **LS method** operates with a region-growing strategy to assign the equation to mathematically determine each plane. This step provides orientation data of all the planes thus allowing the identification of the main discontinuity sets.

The product of the segmentation process is a *labelled point cloud*, where point with the same label are part of the same discontinuity plane (represented with the same colour)



At this stage each plane is defined by an equation that has been assigned by the LS estimation.

The post processing of the segmented point cloud allows to extract the geometrical information of the planes

Figure 5. The segmented (classified) point cloud of the Torre Inglese pinnacle: each segmented set of points represents a potential discontinuity plane.

THE POST PROCESSING

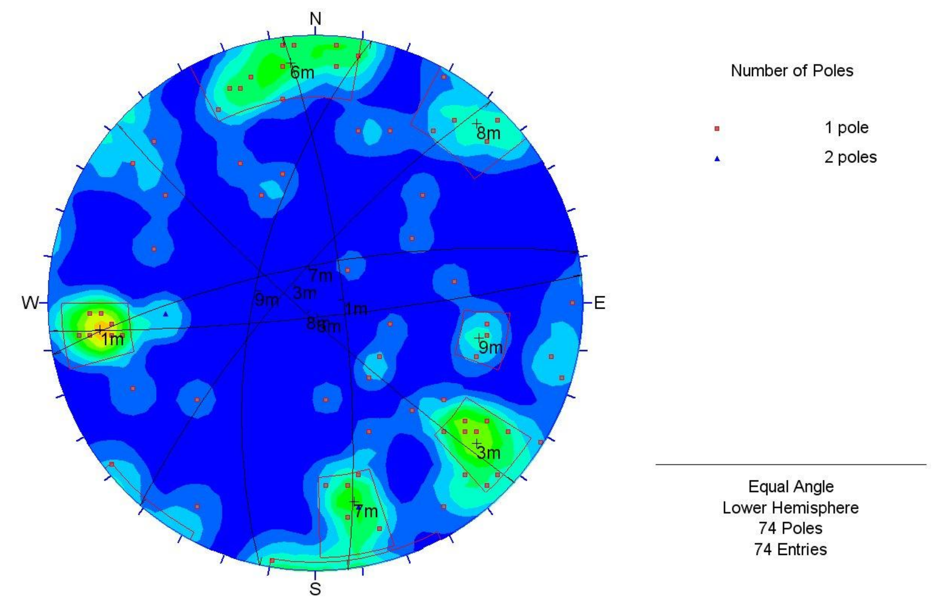
The labelled point cloud is imported in ***Matlab*** and stored in the form of matrices: a (n x 3) matrix (B) that contains the original point cloud coordinates and a (n x 1) matrix (L) that contains the label (plane) numbers. With ***principal component analysis*** the normal vector n to the points in matrix C is computed, which enables to define the dip direction and dip angle of each discontinuity plane.

Some simple statistics of matrix C can be computed, like the number of points, the mean coordinate (the centroid of the plane) and the minimum and maximum extends in terms of x, y and z.

Plane number	Dip direction ( )	Dip angle ( )	Plane equation parameters				XMEAN	YMEAN	ZMEAN	SIZE	Number of points
			a	b	c	d (m)					
1	270.99000	87.14900	-0.99861	0.0173	0.049733	3863.8	4074	5340.8	2254	91.447	349
2	109.49000	65.57800	0.85834	-0.30381	0.41346	-2814	4086.3	5345.6	2250.7	6.1637	383
3	30.70800	83.27900	0.50716	0.85387	0.11704	-6898	4078.1	5346.3	2261.7	22.223	2979

Table n°1 Example of the post-processing results. It summarises, for each segmented plane the most important geometric properties that will be important in determining the sets and set spacing.

Six discontinuity sets were discovered, (Fig. 6) among which are the discontinuity sets directly linking to the regional tectonic and the fragmentation of the Cinque Torri group. The N to NNW striking sub-vertical normal faults of Mesozoic age reactivated with oblique movements during Alpine orogenesis (83°/78°, 282°/64°), the conjugate Riedels to the N-NNW strike slip faults (174°/84°, 349°/74°) and the perpendicular systems of fractures that can be associated to the gravitational phenomenon



The parameter **d** of the plane equations is the orthogonal distance of the plane to the origin of the point cloud coordinates. By referring this parameter to the mean coordinates of the discontinuity set, the computation of the ***equivalent normal set spacings*** is achieved.

SET	XMEAN	YMEAN	ZMEAN	"Equivalent " normal set spacing (m)
6	4077,308	5338,55	2244,967	0,648633772
1	4077,729	5343,357	2241,029	1,304265583
8	4075,1	5337,883	2252,95	0,778950023
9	4066	5335	2238,367	2,494421667
3	4069,35	5343,913	2239,988	0,534739236
7	4071,929	5342,329	2234,786	1,121134286

Table n°2 The main discontuity sets of the Torre Inglese pinnacles: the mean coordinates and the "equivalent" (that does not follow the Priest (1993) definition) set spacing of joints inside each set.

Conclusions

● The approach of this study for accurate structural analysis of an unstable rock body provides specific parameters needed in rock stability analysis.

● The TLS methodology combined with the PCM processing and the PCA post processing represent a very fast, accurate and statistically representative acquisition of geometrical pattern of fractured rock bodies.

● A reliable representation of the potential instability phenomena in terms both of structural evolution and geometries is mainly evidenced by a detailed characterization of the rock body discontinuities.

References

SLOB, S., 2005. Automated rock mass characterisation using 3-D terrestrial laser scanning. PhD thesis.
VOSSELMAN, G., GORTE, B.G.H., SITHOLE, G. and RABBANI, T. 2004. Recognising structure in laser scanner point clouds. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. vol. 46, part 8/W2, Freiburg, Germany, October 4-6, pp. 33-38.

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