MONITORING OF GEOLOGICAL SITES BY LASER SCANNING TECHNIQUES

M. Scaioni[a], A. Giussani[a], F. Roncoroni[a], M. Sgrenzaroli[b], G. Vassena[c]

[a] Politecnico di Milano – Polo Regionale di Lecco, Dept. I.I.A.R., via M. d'Oggiono 18/a, 23900 Lecco, Italy
e-mail: {marco.scaioni; alberto.giussani; fabio.roncoroni}@polimi.it
[b] Topotek – Inn.Tec. srl, via Branze 38, 25123 Brescia, Italy – e-mail: sgrenzaroli@topotek.it
[c] Università degli Studi di Brescia – Dept. of Civil Engineering, via Branze 38, 25123 Brescia, Italy
e-mail: vassena@ing.unibs.it

Commission VII, Working Group 5

KEY WORDS: Laser Scanning, Landslides, Geology, Monitoring, Visualization, DEM/DTM

ABSTRACT:

In the last 5 years terrestrial laser scanning (TLS) technology has shown very large improvements, either in the instrumental aspects and in softwares for data processing and visualization. While first applications concerned only the architectural or in general the close-range field due to the small operating range, nowadays dealing with large scenarios is possible as well. New "long-range" TLS are really suitable to be applied in geological and glaciological surveying and monitoring, representing a very interesting issue for the Italian (and not only) research and social community, due to the mountain character of a large portion of its land.

In the paper some guidelines for executing a survey of a landslide by means of TLS techniques are addressed; problems such as 3D-view registration, survey planning, data processing and information extraction are concerned. Furthermore, two application in this field carried out by a research group made up of Politecnico di Milano and the University of Brescia are presented. Geological application concerns the survey of a slope threatening a part of the village of Caslino d'Erba, near the Lake of Como, and the well-know marble quarry of Botticino (Brescia).

1. INTRODUCTION

Geological instability is one of the most serious problem affecting the Italian country, resulting in a large amount of economic damages and, very often, in the lost of human lives. From North to South of the country, several areas present some geological and morphological characteristics which make them really prone to slope disaster. This nature has been getting worse and worse because of a bad mountain land management, which did not prevent from destruction of forests and the continuous growth of human settlements. On the other hand, monitoring and prevention of geological disasters has been widely ignored, with the only exceptions of cases attracting the attention of mass-media. Furthermore, the changeable behaviour of climate in the latest years has resulted in a further increment of the problem.

However, in the recent years many efforts have been carried out in order to prevent landslides, involving either research insitutes and public administrations. An important impulse to this has been given by the introduction of some new monitoring and surveying methods, which have substituted or integrated traditional approaches and instruments of geology and topography. Concerning topographic and photogrammetric techniques, new sensors have been applied to geometric survey of slopes, integrating the use of automatic total station, digital photogrammetry (aerial and terrestrial) and GPS techniques. Preminently, these new approaches are dominated by *terrestrial laser scanning techniques* (TLS) and by *ground based inteferometric SAR analysis* (Rudolf *et al.*, 1999). Both methods are able to survey the object in a manner that is not more limited to the measurement of a selected number of control points, such as in traditional methods, but resulting in the acquisition of the whole surface in a short time. Thank to a TLS is now possible to acquire a dense point-cloud describing the 3D surface of a landslides with a cm accuracy, referred to a given reference system. Terrestrial *InSAR* techniques allow the determination of relative displacements at different times with an accuracy of few mm.

At the current state-of-the-art, the application of laser scanning techniques seems to be – in the opinion of the authors – the widespread real possibility of surveying a whole slope surface, because of the availability of different commercial TLS models and of SWs for data management and processing. *InSAR* methods are still in development and are limited to a small number of experimental applications.

For the sake of completeness, among new methods for ground movement detection and monitoring, *satellite InSAR* tecniques based on *point scatterers* extraction (see Ferretti *et al.*, 2001) cannot be forgotten. Interesting applications are currently carried on in the Italian Alpine area based on this kind of analysis, which tries to localize those sites featuring anomalous vertical displacements, to be further investigated by terrestrial methods.

