TERRESTRIAL LASER SCANNING AND DIGITAL PHOTOGRAMMETRY TECHNIQUES TO MONITOR LANDSLIDE BODIES

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ABSTRACT:

Photogrammetry and laser scanning, thanks to significant development in last years, are comparable surveying techniques to generate - without object contact and with a precision commensurate with scale - Digital Terrain Models (DTMs), a fundamental tool to detect, classify and monitoring landslides. The traditional way to survey the territory for landslide detection purposes is aerial or, in some cases, terrestrial photogrammetry, that permits to carry out 3D models of the terrain and, by means of DTMs comparisons, to realise multi-temporal studies. The massive introduction of modern digital photogrammetric workstations, with automatic matching procedures, allows for a rapid DTM production for landslide monitoring activities. On the other hand, the 3D reconstruction of the terrain with terrestrial laser scanning methods is another modern way to reproduce the natural surface of the ground with high accuracy and high automation. There are however some open problems concerning the elaboration of the data and the procedures to generate DTM starting from Digital Surface Models (DSMs), taking off vegetation, buildings, etc. The present work describes the terrestrial laser scanning and photogrammetric surveys realised on a small landslide body located on the Northern Apennines in Italy (municipality of Vergato, Bologna), an interesting case in order to test the laser scanning capabilities and the procedure of laser data processing, also in comparison with photogrammetry.

1. INTRODUCTION

The multitemporal monitoring of a landslide is a fundamental tool for its knowledge and the prediction of its possible spatial or temporal evolution. Several surveying methodologies are used to investigate the activity of existing landslides. Two main classes are identifiable: point based (Total Station, GPS) and area based techniques (Photogrammetry, Laser Scanning and Remote Sensing, in particular spaceborne radar interferometry).

It is well known that the geodetic methodologies like triangulation and distance measurements with electronic instruments permit a very high accuracy. By means of GPS (Global Positioning System) or Total Stations it is possible to detect movements on the order of mm/yr or cm/yr, and estimate the boundary of the landslide area. The three dimensional reconstruction of the surface of the landslide can be done interpolating dense profiles realised walking inside the body of the landslide; this operation requires however long on-the-field procedures and in some cases is not allowed due to local accessibility problems.

There are also several promising Remote Sensing techniques used to generate DEMs for landslide monitoring and characterized by high level of accuracy, in particular thanks to the new generation of high-resolution satellite imagery and mostly Interferometric SAR (Synthetic Aperture Radar).

Photogrammetry is the technique most commonly used for this kind of survey, permitting to reconstruct the three dimensional landslide shape with great wealth of information and to study its 3D evolution over time. The development of digital photogrammetry offers today new possibilities and innovative procedures, like the creation of DSMs in automatic mode for the reconstruction of surfaces and the generation of orthoimages.

Laser Scanning is a surveying method conceived more than ten years ago that in a short time can supply DSM (Digital Surface Model) and good quality DTM as a result of elaborations with specific procedures that apply specific filtering and interpolation algorithms; only nowadays this technique is having growing development and applications thanks to information technology improvements. A telemeter laser obtains the 3D reconstruction of objects; the measure of the distance from the ground derives generally from the time employed by the laser beam to go and to come back (time-of-flight principle). While airborne laser scanning (using airplanes or helicopters) constitutes one well established method landslide surveying (Barbarella, Lenzi, Gordini, 2003), terrestrial laser scanning (TLS) can be investigated as an alternative or complementary methodology.

In the present research a traditional photogrammetric technique and a Terrestrial Laser Scanning method have been applied and compared to investigate Cà di Malta landslide (figure 1) located in the municipality of Vergato, near Bologna (Italy). The area is located in northern Apennine on the eastern slope of Reno River Valley. The average slope is about 13 degrees and the area about 40,000 square meters. The landslide affect strongly deformed units known in literature as *argille scagliose* (Pini, 1999). This melange is widespread in the entire Apennines mountain range. The composition in the area is mainly clayey.

The area of study was adopted because of some reasons:

- the landslide is monitored from some years by GPS measurements, evidencing in many cases movements on the order of 1-2 cm/month (Mora et al., 2003);
- historical photogrammetry and geological photo interpretation studies of the area are yet in progress from the authors (Baldi et al., 2002);
- the lacking in vegetation makes the site suitable for photogrammetry and one-echo laser surveys.

