ENGINEERING AND ENVIRONMENTAL APPLICATIONS OF LASER SCANNER TECHNIQUES

Leandro Bornaz (*), Andrea Lingua (*), Fulvio Rinaudo (*)

(*) Politecnico di Torino – Dipartimento di Georisorse e Territorio
C.so Duca degli Abruzzi, 24 – 10129 TORINO
Tel. +39.011.564.7659 / 7700 Fax. +39.011.564.7699
E-mail: bornaz@polito.it; lingua@polito.it; rinaudo@polito.it;

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ABSTRACTS:

The recent introduction of laser scanning devices has led to a set of new surveying products for the field of civil engineering and environmental analysis. The laser scanner is an instrument that permits one to acquire irregular point clouds of land areas, rivers and infrastructures in a fast and cheap way. The use of raw laser scanner data requires orientation and filtering procedures to generate a 3D model of the surveyed object., It is possible to automatically derive a set of geometric information from this 3D model that is useful for a variety of particular applications (engineering and environmental): dense DTM generation, sections and profiles, contour maps, volumes and so on.

This paper describes an original, fully automatic software that has been implemented by the authors and which can supply a set of procedures that makes use of laser scanner data for engineering and environmental applications. Some pratical examples have been shown: the Lys stream in Pont Saint Martin in the Aosta Valley, a stone quarry in Bagnolo Piemonte and a landslide in St. Rhémy en Bosses in the Aosta Valley (Italy).

1. INTRODUCTION

Terrestrial laser scanner devices today represent one of the most widely investigated instruments in the field of engineering and environmental surveying applications. Laser scanner instruments are able to acquire irregular point clouds of land areas, rivers and infrastructures in a fast and cheap way.

However, specific solutions for some problems are often needed: primary data quality, fusion, registration and geo-referencing of multiple scans, practical rules for survey applications in specific fields, and integration with other survey techniques (e.g. photogrammetry). In order to allow a correct and wide diffusion of laser scanner techniques, all these topics must be solved taking into consideration the particular field of application that requires fast, efficient, controllable and easy-to-use solutions.

The data quality of laser scanner acquisition can be considered from two different points of view: accuracy and usability. In the past, many tests on metric quality were carried out to confirm the accuracy declared by laser scanner instrument manufacturers. The quality related to the practical usability of the data can be defined as the possibility of the acquired points of correctly describing the surveyed object and allowing easy management by the final user (e.g. profile production). The complete shape description of the surveyed object can often require a high density of acquired points to correctly identify the break-line positions. High densities generate great amounts of data that can cause several problems in the storage, elaboration and use of the acquired data: a good survey design should define an optimal compromise between these opposite aspects, according to the particular application.

In the engineering and environmental field, multiple scans are often required for a complete description of the surveyed object., Fusion, registration and geo-referencing of multiple scans have therefore been the most relevant topics so far: different research groups have proposed interactive solutions and investigated the possible automation of these procedures, using high reflecting marks or the procrustean approach.

In this paper, we propose a new software called LSR (Laser Registration Software), that has been developed in Visual Basic language and which is able to carry out the automatic registration of multiple scans, the improvement of the quality of laser scanner data using robust statistical tools and the exportation of filtered data using widespread formats (ASCII, DXF and VRML).

Some practical applications of LSR software in the field of engineering and environmental sciences, are here presented and the practical rules that have been used are explained.

1. LASER SCANNER ACQUISITION PLANNING

A laser scanner can be considered as a motorised total station that is able to acquire thousands of points in a few seconds. When the laser scanner operates, the surveyed points are referenced to an internal coordinate system (see fig. 1).