Moreover, laser scanning allows to derive some topographic products that some years ago cannot be. A part from a topographic description of the slope, carried out through the extraction of horizontal and vertical sections, a dense DSM of it can be acquired; this can be used in modelling geological problems (prevision of the movement of a slope, preferable path of fall in case of rolling rocks and the like).

The TLS data can be easily integrated to those taken by other kinds of sensors, such as typical geological investigation instruments, geophisical analyses, photogrammetric and topographic surveys. The 3D point-cloud, once it is registered to a given reference system, could be thought as the geometric framework for representing all different kinds of data used for the landslide monitoring, so that all information could be managed in a unique environment.

The paper will describe firstly some general aspects concerning TLS survey for geological applications. Then, two practical applications would like to better focus on problems and advantages of laser scanning technique applied to geological sites survey and monitoring.

2. LASER SCANNING SURVEY OF A GEOLOGICAL SITE

The acquisition of the point-cloud describing the surface of a slope which has to be investigated is carried out by a long-range TLS from a single or from multiple stand-points. All scans acquired from different positions must be fused together, transforming their coordinates into a unique reference system (*registration*). Very often surveys of geological sites require to be inserted into a pre-defined *ground* reference system (GRS), in order to compare data acquired at different times (*monitoring*) or for the georeference into a cartographic system.
The setup of the survey's workflow stricly depends on characteristics of TLS, registration technique, dimensions of the site, required data accuracy and resolution. In the following some of these aspect will be analyzed in detail.

2.1 State-of-the-art of long-range TLS

A long-range TLS (LRTLS) should allow the acquisition of points belonging to a surface at a distance of several hundreds metres from the stationing position. Upgraded technical features of current available instruments can be found at websites of constructors (see References from Websites).
The common measurement principle of all TLS is the *time-of-flight* method, the unique which permits long range measurement in a fast time. More recent instruments are equipped by a digital camera as well, which may collect images to be used for generating orthophotos or realistic Virtual Reality models.
Almost all current LRTLSs present some facilities which can be very helpful in practical surveys, such as the possibility of controlling the acquisition process by means of a laptop or a palm PC, also via remote wireless connection.
From a logistic point of view, in geological surveys the transportability of the instrument and its accessories (tripod, energy unit, PC) is fundamental, because might easily happen that arduous stand-points have to be reach. However, many efforts are required in the future to reduce weight and dimensions of LRTLSs.

2.2 Registration of views: different approaches

Concerning strategies for registering multiple scans, two different approaches can be followed. In both cases, a set of ground control points (GCPs) is needed to register the point-cloud to a given GRS. As GCPs may be used *retro-reflective* targets or common features which are well identifiable in the scans. Which method is available strictly depends on the TLS and particularly on the data processing software being used. Normally only one option is possible.

2.2.1 Fully GCP based registration: In case enough GCPs are available in each scan, these can be straight-forward registered to the given GRS. From a mathematical concern, this task consist in computing 6 parameter of a rigid 3D roto-translation from the intrinsic reference system (IRS) of each 3D-view to the GRS.
Although this method is largely reliable and leads to a high accuracy in the registration process, sites which are surveyed for geological purposes may present a very complex morphology, which makes difficult, if not impossible, to carry out topographic measurements of GCPs. This drawback may results in a longer survey times and decreases the avantage of using a TLS in many applications.
On the other hand, if different 3D-views share a sufficient portion, GPCs can be positioned to serve more than one model. Moreover, if the TLS features a large horizontal FoV, GCPs can be also external to the area to be acquired.
Usually, the minimum number of GCPs needed to register a 3D-model is 3, but practically a higher one may be required, according to the algorithm used to compute the initial values for the roto-translation parameters (equations are not linear); in literature a large variety of methods to solve for these approximations can be found (see Gruen & Akca, 2004).

