CLOSE RANGE DIGITAL PHOTOGRAMMETRY TECHNIQUES APPLIED TO LANDSLIDES MONITORING

J. Cardenal[a], E. Mata[a], J.L. Perez-Garcia[a], J. Delgado[a], M.A. Hernandez[a], A. Gonzalez[b], J.R. Diaz-de-Teran[b]

[a]Department of Cartographic, Geodetic and Photogrammetric Engineering. University of Jaen. Campus Las Lagunillas s/n. 23071-Jaen (SPAIN). (jcardena, emata, jlperez, jdelgado, acaro)@ujaen.es
[b]Department of Earth Sciences and Condense Matter Physics. University of Cantabria. Avda. Los Castros s/n. 39005-Santander (SPAIN). (gonzalea, diazjr)@unican.es

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ABSTRACT:

This paper deals about the use of non metric reflex digital cameras in landslide monitoring and the analysis of landscape evolution from comparison of present digital photographs and old digitized analogue metric terrestrial photographs. The methodology has been improved in a test area (a slope along a road with instability processes in southern Spain) where terrain failures have been documented in the last ten years. Several photogrammetric techniques were checked as well as combination of both convergent (for calibration and densification) and stereoscopic (for DTM generation) networks. Considerations about the use of terrestrial LIDAR and a comparative example are also made. This paper is included in a wider research project carried out in Northern and Southern Spain for study landslides. This research project (*MAPMUT: The improvement of susceptibility analysis by means of useful digital models of the terrain geometry*), aims with an improvement of susceptibility maps using high quality input information.

1. INTRODUCTION

1.1 Introduction

One of the most widespread earth surface hazards along lineal work (motorways, railroad, etc.) is due to slope processes such as falls of rock weathered fragments on the road and deformations of rocks banks laying into the talus road. These movements are sometimes unpredictable. However slope instability methods help us to resolve certain activity areas. In this case the geometry of the activity area is capital to resolve that problem. The improvement of tools to analyse that geometry is the goal of this work. This paper is included in a wider research project funding by the Spanish Ministry of Education and Science (CGL2006-05903/BTE) titled *The improvement of susceptibility analysis by means of useful digital models of the terrain geometry* in which goals is to get better slope instability models improving the information about the geometry of the unstable slope and reliability of DEM used to depict it using photogrammetric and laser techniques (Cardenal et al, 2006). In this paper, we describe part of the methodology developed in the project. The paper aims with the use of non metric reflex digital cameras in landslide monitoring and the analysis of landscape evolution from comparison of present digital photographs and old digitized analogue metric terrestrial photographs. The methodology has been set in a test area (a slope along a road with instability processes in southern Spain) where terrain failure has been documented in the last ten years. Finally, the work has been completed with an evaluation of terrestrial laser scanner for validation of obtained data and development of additional methods for monitoring landslides.

1.2 Selection and location of study area

To test the close range methodology, we select an area of a medium dipping slope (approximately 30º as average slope) and regular size (80x80 m and 40 m high). The area is located in the province of Jaen (Southern Spain) in the secondary road A-324 near the motorway Jaen-Granada (A-44) (Figure 1).

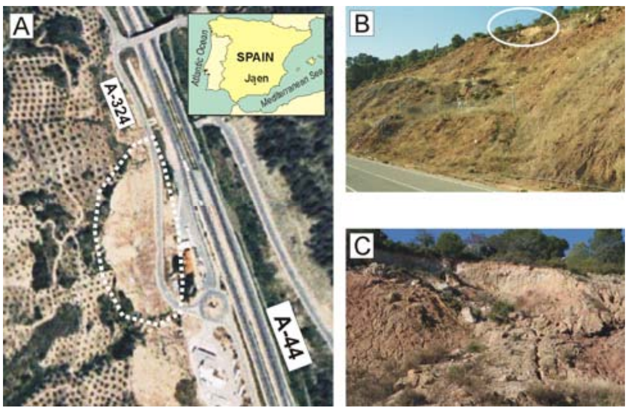

Figure 1. A: Location of the study area. B: General panoramic view of the slope (marked with white dashed line in A). C: Details of one of the landslides detected in the slope (marked in B with white line).