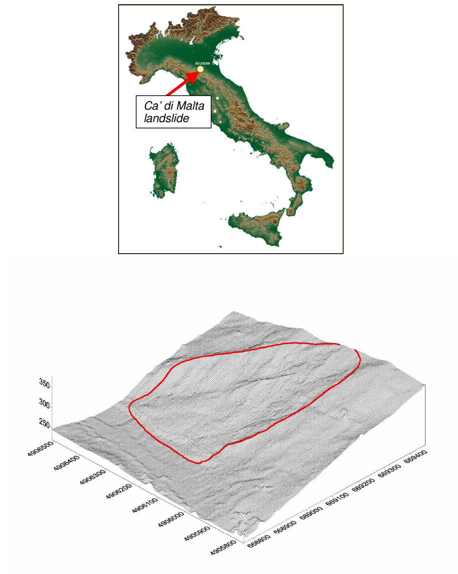


Figure 1 – Location and shape of the landslide

The landslide moreover is still active and consolidation works (creating drainages, removing debris, etc) have been realized during the last period; it must be stressed that this fact can in part invalidate the usefulness of the presented study in terms of comparison with the past, but the experimentation is in any case a test for the methodology and its results will be useful for monitoring this landslide in the future.

A set of recent large-scale aerial photographs is available for this area, taken in year 2000, and two terrestrial Laser scanning surveys were realised in different periods in order to detect displacements of the study area: the first one in May 2001 and the second one in April 2004.
The purpose of the work is to evaluate such methodologies for landslide monitoring applying them to a real case, evidencing the survey strategies, the procedure of elaboration of the laser data (filtering, merging, outliers detection …), the techniques of recording the point clouds in a unique reference system, etc. In the following sections the surveys realised are shown, together with the methodologies adopted for data processing and the results of preliminary comparisons.

2. THE PHOTOGRAMMETRIC SURVEY

In April, 2000 a large scale aerial photogrammetric survey of the landslide was realised. Three photos of the area were collected at a mean scale of 1:4400 and oriented thanks to a GPS network of 24 ground control points (GCPs). Residual of bundle block adjustment on GCPs and tie points for outer orientation were on the order of few centimetres (Mora et al., 2003).
In order to have reference data of controlled quality, a Digital Terrain Model with a grid size of 2 m was generated using an analytical plotter (Galileo Siscam Digicart 40) and semi-automatic or manual plotting, with a significant amount of work by an expert operator. Figure 2 shows the orthophoto depicted on the DTM derived from this photogrammetric survey.
It is clear that digital photogrammetric techniques are currently the most interesting solution for the automatic generation of terrain models and orthophotos, which are highly important for the study of a landslide phenomenon.

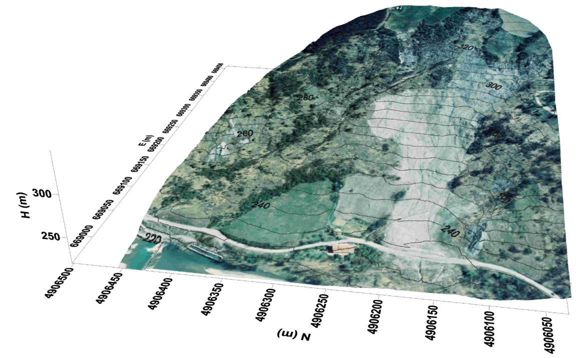


Figure 2. Three-dimensional perspective view of slope under study, coming from the 2000 photogrammetric survey.

In addition to the photogrammetric process performed by analytical stereoplotter, the images were used to generate a DTM with a high-level digital photogrammetric workstation (Helava System) and the low-cost StereoView system (Menci Software), adopting semi-automatic and automatic procedures. The films were scanned using a RasterMaster (Wehrli & Associates Inc., NY, USA) photogrammetric scanner with 1000 dpi resolution, sufficient to guarantee an high level of detail (ground pixel size about 12 cm).
The DTM produced by Helava system was firstly generated automatically, with post-editing by the operator in order to correct errors deriving from the correlation procedure; editing consisted mainly of manual insertion of breaklines into incorrect zones, with consequent local recalculation of the surface area. It was afterwards compared to the one generated by the analytical plotter; the differences between the two models are characterized by a mean value of –15 cm, with a standard deviation of 42 cm, with the largest differences localized mainly in zones with complex morphology and shadowed areas.
The result is therefore acceptable, indicating that digital photogrammetric techniques may now be adopted for routine elaborations, providing the products subjected to precise validation by an expert operator.