2.2.2 Pairwise registration techniques: A second possibility of georeferencing different 3D-views arises in case GPSs are not visible in all of them. In this case the available methods are based on the pairwise registration of scans, starting from a 3D-view which is chosen as reference and registering to it all the other 3D-views sharing a sufficient number of tie points (TPs). Then, neighbouring scans are registered as far as the whole block is oriented. As tie points, in geological applications retro-reflective targets have to be preferably used, because their measurement can be performed with the higher accuracy either by automatic and manual procedures. Methods based on automatic extraction of not-signalized tie points (see Gruen & Akca, 2004 for a review) or directly on matching corrisponding surfaces are very usefull in architectural and mechanical applications, but they do not hold yet in the geological field, where the presence of not coherent terrain and of moveable objects (rocks, vegetations, ...) can lead to errors in registration. After pairwise registration of all 3D-views to the same "project" reference system (PRS), thank to a set of small GCPs the point-cloud can be transformed into the GRS.
In Scaioni & Forlani (2003) a procedure has been proposed to solve for a simultaneous block triangulation of all models, using as constraint only a small set of GCPs. This approach (or another similar) can be usefull if in the interested area GCPs cannot be directly measured, being only possible to put TPs.

2.3 Survey planning

The planning of a landslide survey usually suffers from the typical problems involved in a traditional photogrammetric survey: several factors must be considered, so that standard design methods are not so easy to be established, as happens for flight plans in aerial photogrammetry. Nevertheless, a limited effort has been produced so far in order to give at least some basic addresses for a correct survey planning.
The strategy we followed is based on establishing a set of simplified relations which can be used to setup a TLS survey. Topics decision that have to be made are the following:

- selection of the more suitable TLS model (if possible);
- position and number of TLS stations;
- strategy for 3D-views registration, resulting in positiong and measurement of GCPs.

Input data for the survey design are basically the resolution and the accuracy of the point-cloud describing the surface to

acquire, according to which kinds of topographic product must be yielded.
Assumed as given the long-range TLS to be used (the possibility of selecting between more than one instruments is a chance that seldom happens!), 6 metrological parameters of TLS may affect the result of the survey (see Iavarone & Martin, 2003):

- horizontal and vertical FoVs;
- range measurement accuracy;
- horizontal and vertical scan resolutions;
- size of beam-spot in the range of involved distances.

We would like to proposed in next sub-paragraphs a workflow for data acquisition strategy in case of a typical survey of a geological site.

2.3.1 Preliminary site investigations: Disregarding all concernes involved in the geological analysis of the site (existing geological maps, evident indications and damages, formulation of ground displacement hypotesis) and focusing on the merely geometric survey, available large scale maps of the interested area could be very helpful for the laser scanning survey design. Possibly, maps should be integrated by orthophotos and a DTM, in order to have a complete look over the study area.
Collected information are needed to define the area to survey and the area where TLS could be stationed. Furthermore, in case the data acquisition has to be repeated in future for monitoring purpose, some stable areas must be localized in order to place some monuments to materialize a permanent GRS.

2.3.2 Positioning of TLS stations: A survey design should be first define positions of TLS stations, so that the whole object coverage at requested spatial resolution and accuracy could be guaranteed. To this aim it is necessary to compute the ground resolution of each scan, given the TLS stand-point and the position of the area to survey. Obviously, ground resolution may change inside a same scan, depending on polar coordinates (d, φ, θ) of each measured points and on horizontal and vertical scan resolution ($\Delta\varphi$, $\Delta\theta$). We introduce two relations which allows to compute horizontal and vertical linear footprints (r_H, r_V) as function of the above mentioned parameters. In order to make a rough simplification of the real configuration, we assumed a simplified terrain model consisting in a plane tilted by a γ angle, namely the *vertical attitude* used by geologysts.
Referring to Figure 1 for the meaning of symbols, *horizontal footprint* r_H can be computed by formula (1), where also expression as function of the horizontal range d_o is given; during survey planning, the horizontal distance d_0, can be measured from maps instead of the slope distance d.