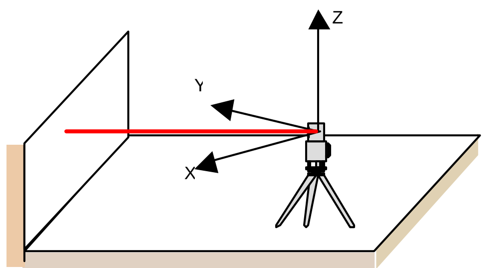

Figure 1. Internal reference system of a laser scanner

In the field of engineering and environmental applications, some rules should be considered so that laser scanner instruments can be used correctly: the maximum measurement range of a laser range finder often limits the survey to a part of the object, if the surveyed object is large or its shape is complex, a series of scans is necessary, the angular constant resolution of laser scanner acquisition corresponds to a variable resolution of the surveyed point on the surface of the object. A good planning of measurement operations is necessary for survey design. The positions of single acquisitions must be choose in order to:

- see the largest possible part of the object considering that the maximum measurement range should be limited to 70-80% of that declared by the manufacturer with the aim of preventing any possible holes;

- not lose any important details or hidden zones;
- establish large overlaps between the adjacent scans so as to preview any systematic errors during their joining.

If the laser scanner positions are known, it is possible to define for each scan: the maximum distance between the laser scanner position and the surveyed object, the angular resolution that allows one to locate the minimum meaningful details located at the maximum distance from the object and any possible filtering processes that are planned.
The registration of the scans in a single local reference system requires the identification of homologous points (e.g. corners) in adjacent and overlapping scans. The collection of tie points and the search for the homologous in adjacent scans can be performed automatically using reflecting targets (Bornaz, 2002). The reflecting targets should be placed on the object in such a way that at least three targets can be found in the overlapping portion of two adjacent scans.
The size of the target should be large enough to allow the laser scanner to record it and the software to recognize it with sufficient accuracy. If the marker is too small, the automatic matching fails or restitutes wrong results. The size of the markers should be approximately chosen according to the angular resolution located at the maximum distance from the object and to the beam divergence.

2. LSR SOFTWARE

In order to generate a correct 3D model of the surveyed object, some elaborations of the raw laser scanner data are necessary.
The data acquired by laser scanner devices are always subject to a noise that is smaller than the tolerance of the used instruments. The noise is caused by the beam divergence: the measured distance is the average of the distances of the points of the object contained in the foot print of the laser beam. In order to resolve this problem a data improvement procedure is required.

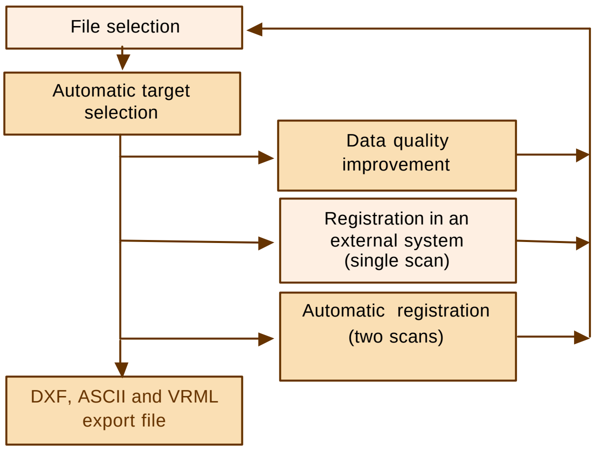

Figure 2. LSR procedures

The multiple scans must be merged in a single 3D model. A specific software (Laser Scanner Registration = LSR) that resolves these problems, has been developed using Visual Basic language.
The LSR program can perform four basic procedures (see fig. 2): filtering of the original data (automatic procedure) and registration of the selected scan in an external reference system (interactive procedure), registration of two adjacent scans (automatic procedure), exporting of the filtered data using widespread formats.

2.1 Data improvement

In order to resolve this problem, a procedure based on robust estimation has been studied and implemented.
The original data are subdivided into 3D meshes whose sizes can be two or three times those of the adopted scanning rate. Each mesh contains a set of measured points. The median ($\tilde{m}$) of the distances is estimated and the deviations of the single values are computed from their median.
The distances that have smaller differences than the laser scanner accuracy are used for the estimation of the real distance using the mean; the other points are rejected.

