

Multi-temporal Analysis of Areas under Landslide: Protecting Soil against Subsidence and Pollution

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Abstract— Landslide is a dangerous phenomenon according to geomechanical viewpoint, being able to produce huge damages because of sliding and can involve structures and infrastructures. However, mechanical aspects are generally recognized since they provoke the above consequences. Environmental aspects related to breaking in the land must be considered. Land breaks or cracks allow outside water, not only from rain, to reach surface and subterranean aquifers. Contacts between external waters, maybe containing diverse pollutants, and aquifers, would be considered as source of contamination. The paper illustrates an experimental multi-temporal monitoring of landslides that have been taking place at Colletorto town (Italy). The proposed method, by means of dedicated instrumentation, and subsequent modeling, has permitted to output innovating approach.

Index Terms - Landslide monitoring, soil water contamination, subsidence, remote sensing.

I. INTRODUCTION

Multi-temporal monitoring of areas, under landslide, is a basic aspect for the knowledge and the prevention of possible spatio-temporal evolutions. Methods of detection, used to control active landslide, are based on: control of fixed points (GPS, total station, digital levels) or areas of control (air-photos, laser scanner from airplane, terrestrial laser scanner, interferometry SAR). Detecting methods through triangulation [1] and laser-based distance measurements allow to obtain a high accuracy (sub-centimetric).

Thanks to GPS it is possible to assess displacements of mm and cm. A reconstruction of the 3D morphology within surface and deepness in an area with landslide can be obtained by interpolating measured profiles inside the mass under landslide. These operations are time-consuming, and influenced by the nature of the soil where the landslide is located. 3D laser scanner is a technological solution apt to obtain high resolution DTM (digital terrain model), then to perform multi-temporal analysis of deformations. This technique also permits to obtain DSM (digital surface model). It is also possible to pass from DSM to DTM. In general, erosion, related to landslide, by overland flow could be a prevalent process in a specific area (mountain or basin) but in hillslopes where appropriate conditions are met, pipe and seepage flow can greatly contribute to the overall sediment production and transport. These conditions are mostly: i) a highly variable rainfall between seasons; ii) the presence of an

underlying impermeable layer in the soil; iii) regolith materials prone to shrinking-swelling phenomena; iv) human or naturally induced reduction of the vegetation cover and, v) the presence of at least one dispersible soil layer [2]. Other important factors are the existence of joints or fractures in the upper layers and their strong [3] spatial autocorrelation.

In general, from the cloud of raw points, we can consider the DSM of the considered area. The necessary steps to obtain the DTM are the followings: i) vegetation filtering, ii) triangulation TIN (surface model), and iii) DTM generation.

II. MATERIALS AND METHODS

The scope of the activities is to perform innovating studies and research to detect areas subject to hydro-geomorphological hazards for environmental protection by using joint techniques based on remote sensing from: satellite, airplane and ground related to 3D laser scanner [4]. The research also intends to develop a modeling from a cloud of 3D laser scanner points so that high accuracy can be reached, that is millimeter. So the kinematic evolution of hazardous areas subject to hydro-geomorphological disaster, by means of multi-temporal analysis, is considered. This evolution takes into account the combination of satellite data along with stereoscopic couples of air-photos acquired based on previous data. The results of multi-temporal analysis point-out the time range in which the soil movement has been generated and undergoes an evolution, indicates the type of movement with its surface and deep geometry. Starting from the results of multi-temporal analysis of soil mass movement, the research intends to develop an integrated method for continuous monitoring in a remote way, taking into account data from GPS (global positioning system) with TPS (automatic robotic stations), air-photos, and 3D laser scanner.

The experimental activities have been carried-out using a terrestrial laser scanner [5] system that consists of a high performance long-range 3D scanner, the accompanying operating and processing software RiSCAN PRO, and a calibrated and accurately orientated and mounted high-resolution digital camera. The instrumentation provides (Fig.1) data which lends itself to automatic or semi-automatic processing of scanning and image data to generate products such as textured triangulated surfaces or ortho-photos with depth information.

It is a rugged and fully portable sensor specially designed for the rapid acquisition of high-quality three dimensional images (Fig.2) even under highly demanding environmental conditions, providing a unique and unrivalled combination of a wide field-of-view, high maximum range, and fast data acquisition. A standard windows notebook and the bundled software package RiSCAN PRO enable the user to instantly acquire high-quality 3D data in the field and provide a variety of registration, post processing and export functions.