$$r_H = 2\frac{d}{\cos\varphi}\sin\frac{\Delta\varphi}{2} \cong 2\frac{d}{\cos\varphi}\frac{\Delta\varphi}{2} = \frac{d\Delta\varphi}{\cos\varphi} = \frac{d_o\Delta\varphi}{\sin\theta\cos\varphi} \quad (1)$$

According to Figure 1, the *vertical footprint* r_V can be computed as follows (both real and horizontal ranges have been considered):

$$r_V = -\frac{d\,\Delta\theta}{2\cos(\gamma+\theta)} = -\frac{d_o\Delta\theta}{2\sin\theta\cos(\gamma+\theta)} \quad (2)$$

Thank to the proposed formulas, for each scan position the ground resolution can be computed and the requirements needed for the information extraction verified.

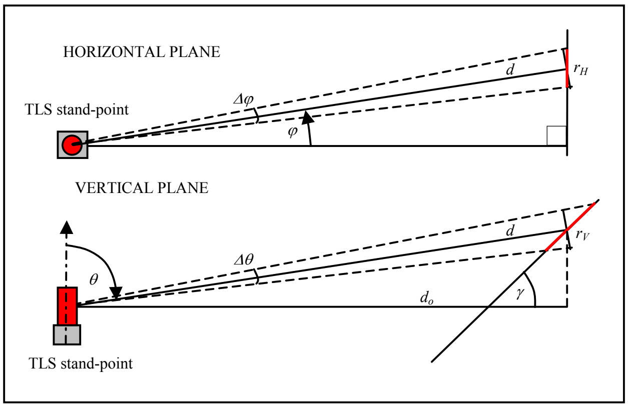

Figure 1: geometric scheme for computing footprints.

Once the coverage of the ground has been checked, a rough prevision of the amount of data to collect has to be done. One of the main open problems in today's laser scanning technique is dealing with a very huge dimension of point-clouds, which get difficult the data processing. Even though a resampling of each scan could be performed after the acquisition on the field, the best solution would be to directly carry out the data collection at a suitable resolution. This strategy will result in a reduction of the acquisition time as well.

2.3.3 Control point position and shape: According to considerations made at par. 2.2, we consider the registration method completely based on GCPs as the only which may guarantee a sufficient accuracy in surveys for geological investigations. This approach needs the positioning of at least 4-5 control points for each planned scan. Even though the direct topographic measurement of all CPs would be the most reliable way (so that all points would play as GCPs), in practise this approach might be largely time-wasting. Moreover, some CPs could be needed in positions where their direct topographic measurement by a total station of GPS would not be possible. In case scans are linked to each other by TPs, these must be positioned to avoid instability and bad determinability of orientations. If the TLS allows an horizontal FoV of 360°, it is possibile to put some GCPs also behind the stand-points, perhaps in poisitions far from the landslide area where GPS measurement can be carried out.

Figure2: reflective target for LR TLS applications with GPS antenna mounted

If more acquisitions are planned at different times for monitoring a landslide evolution, some fixed GCPs should be placed. We consider the permanent positioning of a target as a not very reliable solution for re-positioning of GRS at each survey time. Indeed, GCPs near the landslide area could be not stable, while GCSs in external positions could not be enough to give a strong constraint. A suitable solution would be to place some monuments in stable sites outside the area directly involved in the ground displacement. Starting from these points, coordinates of required GCPs could be measured at each survey time by topographic methods.
Last but not least, the structure of targets adopted as CPs is a critical aspect which should be accurately considered. Yet TLS producers usually proposed their own targets (plane or 3D reflectors, such as

cilinders or small spheres), in surveys where long ranges are involved these may often appear as to small; furthermore, their topographic measurement may be difficult. In experiences carried out so far, we adopted planar retro-reflective targets as TPs, and special targets made up of a retro-reflective disk mounted on a tripod as GCPs, these being equipped of a system to fix a prism or a GPS antenna (Fig. 2).