This area is the typical man-made talus road affecting by slope instability processes and where there is enough workspace for using cameras and survey instruments (total station and laser scanner) and some elevation from opposite slope can be achieved. The area was also selected because there was a previous photogrammetric study and terrestrial metric photographs were available (Chamorro, 2001).

The geology of the area is very complex with Cenozoic sedimentary deposits (Lower Miocene) which comprise an olistostromic unit (IGME, 1987). These olistholiths derive from gravitational slides from Betic Cordillera and consist of Mesozoic and Cenozoic material (gypsum, clays, marls and dolomite blocks) with a chaotic structure. This unconsolidated material, the modification of the natural terrain slope (for enlarging the road) and heavy rain episodes have triggered presents land instability processes. In fact, recently the area has protection measures such as a rock fall barrier and steel wire meshes.

2. MATERIALS AND METHODS

2.1 Instrumentation

The main data acquisition instrumentations used in this study were a Leica reflectorless total station (TCRA1203) for measuring spatial coordinates of control points targets (in an *ad hoc* local coordinate system) and a Canon D5 digital non metric camera. Additional analogue photographs taken in 2000 with an UMK/10 1318 camera were digitized with a Vexcel Ultrascan 5000 photogrammetric scanner. Moreover, a terrestrial laser scanner (Optech Ilris 3D) was used for evaluation (LIDAR data are still being processed at present).

The image pick-up device used in the EOS D5 is a 12.8 million pixels CMOS sensor with noise reduction functions. Effective pixels are 4368 x 2912 and sensor size is 35.8 x 23.9 mm, so it is a full frame camera compared with conventional 35 mm film camera format. The camera was equipped with a Canon EF 35 mm 1:2 lens. This lens was set in manual focusing at infinity and the focus ring was fastened with adhesive tape to avoid variations in the camera inner geometry during the field work. The use of non metric SLR digital cameras in photogrammetry have been largely documented in the last decade in diverse field of applications (archaeology, architectural, industrial, environment, etc.) and a wide variety of methods and instrumentation has been successfully developed and used (Luhmann et al., 2006).

The main data reduction system were a conventional DPW (Leica Photogrammetry Suite® 9.1, LPS), a desktop DPW (Photomodeler® Pro 5), own developed software (for camera selfcalibration) and conventional spatial data analysis software (Surfer® 8).

2.2 Field measurements

Field works were carried out for obtaining a local coordinate system and the control points for the photogrammetric and LIDAR surveys. So a permanent station, preserved from the previous works in year 2000, was selected and eight targets were measured with the total station. These targets where white circles against a black background with a measuring cross in the centre. The target (70 mm diameter) was designed for proper measurement with the total station, photogrammetry and laser scanner. With respect to photogrammetry, this size was optimal for measuring the target centroid (by means of optimal thresholding) in the closer targets (20-30 m) and manual measuring in those ones placed further away (>60 m). Figure 2 shows some targets at different distances.

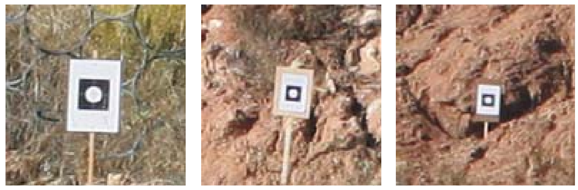

Figure 2. Targets at different distances (approximated). Left: 23 m (the metal net of the barrier is visible behind the target); Centre: 44 m; and Right: 62 m.

The targets were also measured with the laser scanner in order to reference the different scan stations and the resulting point clouds in the same coordinate system. The coordinate system was set for a suitable use of a stereoscopic DPW. This is: X-axis parallel to the road (the foot of the slope); Y-axis, height; and Z-axis, depth.

