EVOLUTION OF A DIACHRONIC LANDSLIDE BY COMPARISON BETWEEN DIFFERENT DEMS OBTAINED FROM DIGITAL PHOTOGRAMMETRY TECHNIQUES IN LAS ALPUJARRAS (GRANADA, SOUTHERN SPAIN)

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GI4DM, GeoInformation for Disaster Management

KEY WORDS: evolution, landslide, DEM, digital photogrammetry.

ABSTRACT:

The Alpujarras region at the South of Sierra Nevada Range (Granada, Spain) is a steep and rocky area with a high density of slope movements. One of the most significant examples because of its morphology, diachroneity, activity and magnitude is Almegíjar landslide whose evolution has been studied by different ways. It is a rock slide developed in the last 50 years, with a length of 250 m and a vertical interval of 140 m, showing a pattern of progressive activity in the last years. To the study of the landslide evolution, three aerial flights are available, corresponding to years 1956, 1992 y 2008. From the more recent flight (20 cm of spatial resolution, 4 spectral bands (RGB-NIR) and LiDAR data captured simultaneously in a combined flight) orientation of all flights has been carried out. Then, a high-precision digital elevation model of 2 m resolution has been built and edited from LiDAR data, meanwhile DEMs corresponding to the other flights have been generated by means of automatic correlation from the stereoscopic models, taking the high-precision model of 2008 as reference. The landslide evolution has been analyzed by the comparison between DEM, obtaining differential models by DEM subtraction, volumetric calculations and longitudinal profiles. The results show that the landslide started after 1956 and since then has been evolved continuously, the main scarp has increased and new minor scarps and cracks have appeared. As a whole, vertical displacements in depletion and accumulation zones have an average value of about 10 m.

1. INTRODUCTION

Remote sensing techniques have been applied in the last years to natural hazards studies related to landslides in several ways (Metternich et al., 2005; Chacón et al., 2006). A first group of techniques is the processing of satellite images in 2D, through two types of approaches: textural and multispectral analyses are often combined (Fernández et al., 2008) to automatic detection of landslides scarps and to determinant factors mapping. The irregular boundaries and surface textures often produce characteristic features that can be enhanced in remote sensing imagery through textural analysis (Hervás & Rosin, 2001). On the other hand, the most used multispectral analyses are color compositions, determination of vegetation indexes, spectral signatures analysis and digital supervised classifications.

In the landslide study analysis it is very interesting the 3D analysis using a multitemporal schema. 3D and especially stereoscopic analysis allows a good interpretation of landslides through recognition of morphological features such as scarps, accumulation zones, etc., not easily identifiable in 2D views. From 3D image views overlaying a DTM (Hervás & Rosin, 2001; Haeberling et al., 2004) to photogrammetric techniques such as stereoscopic viewing or DTM extraction (Weirich and Blesius, 2006; Gonzalez, et al., 2009), these methodologies have been used in landslides studies when data are available. Multi-temporal imagery has been used to study landslide activity from pixel change detection methods (Rosin and Hervás, 2003).

Besides optical remote sensing techniques, other techniques such as LiDAR and RADAR are also widely used. Terrestrial and airborne LiDAR allow very accurate DTMs (Derron and Jaboyedoff, 2010) and DInSAR allows the estimation of vertical displacements in a milimetric range from temporal series of images (Fernández et al., 2009).

Although some works use only image based techniques (Walstra et al., 2004; Karperski et al., 2010; Prokesova et al., 2010) o LiDAR (Sterzai et al., 2010), other approaches employ the combined use of both LiDAR and photogrammetry (DeWitt et al., 2008). Other additional methods such as GPS data measurements (Brückl et al., 2006) or historical maps digitalization (Corsini et al., 2009) can also be used.