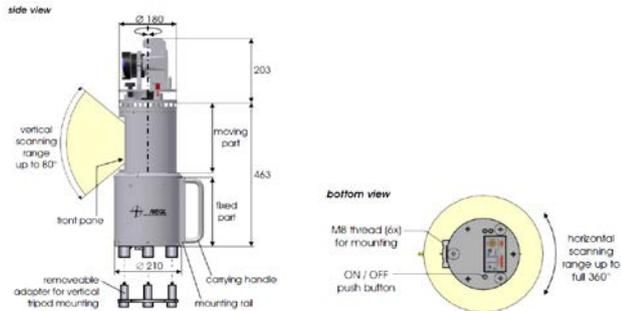


Fig.1. Laser scanner side view and bottom view.

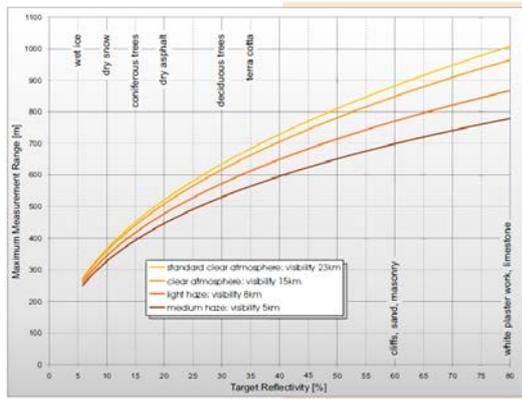


Fig.2. Laser scanner performance

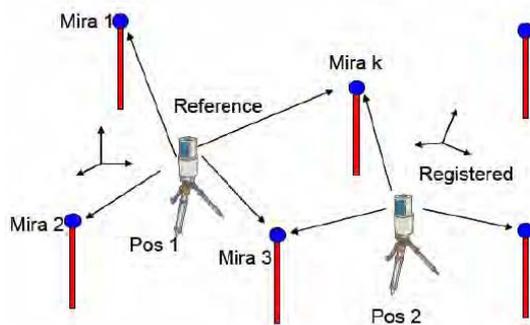


Fig.3. Scanning position storage in unique system of spatial reference.

Spatial references are illustrated in Fig.3 and they are very important because they correlate different positions with respect to the laser sources. We use topographic lines of fire for the implementation of 3D laser scanning. The acquisition

software provides for three systems of reference: SOCS (scanners own coordinate system), PRCS (project coordinate system) and GLCS (global coordinate system). Fig. 3 depicts a SOCS configuration that defines the position and the orientation of the instrument. Both are generally described by 6 parameters (3 for position and 3 for rotation) or by means of matrix of transformation. In general a 4x4 roto-translation matrix, called MSOP (sensor orientation and position), is used, that is

$$M_{SOP} = \begin{bmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

The matrix is characterized by 9 parameters of rotation (r) and 3 parameters of translation (t) as also indicated in Eq.(1) and Fig.4.

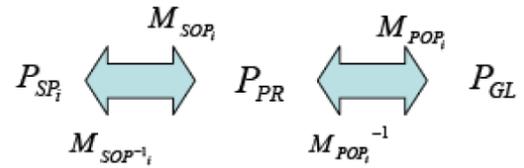


Fig.4. Laser scanner performances.

After the previous preprocessing, the optical method, that is illustrated here, foresees, two adjacent scanning processes with at least four common lines of fire and an overlapping surface not less than 30%. The used lines of fire, to be retrieved within a 3D point cloud, must guarantee the estimation of spatial transformation parameters based on the following:

$$\begin{pmatrix} X_1 \\ Y_1 \\ Z_1 \end{pmatrix} = \begin{pmatrix} X_u \\ Y_u \\ Z_u \end{pmatrix} + R \begin{pmatrix} X_2 \\ Y_2 \\ Z_2 \end{pmatrix} \quad (2)$$