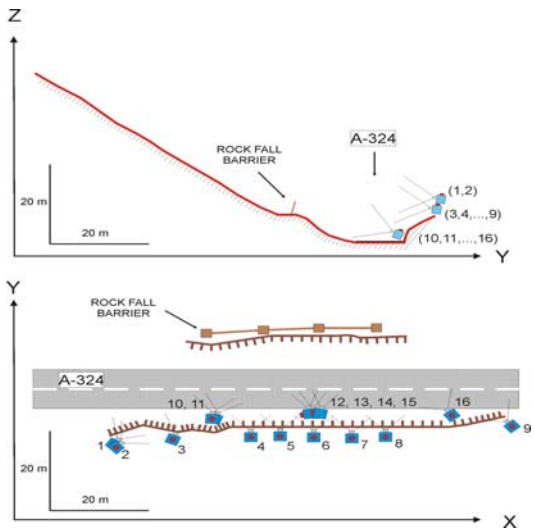

Figure 3. Photogrametric network (2007). Upper: vertical section shows the three height levels of camera poses (2, 6 and 10 m above road level). Lower: camera shots in plan view. Parallel shots 4, 5, 6, 7; rest convergent shots.

2.3 Photogrammetric network (2007).

The photogrammetric network was constrained by the limited camera-slope foot distance (near 25 m), constraints to the height of the camera stations (2-10 m above the road level) and the occlusions and hidden areas because the rock barrier, the wire meshes and the presence of large rock blocks and vegetation (shrubs). Given the size of the slope and the limited workspace, the camera was equipped with the 35 mm lens. The images block (16 camera stations, Figure 3) combined both convergent and parallel shots allowing suitable geometry for camera selfcalibration and stereoscopic measurements. As usual in selfcalibration network geometry, some shots were 90º rolled (photographs 12, 13, 14 and 15 in Figure 3 and Figure 4B).

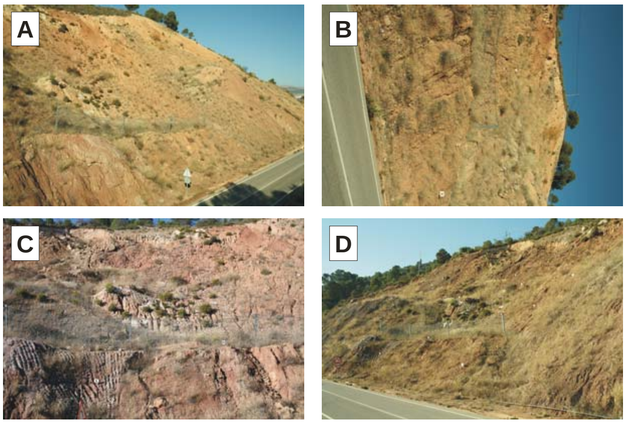

Figure 4. Some Canon D5 photograph from 2007. A: phot. 1; B: phot. 12; C: phot. 5; D: phot. 9 (see Figure 3).

2.4 Selfcalibration

At first, a previous image measuring work was done with Photomodeler®. All targets and additional tie points were measured and the photographs were processed. These computed data were exported to employ them as initial approximations for the exterior orientation parameters and the tie point spatial coordinates in a further analysis. Next, data were processed considering several options (Table 1) with algorithms, programmed under IDL®, based in the collinearity equations (Cardenal et al., 2004). Calculations were made for focal length, principal point offset and first and second order radial distortion coefficients. Other inner parameters (higher order coefficients, decentering distortion, affinity parameters, etc.) were not significant or not considered into calculations.

Figure 5. Some photographs of the calibration range.

At first, the camera was considered as calibrated. Inner parameters had been previously obtained by calibration using a test range (a building with known control points, figure 5). This calibration (at infinity) had been carried out several months before this work. Meanwhile, the camera was employed in another works, so the 35 mm interchangeable lens was removed several times from the camera and the focus ring altered. In fact, this was going to be a check for the stability of the inner parameters. With these inner parameters and the 2007 images, a triangulation was performed with 4 control points, 4 check points and more than 50 tie points (Table 1, column A).

A field selfcalibration was the second option and inner parameters were computed together with exterior parameters and the point spatial coordinates (Table 1, column B). A priori this is the best choice since the inner parameters representative of this particular block are recalculated avoiding the instabilities of a non metric camera inner geometry.