2.4 Data acquisition

This stage is the core of the whole process, because the complexity of the context to be surveyed requires to verify all the hypoteses established during the design stage. By positioning the TLS in all planned stand-points, the complete coverage of the object at the wanted ground resolution can be checked; also the acquisition of CPs must be verified. To do this, a really usefull instrumental tool is the preview at low resolution of the whole scan. After this check, possible modification or integration of the survey layout can be carried out during the same measurement campaign.
Another important task is the verification of the registration procedure, resulting from a correct targets' displacement and acquisition in all scans.
Acquisition of *digital images* can be carried out during the range data collection, in order to add up information about the color texture of the objects (Sgrenzaroli & Wolfart, 2002). Digital camera may be fixed to the TLS or may be used independently: in the former case, the image geometry of the camera can be related to that of the scanner, so that a corrispondence between each point of the 3D-view and the image can be established by "on the job calibration", to be carried out only once time before an acquisition session (Ullrich *et al.*, 2003). In the latter case, each image can be oriented with respect to the point-cloud in post-processing by *space resection*. In both cases, image registration to the point cloud is performed by manually measuring well identifiable points on the 3D-view and the images. The *a priori* knowledge of intrinsic camera calibration parameters would reduce the number of control points to adopt.

2.5 Data processing

Data processing is based on three main stages:

1. pre-editing of each scan, i.e. resampling of scans in case they are too dense and measurement of CPs;
2. registration of all 3D-views to a given GRS; cleaning of points located in not interesting parts, in order to reduce the total amount of data before next stages. Furthermore, after registration, large portions of the point-cloud may be made up by the overlap of more scans. Thank to a filtering method, duplicate data should be eliminated;
3. extraction of required information.

In the last stage, information needed by the final users has to be derived. From an operational point of view, this task (as the registration and pre-editing as well) should be performed by devoted SWs, either commercial or scientific. In the following we briefly address to some products that can be derived from the registered point-cloud which may result very usefull in geological investigations and analyses.

2.5.1 Digital Surface Model: From the registered point-cloud a DSM describing the external surface of the surveyed slope can be derived. Thank to *meshing* techniques, the set of raw 3D points is converted into a continuous surface and thus results in a visually more intuitive representation and in reducing the amount of data. Moreover, meshing represents a preliminary task to the extraction of sections and contour lines, to generation of orthophotos and photo-textured models. The widespread used meshing technique is *triangulation* of scan data (Edelsbrunner, 2001).
The availability of an accurate DSM of a landslide area may be very important for geological investigations, for which usually only rough information read from mid scale maps is used. In particular we would like to focus on some products than can be obtained from the DSM:

- as input data for specific SW simulating possible landslide behaviour;
- simulating the path of possible falling rocks;
- computation of volumes (and their variations if multi-temporal data were available);
- computation of vector field describing movements of the landslide surface.

2.5.2 Cross-ections and countour lines: Very simple products that can be derived from TLS survey are cross-sections and horizontal countour lines. Thank to the high density of points, they give an accurate description of the site, very usefull in planning of works of consolidation and protection. Because of the possible presence of moving objects, a smoothing method should be preferably applied to remove noisy data from extracted lines.

2.5.3 Photo-realistic 3D Models: Among different approaches to display 3D models (wireframe models, shaded moded – see Remondino, 2003), *photo-texture 3D models* allow the most realistic visualization of the object. Texture mapping involves an image being mapped onto the surface composed by a triangulated model, so that the colour of the object at each pixel is modified by the corrisponding colour derived from the texture (Sgrenzaroli & Wolfart, 2002).

2.5.4 Orthophotos: The knowledge of a DSM allows to generate orthophotos, that may be very usefull in geological analysis. Indeed, orthoimages offer a detailed view of the slope, which could be intergated by other information (cross-sections, contour lines, positions of different sensors an so on).