2.2 Data registration

Laser scanner devices record the X, Y, Z point coordinates and the average reflectivity of the impact area of the laser beam. Engineering and environmental objects are usually composed of poor reflective material (e.g. stones, clay, soil). If some reflective targets are superimposed onto the object, they can easily be found simply by selecting, from all the acquired points, those which have a higher reflectivity than a prefixed value (e.g. the higher reflectivity value of the material of the object). All these targets can easily be automatically found and the coordinates can be recorded.
The LSR software automatically connects each point of a reference scan to the homologous point of the adjacent scan; the reference system of the latter scan is fixed and only the point recorded in the adjacent scan can rotate and translate in space.
The same procedure can be used to register all the scans in an independent reference system (e.g. national system or photogrammetric system) using some markers of which the coordinates in this reference system are known.

2.3 Export Data

The processing result (filtering, registering, fusion) can be exported into a commonly used format so as to be able to use other commercial software that allow the creation of the final surveyed products (e.g. TIN models, surface models, mesh models, profiles and sections, contour maps).
The LSR software is able to write laser scanner data in the following formats: DXF for CAD and 3D modelling software (e.g. Autocad, 3D studio), ASCII text file for 3D surface modelling software (e.g. Surfer, Spider), VRML for a direct visualization (e.g. Cosmos).
Some example of engineering and environmental application are shown in the next paragraphs.

3. THE LYS STREAM IN PONT SAINT MARTIN (AOSTA VALLEY – ITALY)

The first example shows a 3D model of the Lys stream in Pont Saint Martin in the Aosta Valley has been obtained (see fig. 3).
Before the laser scanner acquisition, 5 reflecting targets (size 10 cm) were placed on the structures close to the stream (see fig. 4). A Riegl LMS-Z210 laser scanner was used. This instrument, recently acquired by The Politecnico di Torino, has a measuring range of 350 m and a measurement accuracy of ± 25 mm. An angle step-width range was selected from 0.080 gon to 0.4 gon while an angle readout accuracy of 0.04 gon was selected for the line scan mode and 0.02 gon for the frame scan.
Figure 4 shows the location of the instrument during the acquisition phase. The acquisition distances range from 3 m to 330 m; the measured points of the stream therefore have an average step of about 5 cm. The overlap between two

adjacent scans is almost 50 %. The selected angle step-width is 0.080 gon for each scan.

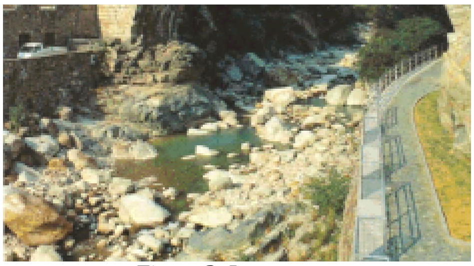

Figure 3. Lys stream

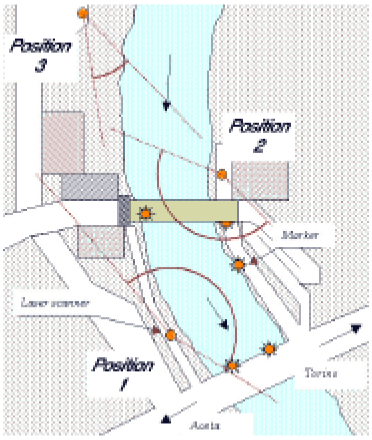

Figure 4. Laser scanner acquisition

All the acquired 3D models have been processed using the LSR software. All the surfaces of structures close to the stream show a reflectivity that is lower than 100 Digital Numbers (reflectivity range 0-255 DN) and the reflecting targets have a mean reflectivity of about 200. The program found all the reflecting targets recorded by each scan because of the great differences in reflectivity values of the targets.
Figure 5 shows the automatic marker positioning for an example of laser scanner acquisition.