In this work we will focus in the combined use of photogrammetric and LiDAR techniques, from which DTMs of different resolution and dates are obtained and compared to study landslides evolution. But, in previous works a detailed description of the methodology to geo-referencing data to the same reference system is not found. So in the present study we describe a methodology to address this issue clearly; it allows carry out accurate estimations about the displacements in landslides. The data georeferencing of each campaign (through a photogrammetric adjustment process) are made considering the most accurate data (corresponding to the more recent flight) as reference, and all available information is referenced to the same terrestrial coordinate system.

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2. GEOGRAPHICAL AND GEOLOGICAL SETTING

The study zone is located in the Alpujarras region, a mountain area at the South of Granada province between Sierra Nevada and the Mediterranean Sea (figure 1). This region is affected by many landslides processes such as rock falls, rock slides and debris flows because of a combination of a steep relief and materials prone to slope instability. These materials are metamorphic rock massifs belonging to Alpujarride complex of Internal Zones of Betic Cordilleras. The triggering factors of landslides are the rainfalls (irregular and often torrential) and the geomorphologic evolution of the zone.

The studied landslide is located in the channel of Guadalfeo River, next to Almegíjar, a little village in Alpujarras region, but it does not affect to urbanized zone or relevant infrastructures or edifications. It is a translational rock slide, with a net main scarp whose morphology correspond to an almost plane surface and a vertical displacement near to 20 m; besides, it presents minor scarps and debris flows in the front. Its dimensions are: length is about 250 m; width is about 300 m; and, vertical interval is about 140 m. Its activity appears to be not uniform (diachronic landslide) as will be discussed later.

The affected lithologies are mainly phyllites and quartzites of Permo-Triassic age; nevertheless, the landslide is located in a general unstable zone upwards in the slope, in which large unstable blocks and cracks can be observed affecting overlying carbonate rocks that drain water on the phyllites (figure 2).

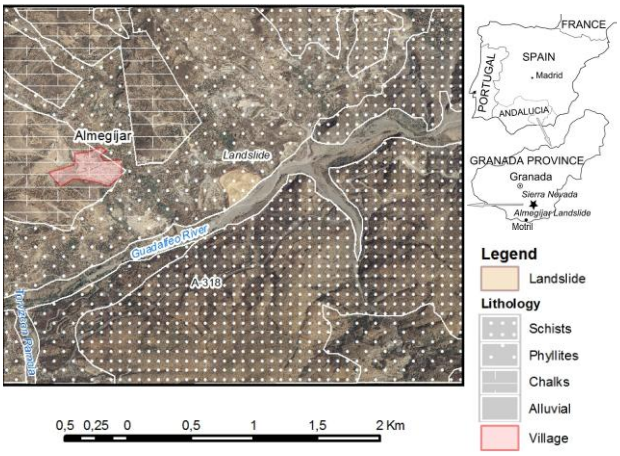

Figure 1. Geographic location.

Figure 2. Almegíjar landslide.

3. IMAGE DATA

First, an aerial photogrammetric flight carried out in 2008 is available. The data acquisition systems are a digital camera (Z/I DMC) and a LiDAR sensor (Leica ALS50-II) with GPS/IMU systems for direct orientation. The camera has 4 spectral bands, three in visible (RGB) and one in NIR. Besides, two historical flights are available corresponding to 1956 and 1992 years. The first one is a 1:33.000 scale flight and panchromatic film; the second one is a flight made by the Regional Government of Andalucia, with 1:20.000 scale and panchromatic film. The flights properties are shown in table 1 and its distribution in the study zone in figure 3. The considered period of about 50 years is wide enough to study the relief development, especially the evolution of the landslides in the study zone.

Campaign	GSD	Bands	Format
1956	0,60 m	Panchromatic	Film
1992	0,30 m	Panchromatic	Film
2008	0,20 m	RGB-NIR	Digital

Table 1. Properties of the aerial fights.