2.5.5 Topographic maps: Nevertheless, information described so far can be integrated by a vector map directly derived from the 3D point-cloud. For example, while the DSM and its by-products are the most appropriate methods to represent a slope, concerning building, street, infrastructures, these could be better drawn by extracting their contours. Moreover, vectorization results in a simplification of the whole point-cloud, which becomes lighter to be managed.

3. TWO APPLICATIONS

3.1 A landslide in Caslino d'Erba (Como)

The first application concerns the acquisition of 3D model of a vertical slope threathening a portion of the village of Caslino d'Erba, located between towns of Como and Lecco in Northern

Italy. The interest of this survey is in the fact the disaster has not yet happened, and the acquired data will be used to design works for consolidating and preventing a possible landslide. After a long period of intense rain at the end of 2002, water infiltrations has begun to corroded the bottom sector of the slope, calling for interventions of surveying and protection.
The studied slope is about 70 m in length, 45 m in width and 50 m in height.
In order to define a permanent GRS for multi-temporal acquisitions, 4 monuments have been placed on the other side of the small valley. Relative positions of these points have been determined with a sub-cm accuracy either by static GPS measurement and by a polygonal network by total station. Thank to the avilability of two GPS permanent station of the Politecnico di Milano located in the research centres of Como and Lecco, coordinates of monuments have been also referred to the national geodetic network IGM95, so that the whole laser scanning survey can be inserted in existing maps. Thank to the positioning of these points, we have then placed targets in positions to assure a good stability for 3D-views registration, disregarding the fact they could be in sites subject to movement in the future. In fact, 8 targets have been placed, 5 of these consisting in a special structure (Figure 2) mounted on a tripod, made up of a disk covered by a highly reflective material and by a plug to fix a prism of a GPS antenna; two different diameters for targets are possible on two side of the rotating plane (20 and 50 cm). Positions of these targets in the GRS have been determined by intersection from monuments, so that they can be considered as GCPs. Furthermore, 3 circular small reflecting targets (diameter of 8 cm) have been placed in the central part of the surveyed area to register a detail scan to the other ones; they are not known in the GRS, playing the role of TPs.
A Riegl LSM-Z420i laser scanner has been used (more information can be found at website of Riegl). Three scans have been acquired, two (scan 1 and 2) giving a general view of both sides of the whole slope, the third (scan 3) focusing on a detail of the critical central part where a landslide could start.
All acquired 3D-views have been processed using the *RiSCAN PRO* Riegl SW, used also for scanner control. Processing has involved a pre-editing of each scan, consisting in removing trees and marginal areas, in resampling to reduce the number of points, as well as in automatic measurements of reflective targets. Registration has been carried out by using 5 GCPs for both scans 1 and 2; then scan 3, where only three GCP could be view, has been pairwise registered to scan 1 by introducing also TPs. A mean sigma nought of 2 cm for each registration (directly to GRS or pairwise to another scan) has been reached.
After each scanning, some images have been collected by a Canon EOS 1Ds (11.1 Mpixel) digital camera, fixed on the top of LSM-Z420i TLS in stable way. Once the camera has been positioned in a such manner, the RiSCAN PRO SW allows to register images to 3D-view. By using an approximate registration, the user can view the position of reflective targets (or some other features manually extracted) projected into the images; by simply interactively correcting residuals between position of targets on the image and their projection from 3D scan, the registration parameter from image to scan can be computed. However, the intrinsic calibration of digital camera must be known. The advantage of using a camera already registered to the scanner results in the possibility of colouring the 3D-models or obtaining a photo-texture representation without any further task; in Figure 3 a colour 3D model of the whole study site is reported.

Figure 3: frontal view of the landslide in Caslino d'Erba; the point-cloud have been added up by the colour information.

3.2 Botticino Marble Quarry (Brescia)

A Marble Quarry in the Botticino area (Brescia, Italy) has been selected to test the TLS technology for geological survey (Monti *et al.* ,1999). Main objectives of this test have been:

- defining the technical procedure for the usage of TLS in quarries;
- testing laser scanning approach for geological applications.