3. THE MULTITEMPORAL TERRESTRIAL LASER SCANNING SURVEYS

Terrestrial Laser Scanning, usually adopted in industry, piping, architecture, archaeology, control of quarries, has been applied in this work for deformation monitoring of the Cà di Malta landslide.
Such a methodology offers the advantages typical of non-contact techniques, and moreover permits to collect in short time dense 3D point clouds over the surface of interest, to record a perspective image (intensity data and sometimes RGB data), it doesn't requires necessarily deployment of reflectors, and it permits immediately and easily to take measurements between points.
There are various terrestrial laser scanners available, characterised by different accuracy, measurement range and data acquisition quickness. The distance is measured applying different principles: the time-of-flight principle (ranging scanners), the phase difference, the triangulation. Ranging scanners are able to survey objects and scenes with greater distances and so were adopted in the frame of this work.

3.1 First terrestrial laser scanning campaigns

Two 3D Terrestrial Imaging Laser Scanners were used to realise in different epochs the landslide survey: a Riegl LMS-Z210 system (May 2001) and a Riegl LMS-Z420i system (April 2004). These scanners, born to cover wide areas, collect four measurements for each impulse: 2 angles, the distances and the intensity of the received echo impulse. The polar coordinates are immediately transformed in a local 3D Cartesian system (sensor system). Automatic recognition of targets by intensity images matching is supported.

Riegl LMS-Z210 system can perform data acquisition at a distance from 2 to 350 metres with a nominal accuracy in the distance of about ± 2.5 centimetres. The system is able to acquire intensity range and also RGB images for an angular Field Of View (FOV) of 370 gon (horizontal; angular resolution ± 20 mgon) x 88 gon (vertical; angular resolution ± 40 mgon), with a minimum angle step resolution of 80 mgon and a capture rate of 6000 points per second. The new Riegl LMS-Z420i system (Riegl, 2004) has better performances: concerning the rangefinder, the measurement range is from 2 to 800 metres with a nominal accuracy of ± 1 centimetre; the system is able to acquire intensity range for a scanning range of 360 gon (horizontal; angular resolution ± 2 mgon) x 80 gon (vertical; angular resolution ± 4 mgon); the minimum angle step width in vertical scans is 9 mgon, 11 mgon in horizontal scans and an acquisition rate of 12000 points per second is achieved.

Three scans were carried out in 2001 survey, with 80 mgon resolution, starting from different positions on the landslide in order to minimise the absence of data in the clouds of points due to the perspective view of the scans. In order to registry together the multiple scans, 6 reflective 6x6 centimetres targets tapes and 4 retroreflector prisms were placed inside the landslide.

Figure 3. Instruments adopted for the Laser Scanning surveys: A) Riegl LMS-Z210; B) Riegl LMS-Z420i; C) Cylindrical Retroreflector (height 100 mm x diameter 100 mm); D) Retroreflector prism used in the first campaign.

With the purpose to define a topographic local reference system and to validate the accuracy of the laser scanning measurement over the control points, a survey was realised by a Leica TC2000 Total Station from two stations located inside and in the proximity of the landslide, with high precision results.

The 3D-RiSCAN software package was used to locate in automatic mode the targets, based on their intensity values. The coordinates of these points were used to stitch together the different scans, by means of 3D similarity transformation. The residuals coming from these transformations produced standard deviation values less than 4 cm.

A similar survey was performed in 2004 with the LMS-Z420i instrument. Four scans were realised with 80 mgon resolution and, in order to registry the multiple scans, 13 dedicated cylindrical retro reflectors were placed inside the landslide (figure 3C).

The acquired points clouds data have to be connected together in order to reconstruct the continuous surface of the landslide, so they were automatically aligned during the survey and merged by the RiSCAN PRO, the new software package for RIEGL 3D laser imaging sensor of the LMS-Z series, that permits even to filter, to create polygonal surfaces and to map the surface with textures using digital photos obtained during the scanning by a digital semi-metric camera placed over the laser instrument.