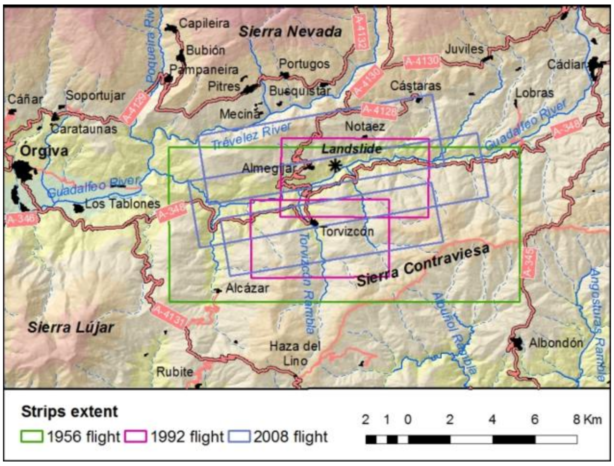

Figure 3. Flights distribution in the study zone.

4. METHODOLOGY

Digital photogrammetry is a step forward to the study of evolution of terrain morphology due to landslides or other causes. Working with digital photogrammetric stations a better and more accurate interpretation of changes can be carried out (Walstra et al., 2004; Gonzalez et al., 2009).

High quality landslide inventories (scarps, crowns, lateral boundaries, cracks, etc.) can be elaborated by means of digital 3D stereoplotting. A GIS overlaying of these inventories allows study the evolution of landslides in a given region and, identify zones of reactivation, enlargement or new movements; anyway, the activity of landslides even in those dormant or relict ones can be determined. Recently, the concept of diachroneity has been defined, in relation to activity and duration of movements (Chacón et al., 2010); some movements present an irregular development and a long-time duration, alternating periods of more o less activity that can be well described by several diachroneity degrees. The determination of diachroneity or activity of landslides in a region allows obtain not only susceptibility maps, but hazards maps.

Moreover, single landslides or unstable zones can also be analyzed by means of these techniques, building accurate DEM and digitalizing landslide features and boundaries in 3D. The evolution of a landslide can be studied if several campaigns are available. Two types of approaches can be made: first, the comparison between DEM obtained from different flights, calculating distances and volumes (Prokesova et al., 2010; DeWitt et al., 2008; Corsini et al., 2009); second, the comparison between points and features unambiguously identified in at least two campaigns that allows determine the 3D vectors between them to define in detail the cinematic of movement (Brückl et al., 2006; Karperski et al., 2010). In this work, we focus in the comparison between DEM to analyze the quantitative changes in landslide. Previously, a processing of aerial photography and LiDAR data is required to obtain accurate DEM for the analysis.

The next methodology has been developed by the working group and calibrated in some previous works (Cardenal et al., 2006, 2008). It includes the following steps:

1. Digitalization of aerial analogical photographs.
2. Image orientation using block adjustment.
3. Digital stereoplotting of morphologic features.
4. Building DEM and orthophographs.
5. Comparison of models and calculus.

4.1 Digitalization

The older flights, both panchromatic, require digitalization, Scanning has been made using a Vexcel Ultrascan 5000 photogrammetric scanner with a pixel size of 15 microns, that implies a spatial resolution or GSD equal to 0,6m and 0,3 m for the 1956 and 1992 flights, respectively. The more recent flight (2008) was executed by a digital camera and it is directly available in this format.

4.2 Image orientation

The process starts with the orientation of the more recent and accurate 2008 flight (GSD=0.20m). In this case, we have data for a direct orientation, although further refinement by means of bundle adjustment in Socet Set software has been carried out. For this operation, the points used in the control of LiDAR data have been incorporated, besides the flight control. In this way, a more robust adjustment and a better matching between photogrammetric and LiDAR data is obtained. After the quality control of this orientation and data matching, we can transfer the reference system to the other photogrammetric flights.

The use of control points that were accessible and identifiable on the field in an unambiguous way –in which GPS observations can be made- is difficult and even impossible when historical flights intervene, because the wide period of time between campaigns. So we propose to use control points measured in the reference flight (second order or transferred control points) that can be recognized in the other flights.