Field survey campaign is organized in the following main steps:

1. definition of TLS stand-points;
2. target (GCPs) displacement;
3. acquisition of range scans and digital imagery;
4. georeference of targets by GPS.

Two TLS stand-points have been selected outside the quarry so that both excavation area and GCPs were well visible, and in the way that extraction activity would not be interrupted. (Fig. 4).
Scans obtained from different viewpoints have been transformed into a single reference frame (Fig. 4) using highly retro-reflective targets built for LRTLS applications (Fig. 2). A GSP antenna mounted over the target has been used for georeference. The shift between antenna's phase centre and retro-reflective target centre has been previously measured.
During laser data acquisition, digital image of the quarry have been acquired as well.

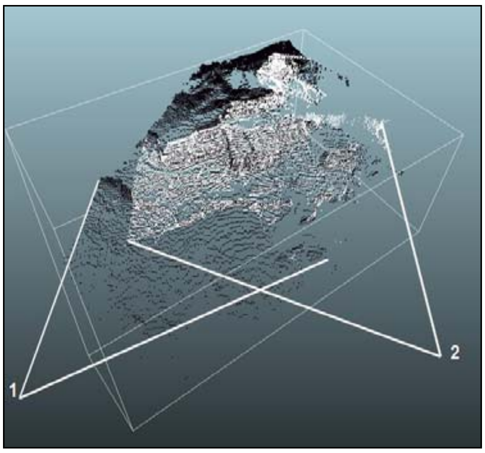

Figure 4: Range scans obtained from different viewpoints (1,2) are transformed into a single reference frame.

Data processing stage has followed data acquisition to provide a cartographic representation of collected data, to support quarry management and to allow geological analysis.
Laser data and digital image have been processed using the *Reconstructor* software developed by the Joint European Commission Centre (Sequeira V. *et al.*,1999) according to the following steps:

1. range scans pre-processing, editing, geo-reference, meshing and texturing;
2. geometrical information extraction (cross-sections, surface measures, iso-lines) and DSM generation;
3. geological analyses.

Pre-processing is performed immediately after data capture and includes *local surface normal* computation. This information is a very valuable support for next geological analyses.
A fully GCP-based registration method has been adopted. The software allows also a *feature-based* registration (ICP method) which could be useful for comparison with future acquisitions. Starting from the actual survey which can be chosen as reference and registering to it all the other range scans, it will be possible to verify quarry temporal changes. *Reconstructor* provides tools to build 3-D models and perform automatic comparison between models built at different time of the quarry life.
An intelligent data reduction is provided through a multi-resolution meshing process which converts the set of the raw 3D points into a continuous surface. The *Reconstructor* software allows mapping external 2D images on the 3D mesh; color information enriches geometrical information helping the geological data interpretation.
The data processing creates a texture-mapped 3D model of quarry containing the complete geometric 3D and 2D information. The software becomes a virtual surveying tool, which extracts the information from 3D and 2D surveyed data and hands it over to standard software for cartographic representation and DEM generation.
Major results of the marbel quarry laser survey campaign have been: point and distance measurements, area and volume measurements, interactive and automatic fitting of planes, creation of cross-sections, DEM generation, iso-lines cartographic representation (see Figure 5).
This dataset of results and products constitutes a valid support for geological and geo-mechanical analyses of the excavation area, requiring both geometric and colorimetric data.

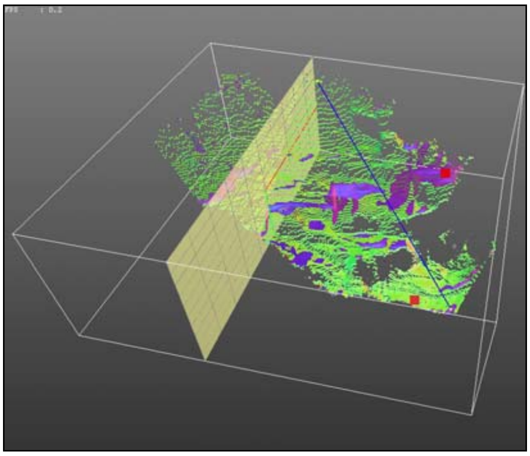

Figure 5: Processed range scans used for geological analysis: different colors correspond to different quarry slopes