3.2 Procedures for DTMs extraction

The first products resulting from clouds alignment are DSMs (Digital Surface Models) of the area in correspondence of each survey; the second step of data analysis is to obtain the DTMs (Digital Terrain Models) that reproduce the natural surface of the ground, without vegetation and buildings. The software used for segmenting purpose has been the Microstation module TerraScan, by TerraSolid Inc.

The instruments used are able to estimate, during data acquisition, two different responses of the same pulse but it’s necessary to decide for the first echo or the second echo response before starting data recording. One of the own technical characteristics of these instruments is the ability to distinguish the two different echoes only if their difference is greater than 2 meters. Considering the purpose of the survey, the scanners were set-up to record the last echo in case of discrimination between the two responses.

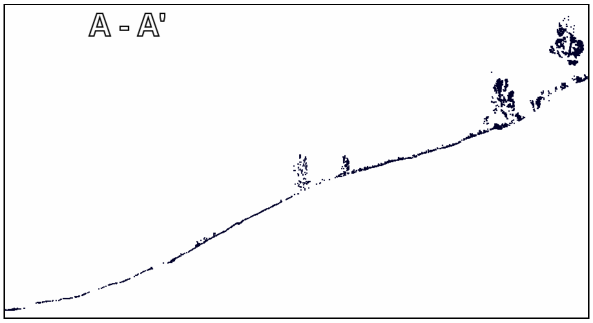
The most important phase is being able to discriminate terrain points for DTM construction; opportune editing routines (data segmentation) are necessary for this purpose. Data segmentation requires for a explicit parametrization of the classification algorithms provided by the software, following some criteria related to the object and surface.

TerraScan provide different segmentation procedures depending on the kind of classification requested. In this case, two routines were adopted in sequence, named “Low point” and “Ground”. The first one permits to identify the points subject to errors on the basis of an analysis of outliers and clustering in the original data. The second corresponds to an iterative process: starting from a TIN surface derived from a subset of points, identified as terrain because of their smaller elevation in respect of the neighbouring, the surface incorporate other points on the basis of a geometrical analysis of slopes and distances, based on some user-assigned parameters, finally generating a surface defined as “ground”.

The use for terrestrial applications of a software normally adopted in airborne laserscanning impose a different operating approach, firstly at all because of the very high density of the points (a value of 1000 points per square meter can be achieved) and geometrical condition of the scanning, and also for the unavailability of multiple echoes.

The definition of a set of optimal parameters for data segmentation needs a careful examination of sample areas and some testing on different morphological situations, different materials and different distances; normally, this choice is instead more general and reproducible for airborne scanning. In the case study, morphological situation can vary abruptly from an area to another, with strong changes in slope and the presence of rock blocks that affect the geometric “surface uniformity” characteristics.

In any case the results of the automatic procedures required a successive interactive editing and this operation has been assisted by the exploration of digital images acquired together with laser data.



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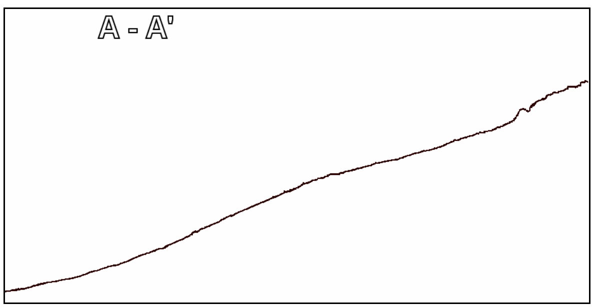

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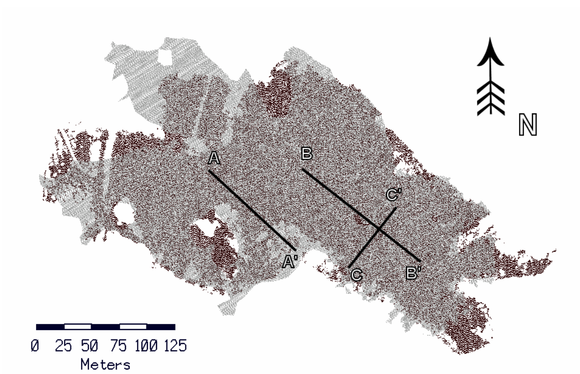


(C)

Figure 4. Example of laser scanning data filtering: A) Cross-section profile A-A’ before data filtering; B) The same profile after removing vegetation. C) original cloud of points (2004 and 2001 surveys) with location of profiles.