where X_1, Y_1, Z_1 are the coordinates within reference system of the first scanning, X_2, Y_2, Z_2 are the coordinates within reference system of the second scanning, X_u, Y_u, Z_u the coordinates of the origin of reference system of the second scanning with respect to the first, and R is the rotation matrix that rotates around the axis of reference system of the first scanning, making them parallel to those of reference system of the second scanning. The choice of lines of fire and their related positioning affect the estimation of noise of recording [6]. In particular, used targets (lines of fire) are cylinders of specific diameters (5 cm or 10 cm) depending upon the chosen distance between sensor and target to be applied on 1 m-based support coated with backscattering material with high level of reflectance. Fig. 5 illustrates the so-called technique of phase-locking with optical method. Once the DTM is obtained, it is

possible, using commercial software, to pass from model with level curves to precise direction. If we add temporal characterization to spatial one, it is possible to compare successive DEMs or selected profiles to find morphologic variations of the surface of the entire area [7], subsequent to the kinematics of mass movement. Thus, the output of multi-temporal analysis becomes concrete in a series of thematic maps in which areas under movement are represented as well the analysis of "ripple" of profile variations. Another aspect of scientific interest is the possibility of using databases where all data sequences (digital clones) are recorded during different instant of sampling. From recorded data, it is possible, then, to perform statistical analysis or reconstructions to guarantee necessary interventions, that can also take in account soil and subsoil contamination [8].

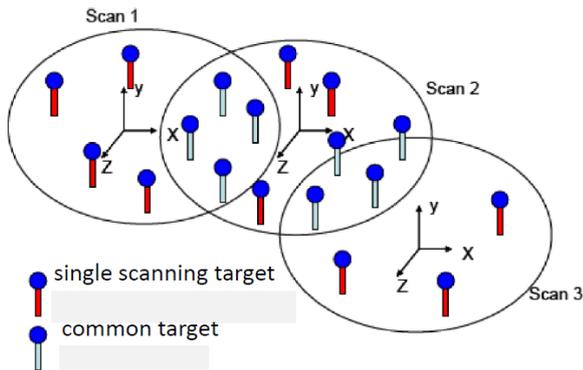


Fig.5. Grouping laser scanners and recording with optical method.

III. RESULTS

The technique presented in this paper is part of a continuing research developed by the authors in the center of Italy, involving different sites. Here, the chosen site where to apply the technique is Colletorto as recalled in the abstract. The site along with the sensors/locations are reported in Fig.6.



Fig.6. On ground positioning with six points



Fig.7. Example: scan position 1.

One of the six scan positions is shown in Fig.7. The position is simultaneously a target and an active sensing location capable of transmitting its coordinates [9]. A historical reconstruction of the positions have been made, namely the following years 1954, 1977, 1991, and 2003 and they have been converted in digital using dedicated software like Z-map, and micro-map software [10].

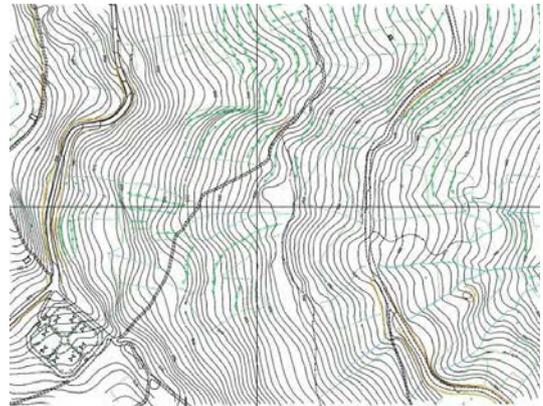


Fig.8. Aerophotogrammetry of the area related to nov 9th 1954 (1:5000 scale).

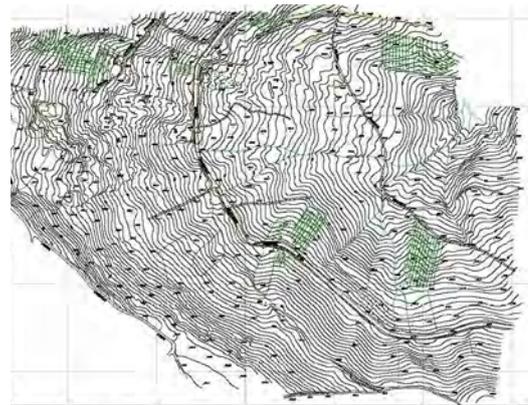


Fig. 9. Aerophotogrammetry of Colletorto from 3D laser scanning sensing related to sept 29th 2009.