And finally, the third option was a free network adjustment with minimal inner constraints (Atkinson, 1996). Since control points do not define the coordinate system, their computed spatial coordinates were compared by means of a 3D similar transformation with those surveyed with the total station. Residuals at 4 check points after transformation were checked out. Results of the three calculations are given in Table 1.

	A (mm)	B (mm)	C (mm)
rms_{XYZ}	2.6	1.7	3.0
V_{max} X	5.2	3.3	5.5
V_{max} Y	5.7	1.9	6.1
V_{max} Z	3.1	1.6	3.4

Table 1. Spatial coordinates errors of check points after orientation of the 2007-epoch. A: camera calibrated at laboratory. B: Field selfcalibration (option finally considered). C: Free network adjustment with minimal inner constraints.

2.5 DTM generation for 2007 network

After selfcalibration and orientation of the 2007 images block, exterior orientation and images measurements were imported in LPS® DPW and a camera file was created from the inner computed parameters. The parallel shots (phot. 4, 5, 6, 7 and 8; figure 3) were very near to the stereoscopic geometry (although they were taken without any orientation device) and stereoscopic view was possible. Overlap was very high (above 80%). Some additional convergent shots (phot. 3 and 9; figure 3) were added to avoid possible occlusions. Exterior orientation parameters were set fixed and then a densification of tie point measurements was carried out.

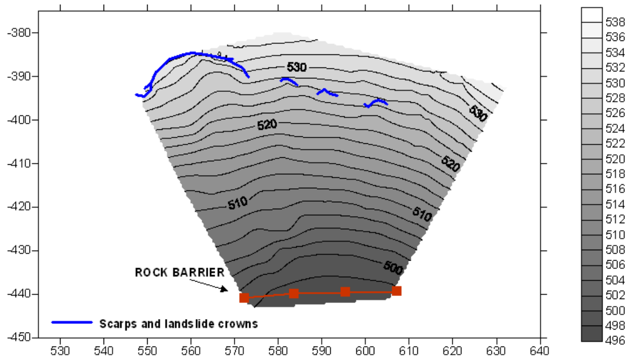

Figure 6. Contour map derived from the 2007 DTM. Scarps and the crown of the main landslide in the upper part of the slope have also been plotted.

An automatic point measurement process (APM) was launched but the APM failed in large areas of the slope because large depth differences, occlusions from the barrier and meshes and large presence of vegetation in some parts. To avoid extensive manual edition, it was preferred measuring manually most part of points. This procedure allowed the selection of appropriate areas of the slope to be measured for a proper definition of the enveloping surface of the terrain. So points were not measured on top of large rocks, vegetation or in the inner part of deep gullies formed by water erosion. More than 400 points were measured as well as some well defined breaklines including some scarps and the crown of the main landslide detected in the slope. With these data a DTM was generated (figure 6). A change in the coordinate system was done in order to adapt the photogrammetric system to a topographical system. X-axis remained unaltered and Y-Z axes were exchanged, so the new Z-axis was the height. Additionally Y-axis was inverted.

3. PHOTOGRAMMETRIC SURVEY YEAR 2000

3.1 Photogrammetric network (2000)

The 2000 photogrammetric survey was a comparison of analytical photogrammetric techniques and conventional geodetic techniques with the purpose of checking methods for deformation measurements (Chamorro, 2001). From this survey we have recovered a block of 5 convergent metric photographs made with similar network geometry to that of figure 3, but without the stereoscopic sub-block (Figure 7). Since 18 circular targets were set in the slope and their coordinates known from surveying, they were used as control and check points. For this paper the analogue photographs were digitized at 20 micron (Vexcel Ultrascan 5000).

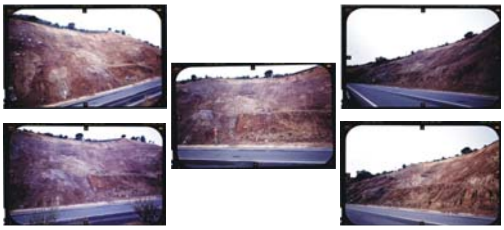

Figure 7. Block of five convergent UMK/10 1318 photographs from year 2000. Landslides still were not apparent, so the rock barrier and the wire meshes were not present.