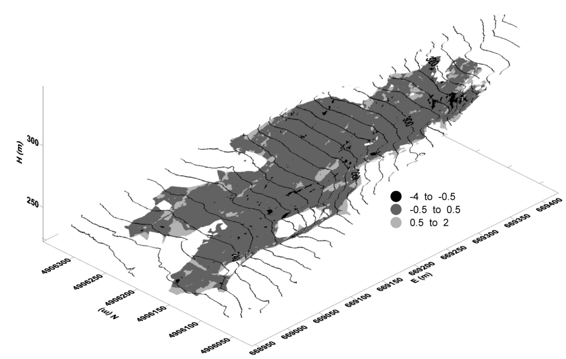
3.3 Alignment of the multitemporal DTMs

To investigate the multitemporal evolutions of the landslide, the results of the two surveys were reduced in a unique reference system using PolyWorks software by InnovMetric. After manual selection of some homologous points, PolyWorks aligns simultaneously all the data by minimizing the total sum of positional errors between corresponding points among overlapping point clouds.

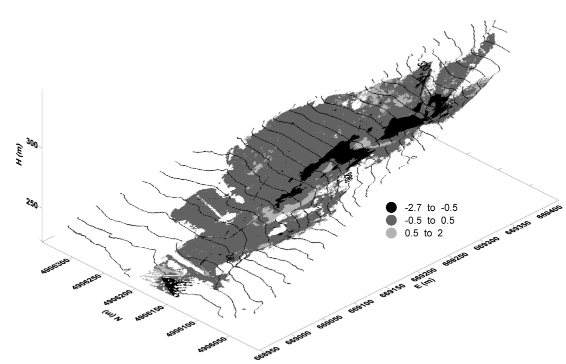
The homologous points were individuated outside the landslide body, thanks to the long range operation characteristic of the adopted laser instruments (350 m for the Riegl LMS-Z210; 800 m for the Riegl LMS-Z420i).

Together with the obvious advantage to survey large areas, this fact could be certainly considered in choosing a class of instruments for monitoring of changes occurring in territory.

An analysis of the map of the residuals coming from the 2001 and 2000 DTMs comparison doesn’t show significant large mass movements, made exception for very restricted areas (figure 5-A). The irregular distribution of high residuals may be ascribed to the effect of artificial mass movements or to the presence of vegetation not correctly eliminated during filtering works. The highest topographic changes are detected in the differential maps (figure 5 B, C) concerning 2004-2000 and 2004-2001 DTM height differences. The negative values are located in scarp areas and in the middle part of the landslide body while the most significant uplifts are localized generally after the degradation areas and not in the expected position at the foot of the landslide (figure 5 and 6). The analysis of the mass movements reveals the effects of human activity to improve the stability of the landslide.



(A)



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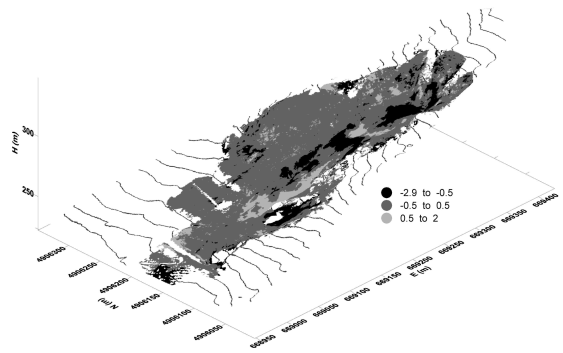
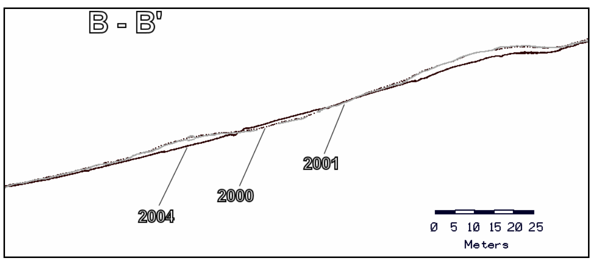
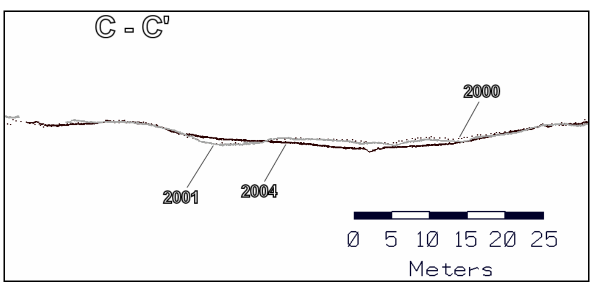