The promoted procedure has analyzed data from 1954 by means of a first map (Fig.8), and this yields to a 3D laser scanning sensing map (Fig.9). Now the we are ready to illustrate the findings of the proposed method. Fig. 10 shows the symbols utilized in the expression of results. We distinguish the results in two main indicators: detached area and accumulated area in Colletorto area. The first result is the multi-temporal displacements, in terms of sliding phenomenon in the period 1977 - 1999., see Fig.11. The same has been obtained in a large period, as reported in Fig.12. Both figures shown the detached and accumulated areas where it is possible to quantify the amount of terrain and mud displaced by the landslide [11].

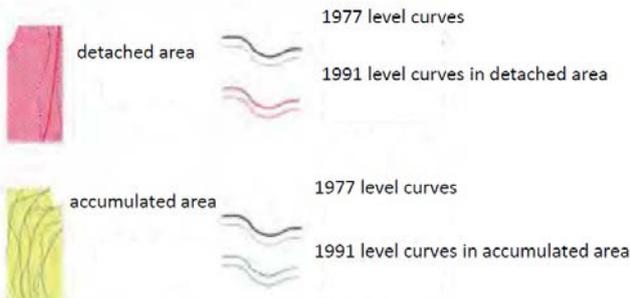


Fig. 10. Legends and symbols expressing geomorphological results.

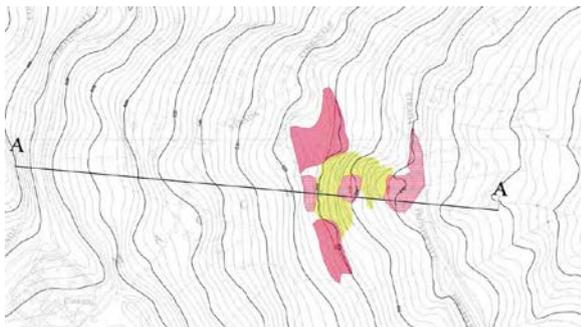


Fig. 11. Multi-temporal analysis of sliding areas (1977-1991).

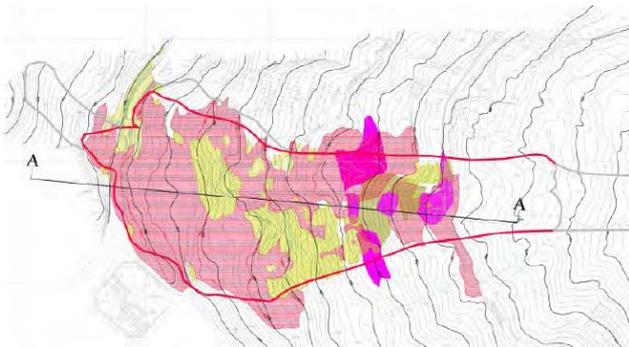


Fig. 12. Multi-temporal analysis of sliding areas (1977-1991-2003-2009).

Finally, the DEM (digital elevation model) depicted in Fig.13 is a summary of all processing and it overlaps all level curves.

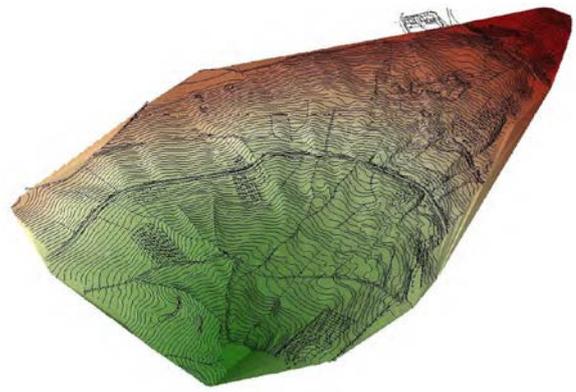


Fig. 13. DEM with overlapping of level curves

IV. CONCLUSIONS

This work is based on 3D reconstruction of laser scanning measurements of landslide in conjunction with historical retrievals to be implemented by means of aerophotogrammetry. The DEM recovery can be also useful for contaminated land to detect soil pollution [12]. Signal processing is a key issue, like searching an item [13] within the landslide. This aspect represents a precious objective because an item included in land displacement can be detected, and then delivers necessary information.

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