Since the targets used in 2000 had missing, in order to reference both networks it was necessary looking for common and stable points. This was a difficult task because large changes in the slope surface had occurred. Some apparently stable points were rejected because large residuals were found after block triangulation. Finally, 10 common points between both epochs were selected at the foot and brow of the slope. Orientation was calculated with errors less than ± 3 cm (Table 2). Spatial coordinates of targets were also calculated and compared with the original surveyed values in 2000 by means of a 3D similar transformation (errors were below ± 3 cm; Table 2). After these results orientation of the 2000 block was accepted. Errors higher than those in 2007 were expected since the common points were natural points not as well defined as targets were.

Errors at control points (natural points) in 2000-epoch			
rms_{XY}	27.5	mm	Errors after orientation of 2000-epoch with common points measured in 2007-epoch.
rms_Z	29.7	mm	
$rms_{XY\ (MAX)}$	65.3	mm	
$V_{Z\ (MAX)(abs.\ value)}$	68.6	mm	
Errors at check points (targets) in 2000-epoch			
rms_{XY}	12.4	mm	Errors after 3D transform between computed targets and spatial coordinates surveyed in 2000.
rms_Z	3.0	mm	
$rms_{XY\ (MAX)}$	24.0	mm	
$V_{Z\ (MAX)(abs.\ value)}$	7.0	mm	

Table 2. Errors after 2000 UMK-images block orientation.

Figure 8. Some of the common points selected for referencing both photogrammetric surveys (2000-2007).

3.2 DTM generation for 2000 network

Once the orientation of the UMK block was accepted a point measurement process was carried out in order to define the DTM for the 2000 network. Since no stereoscopic pairs were taken, larger difficult in the measuring process with respect to the Canon block was found. As in 2007 block, more than 400 tie points were measured. The 2000 DTM (represented as a contour map) is shown in Figure 9.

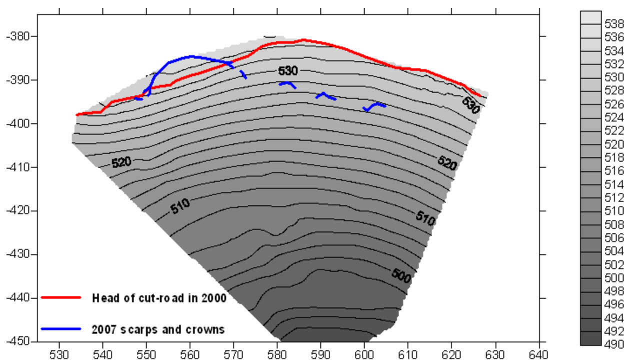

Figure 9. Contour map derived from the 2000 DTM. In red is the head of the talus road in year 2000. In blue the scarps detected in 2007.

4. SLOPE EVOLUTION (2000-2007)

4.1 Comparison of both photogrammetric networks

After evaluation of both networks the drastic changes occurred in the higher parts of the slope can be seen. The most noticeable feature is the retreat of the summit line (the head of the slope in 2000) because a landslide. This landslide has affected to near 20 m length of the summit line and the retreat of the scarp have been more than 5 m (Figure 10).

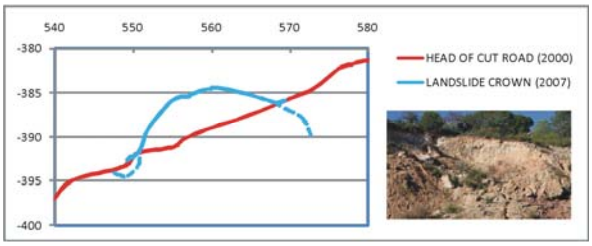

Figure 10. Plan view of the landslide crown in 2007 (blue) and head of the slope in 2000 (red). Image of this landslide in 2007 is shown.