Figure 5 – Marker recognition

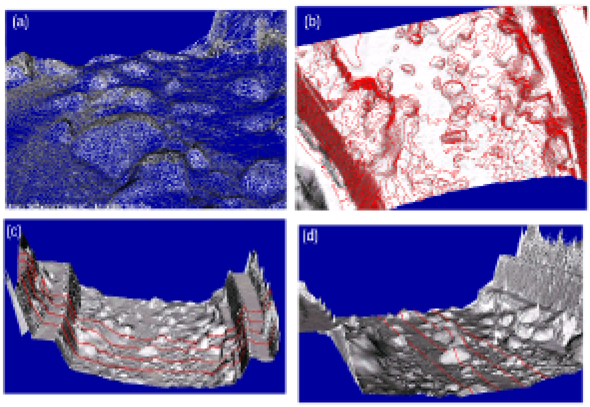

Figure 6 – Post-elaboration of laser scanner data

After the computation of the registration parameters, each scan was filtered to remove the acquisition noise (see paragraph 2.1). The mesh used for the data noise reduction is 0.24 gon, which means an average distances between the filtered points of about 15 cm. The filtered scans were registered using the reference system of acquisition 1 as the local reference system for the 3D model. Finally, the 3D model was converted into DXF and VRML format and imported into Cirrus external software (produced by Menci Software).
A TIN (Triangular Irregular Network) model generated with Cirrus Software is shown in fig. 6a. This model is used to automatically generate the contour map (fig. 6b), sections (fig. 6c) and profiles (fig. 6d).

4. A STONE QUARRY IN BAGNOLO PIEMONTE

The second example is a stone quarry in Bagnolo Piemonte (see fig. 78) that has been surveyed using the same Riegl LMS-Z210 intrument.

Figure 7. The stone quarry (main excavation surface)

Before the laser scanner acquisition, 8 reflecting targets (size 5 cm) were placed on the excavation surface. Figure 8 shows the two locations of the acquisitions. The acquisition distances range from 3 m to 185 m. The overlap between the two adjacent scans is almost 80 %. The selected angle step-width is 0.080 gon for each scan.

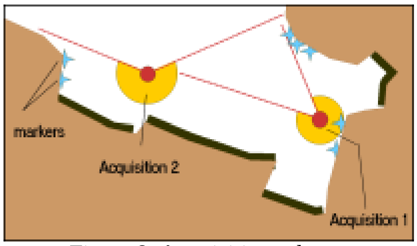

Figure 8. Acquisition scheme

All the acquired 3D models have been processed using the LSR software: the software LSR found all the reflecting targets (see fig. 9), registered each scan in a unique reference system (acquisition 1) and filtered them to remove the acquisition noise. The results are exported into ASCII format and then imported into the ENVI external software (by Research Systems).

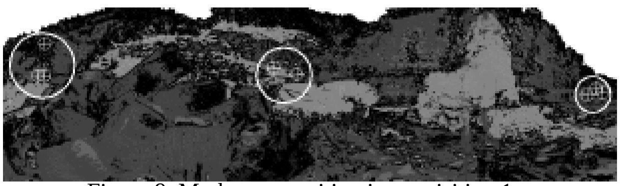

Figure 9. Marker recognition in acquisition 1

Fig. 10 shows the DTM (20 cm x 20 cm mesh) generated with the laser scanner data utilising ENVI through a grey

scale digital images (a low grey level corresponds to an elevated height)., A contour map is visualized in overlapping mode (levels each 10 m) with the profile direction. The generation of these four profiles perpendicular to the main face is performed in a few seconds.
These documents constitute the correct elaborations for the planning of quarry cultivation: volume calculation, principal directions, etc.

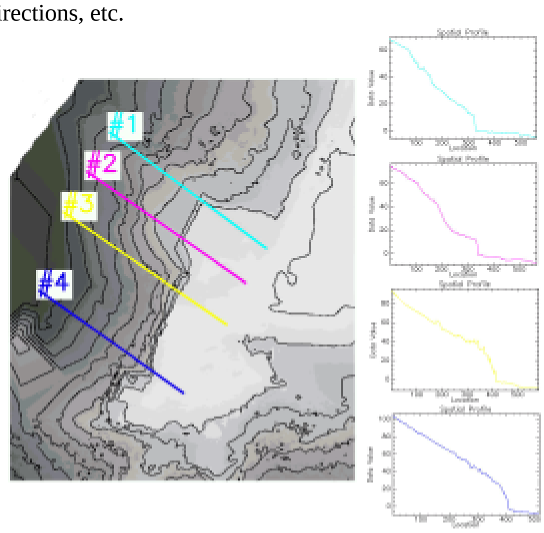

Figure 10 – Profile generation

5. A LANDSLIDE IN ST. RHÉMY EN BOSSES

The third example concerns the multi-temporal acquisitions of a landslide in St. Rhémy en Bosses (see fig. 11): the same Riegl LMS-Z210 laser scanner was used.