4. FINAL DISCUSSION

In the paper some technical aspects of the application of terrestrial laser scanning to survey site of interest by geological purpose have been presented. The current availability of long range TLS becomes possible the operational use of this survey tool, which may provide products that cannot be obtained by other topographic and photogrammetryc methods, or can be obtained with a largely minor effort and consumed time.
Two tests leaded by the research groups of the authors have permitted to have a look on practical methods, solutions and problems as well. Within the main advantages of laser survey applied to geology, the following can be listed: fast data acquisition due to remote data collection (direct survey of 100 m^2 surface can require around 2 hours to an expert operator); completeness with respect to traditional survey using "spot" data acquisitions (1 local spot survey every 1 km^2; increased measurement accuracy (e.g. in traditional geological survey, local compass measurements are still collected to establish attitude of discontinuities).
Further developments either in algorithms and procedure for registration, and in application and operational aspects have to be carried out in the near future. A laser scanning survey results in several hundreds of Mb data, which are still difficult to be managed by commercial softwares and common PC. Optimization of processing and visualization tools is needed, while techniques to optimize the survey planning in order to reduce the size of point-clouds from the acquisition stage are expected.

ACNOWLEDGEMENTS

We would like to thank Simone Orlandini (MicroGeo, Firenze, Italy) and Riegl company (Horn, Austria) for having provided TLS instruments used in both experimental tests.

REFERENCES

References from Books:
Edelsbrunner, H., 2001. *Geometry and Topology for Mesh Generation*. Vol. 6 of Cambridge Monographs on Applied and Computational Mathematics, Cambridge University Press, UK.
References from Journals:
Ferretti, A., Prati, C., and F. Rocca, 2001. Permanent Scatterers in SAR Interferometry. IEEE Trans. on Geoscience and Remote Sensing, Vol. 39(1).
Sequeira, V., Ng, K., Wolfart, E., Gonçalves, J.G.M., and D.C. Hogg, 1999. Automated Reconstruction of 3D Models from Real Environments. *ISPRS Journal of Phot. and Remote Sensing*, Vol. 54, pp. 1-22.
References from Other Literature:
Gruen, A., and D. Akca, 2004. Least Squares 3D Surface Matching. *IAPRS*, Vol. 34(5/WG16), on CDROM.
Iavarone, A., and E. Martin, 2003. Calibration Verification Facilities for Long-Range Laser Scanners. In Proc. of *Optical 3D Measurement Techniques VI*, Gruen, A. and Kahmen, E., (ed.s), Zurich, pp. 268-278.
Monti, C., Brumana, R., Fregonese, L., and G. Vassena, 1999. GIS Technology to Support Survey Data and Management of Different Quarry Typologies, *IAPRS*, Vol. 32, Part 6W7, pp. 344-350.
Remondino, F., 2003. From Point Cloud to Surface: the Modeling and Visualization Problem. *IAPRS*, Vol. 34(5/WG10).
Rudolf, H., Leva, D., Tarchi, D., and A.J. Sieber, 1999. A mobile and versatile SAR system. In Proc. of IGARSS 99.
Scaioni, M., and G. Forlani, 2003. Independent Model Triangulation of Terrestrial Laser Scanner Data. *IAPRS*, 34 (5/W12), pp. 308-313.
Sgrenzaroli, M., and E. Wolfart, 2002. Accurate Texture-Mapped 3D Models for Documentation, Surveying and Presentation Purposes. In Proc. of CIPA Work., Corfu (Greece).
Ullrich, A., Schwarz, R., and H. Kager, 2003. Using Hybrid Multi-Station Adjustment for an Integrated Camera Laser-Scanner System. In Proc. of *Optical 3D Meas. Tech. VI*, Zurich, pp. 298-304.