Also an analysis of both DTM has been carried out with Surfer® 8. Figure 11 shows two profiles through both DTM: Profile I in the left side of the slope; Profile II in the right side. Profile I shows clearly the effects of the terrain instability showing the landslide (in the upper part) and the debris accumulation down the slope. A smaller accumulation occurs in the lower part because the material is retained by both barrier and mesh. In profile II there is less amount of material slide down the slope, since the landslide in this part seems to be shallower. In fact in profile I the shape of the section looks more irregular and instable than profile II.

A further analysis was done by comparison of height differences between both DTM. Figure 12 shows clearly the main landslide and a loss of material up to 5 m thickness. Large amount of material (up to 2.5 m) are accumulated down the slope. On the right side of the slope the loss of material is less, although with terrain losses up to 1.5 m (near position marked with A). Levels between ±0.25 m have been set white. This has allowed a better recognition of accumulation and denudation areas

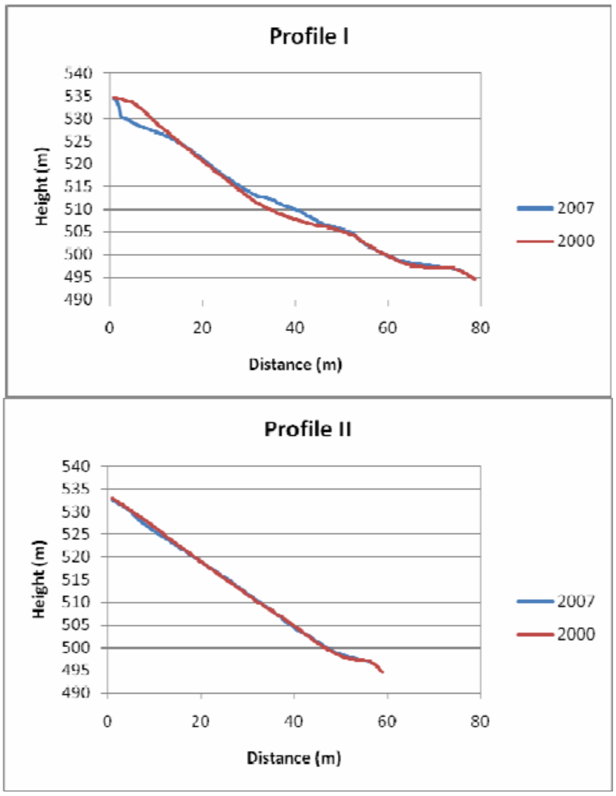

Figure 11. Profiles for both 2000 and 2007 DTM. Locations of profiles are indicated in Figure 12.