(C)

Figure 5. Height differences between DTMs obtained from 2000 (photogrammetric), 2001 (Riegl LMS-Z210 laser scanner) and 2004 (Riegl LMS-Z420i laser scanner) surveys. Differences (in meters) are indicated by different grey values. A) 2001 – 2000; B) 2004 – 2000; C) 2004 – 2001.



(A)



(B)

Figure 6. Cross-section profiles concerning 2000, 2001, 2004 surveys (location depicted in figure 4).

4. EVALUATION OF THE EXPERIENCE

The experience carried out, although not directly useful for the monitoring of the main body of the Cà di Malta landslide because of the reasons already mentioned (recent works that have artificially altered the surface of the landslide, as well confirmed by the profiles and volume difference calculated), have shown that the terrestrial laser scanning technology can be applied for this kind of application.
The main advantage in comparison with the traditional topographic surveying is the large area surveyed in a very short time and with a very high level of detail, without having to chose a limited set of points to be monitored; this is of course of great interest when the landslide behaviour is unknown. The same happens also, in different way, in respect to GPS measurements. The achieved precision and accuracy is in many cases satisfactory, but for this aspect the quality of segmentation operation is fundamental (low vegetation can represent a major obstacle in a lot of situations), and also the geometrical characteristics of the scan must be taken in account for each case (large distances, laser beam angle in respect to the terrain, footprint size, etc. reduce the survey precision).
In comparison with airborne photogrammetry and airborne lasers canning different considerations arise; in front of a general lower accuracy, these techniques do not suffer for the problems of intervisibility and masking of areas that can affect terrestrial measurements, and provide data for larger investigations, more easily integrable with other information. On the other hand, airborne surveys are expensive and their execution highly dependent also on meteorological conditions and organizational context. The time needed for production of the results is in general longer (photogrammetry), and different skills required.
If terrestrial laser scanning could represent a more flexible solution for small/medium size landslides that have to be monitored with high frequency to detect small movements, the high cost for the acquisition of the hardware and software must be considered, together with some problems for on-the-field operation: the remarkable weight of the instrument can pose some difficulties in movement and displacement on rugged areas, and power supply is an important question. For data processing, the single pulse files deriving from a terrestrial survey do not permit the adoption of established filtering procedures, requiring in any case a significant interactive editing by an experienced user.

5. CONCLUSIONS

The surveys realised over the studied area have demonstrated that in many cases Terrestrial Laser Scanners could represent an effective and rapid solution to produce economical and accurate terrain models for landslides investigation.
Airborne surveying of landslide areas, traditionally done with photogrammetric methods, requires more expensive instruments (metric aerial cameras, photogrammetric scanners, digital photogrammetric workstations or analytical plotters) and a more complex organization framework. In effect there are at least six steps to obtain DTMs by means of photogrammetric techniques: aerial survey planning and execution; GCPs measurement; reproduction of the diapositives with scanner; determination of the orientation parameters with respect to an object space coordinate system; plotting of DTMs; controls and DTM editing. These steps require more time in respect to a simple TLS survey and data processing.
Further more, even if analytic photogrammetry is being gradually replaced by digital photogrammetry, thanks to improvement of computer power and software, manual work of an expert operator is generally indispensable to generate a DTM in semi automatic mode or to correct errors coming from image matching procedures. Sometime automatic procedures are not feasible, in particular for zones characterized by vegetation cover, shadows or other obstacles. In theses cases only the interpretation by an operator can produce high quality DTM data.
Moreover, concerning laser scanning surveys, interesting is the possibility to registry DTMs realized in different periods also in the cases where classical ground control points are unavailable to reduce in an unique reference system the clouds of points.

Even if the standard and more accurate way to do this is to apply a 3D similarity transformation using sets of common points, the point based (Besl and McKay, 1992) registration algorithm adopted by some powerful software permits good data registration results. Finally, for displacement detection it is frequently important to detect homologous points outside the body of the landslide, and for this aim is really relevant the current availability of long-range high precision laser range scanners.

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