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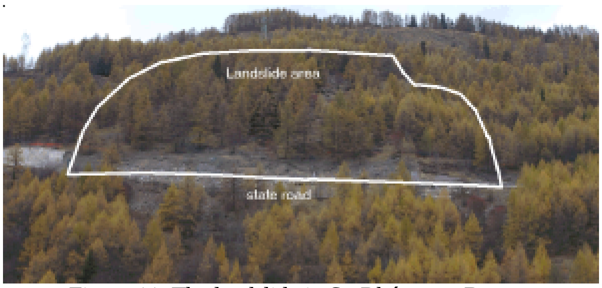

Figure 11. The landslide in St. Rhémy en Bosses

The planning of laser scanner acquisition is shown in fig. 12.
Before the laser scanner acquisition, 10 reflecting targets (size 10 cm) were placed: 5 markers in a zone that is not subject to the landslide movement (to define a permanent reference system for multi-temporal acquisition), the other five in a part near the road, these being necessary for the registration of the two acquisitions.
The acquisition distances range from 6 m and 340 m. The overlap between two scans is almost 75 %. The selected angle step-width is 0.080 gon for each scan.
The scans were recorded in two different periods (November 2001 and May 2002) to evaluate the landslide movements. All the acquired 3D models were processed using the LSR software (registration on the same permanent reference system and filtering) and the results were exported into ASCII format to use Surfer external software (by Golden Software). Two grid files (mesh size 1 m) were calculated (2001 and 2002) to define the landslide movements.
Figure 13 show a contour map of the landslide surface in two periods (2001, 2002) and a representation of the vertical displacements (differences between 2001 and 2002).

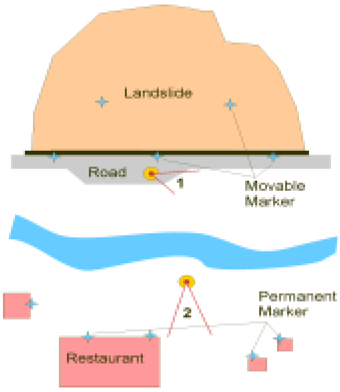

Figure 12. Acquisition scheme

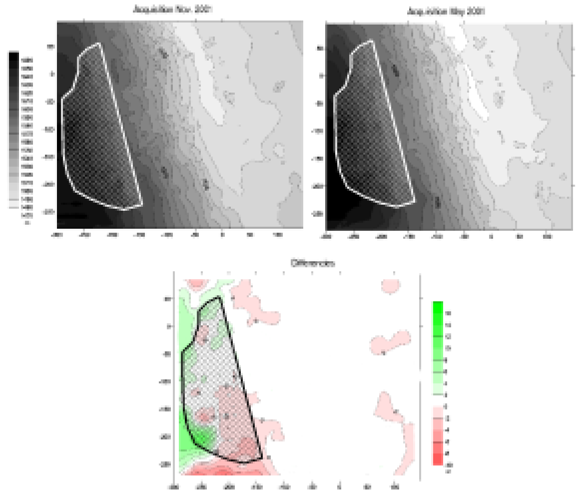

Figure 13. Surfer software elaborations

6. CONCLUSIONS

The proposed algorithm and its practical application through the LSR package offers the possibility of correctly managing the data acquired using terrestrial laser scanner devices for the surveying of engineering and environmental objects.
The automation level reached by the LSR software allows even unskilled operators to use the acquired data; all the problems that involve specific metric survey knowledge are solved by the software itself.
The 3D model produced by the LSR is not the final product of the survey but represents the correct starting point for vector extraction, 3D image model construction and basic geometric interpretation.

7. REFERENCES

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