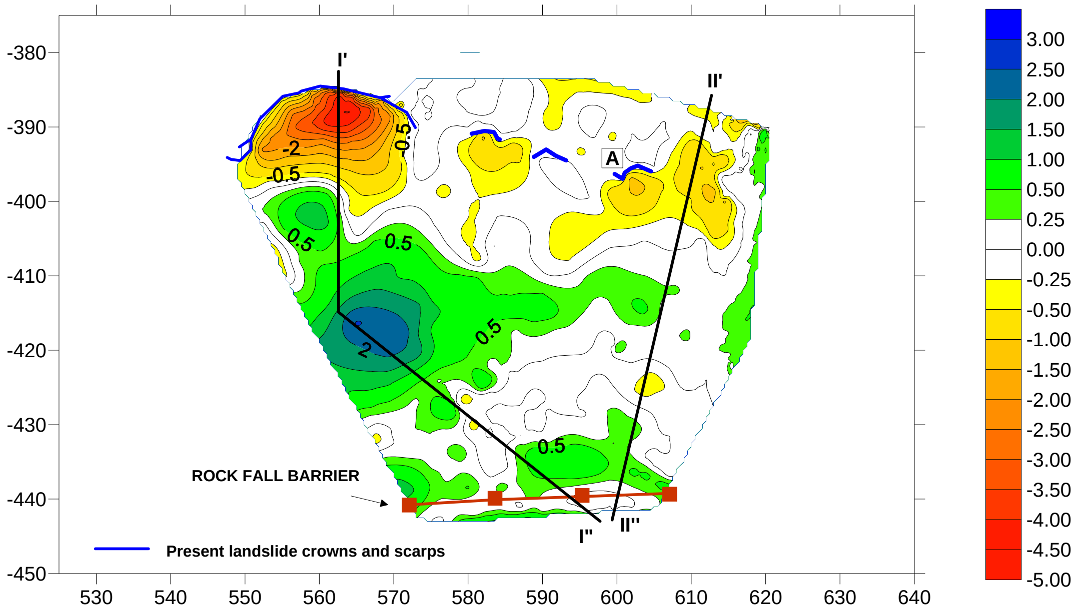

Figure 12. Height differences between 2000 and 2007 DTM. Red-yellow colours indicate denudation, blue-green colours accumulation. Profiles in figure 11 are marked (I: from I' to I"; II: from II' to II").

5. 3D LASER SCANNER SURVEY

At present, results from the photogrammetric survey are being compared with the use of a 3D laser scanner. An Optech Ilris 3D scanner has been employed (Figure 13). Data of the LIDAR survey are still at process, but some of the results can be shown. Three scan stations were set and the point clouds were correlated amongst them in order to referencing data to the same coordinate system. Since targets were also scanned, the final point cloud (more than $4 \cdot 10^6$ points) was referenced to the common local coordinate system. I-Site™ Studio software was used to correlate and reference the point clouds.

Figure 13. Optech Ilris 3d laser scanner

Indeed definition of the slope surface from laser data is more reliable than photogrammetric survey with respect to density of data. But intense post processing work is being carried out in order to filter the data (barrier and mesh, vegetation, targets, pylons, etc.). Figure 14 shows first results of LIDAR survey. The sector in this figure corresponds to the upper area of slope. The main landslide is clearly visible. After the use of geometric filters (with TerraScan module of Terrasolid software for processing laser data) and some manual edition, the vegetation (green colour) has been separated from terrain (brown colour). In Figure 14, contour levels (in red) from the 2007 photogrammetric survey have been added showing a good fit between both data.

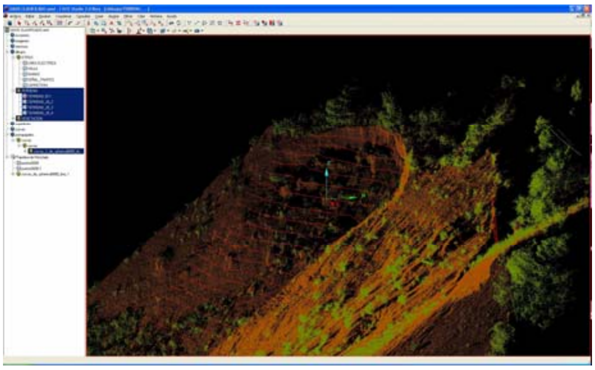

Figure 14. Screen capture from I-Site Studio showing the filtered laser data: vegetation (green); terrain (brown). Contours (red) from the 2007 photogrammetric survey have been added.

6. CONCLUSIONS AND FUTURE WORK

As conclusion, digital close range photogrammetric techniques were successfully used for landslide monitoring in a slope up to 100 m size, but at moderate costs with the extensive use of a non metric camera and comparison of DTM's evaluated at different dates (instead of photogrammetric recording of discrete points at permanent bench marks). Present off the shelf reflex digital cameras can achieve interesting accuracies when proper methods are used (convergent networks with selfcalibration), even in case of pre-calibrated cameras or when there is a lack of externally surveyed control points. Also stereoscopic networks can facilitate the generation of DTM, so a conventional mapping DPW can be used. In any case, low cost desktop DPW`s are also a cost effective choice. Anyway, the use of new powerful measurement techniques (3D laser scanners) has to be considered in this field because high performance in data acquisition. Although as main drawbacks, terrestrial LIDAR is a high cost technique (at least compared with the cost of a complete photographic equipment: camera body and several lenses) with an intensive and cumbersome post-processing.

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