The main disadvantage of this methodology is the supposed loss of accuracy in the coordinates of the transferred control points regarding to the higher accuracy of the points of first order (observed externally to the system). However, since in this process we take as reference the flight with higher resolution, it may be admitted that the accuracy of control points obtained in this way is higher than the resolution of the lower resolution flights. Besides, because the control points are located directly on the photogrammetric flights (the one to be oriented and the reference) we can know at the moment if the control point is observable and recognizable in both flights. Finally, as a consequence of the aerial point of view, the operator can observe the whole study zone without limitations.

The process of control point transfer can be summarized in the following steps:

- Initial image pre-orientation in the reference system (approximated).
- Once the two flights are in the same reference system, common points in both flights are located in a stereoscopic or monoscopic way.
- All these points measured in the reference flight are considered second order control points in the flight to be oriented.
- Orientation is computed and the process is repeated, from step 2 to 4, until the result of the orientation are good enough.

At this moment, there is a spatial matching between the coordinates of points in both flights, because the stable zones (those not affected by landslides or other natural or anthropic causes between campaigns) must have a complete matching between points.

The quality of the orientation process can be checked uploading in the photogrammetric workstation the DEM corresponding to the reference flight (in this case, the LiDAR data) and the stereoscopic models of the 1956 or 1992 flights; if the reference DEM fits to the terrain in the stable zones (not mobilized) we can establish that the orientation is of adequate quality.

4.3 Digital stereoplotting

Since present aerial digital cameras capture four spectral bands (the three RGB and NIR), two types of color compositions have been prepared: true color composition (RGB) and false color (NIR-R-G). On the basis of these compositions and stereoscopic vision, we have digitized carefully landslide boundaries and other morphologic features (main and minor scarps, cracks …) in each stereoscopic model. The digital stereo-plotting has been made by means the edition tools of software Socet Set, and the result are lineal or polygonal 3D features, easily introduced in Geographical Information Systems.

This work has been applied to both recent and historical flights, although in the first case, the image quality produces a better identifications and cartography of the different features. Finally, we obtain inventories that will be used to the evolution study of landslides and to elaborate hazard maps. On the other hand, digitizing some features such as scarps, streams, slope changes, etc., in the stereoscopic models corresponding to historical flights allows DEM edition with a high accuracy and reliability.

4.4 Building DEM and orthophotographs

The reference DEM from the 2008 flight is directly obtained from LiDAR. The LiDAR raw data have to be processed to avoid usual discrepancies between strips; the procedure is the relative orientation of the LiDAR strips in a single block (made by an own developed software). Then, data are integrated with photogrammetric flight and a new orientation is made by means surface correlation if it is necessary. Finally the reference DEM was obtained resampling all data to a grid of 2 m resolution.

After historical images orientation has been validated and the 2008 reference DEM is available, the next step is to build historical DEMs. Because the reference DEM has a higher quality than that obtained by means automatic correlation working with historical flights, we propose a methodology to maintain quality as far as possible. For this purpose, the reference DEM is used as a seed model, modifying the other DEMs only in those zones where the correlation between models fails, instead to generate an entirely new model by means of automatic correlation or image matching. In these zones without correlation, the elevation was modified in an automatic way by means of the photogrammetric software and/or editing the model where it is not possible. With this procedure we pretend modify the DEM only in those zones where significant differences between models can be discriminate. In this way, the introduction of noise in stable zones is avoided and the analysis will be clearer.

DEM is edited through the stereoscopic viewing of contour lines overlayed on the corresponding stereoscopic model. Several break lines (scarps, ridges, streams, ways, etc.) were added. DEM edition finishes when all the contour lines fit properly the terrain in the whole study zone. This procedure allows to ensure the coincidence of models in the stable zones and to optimize the time employed in building and editing DEM, with respect to other methodologies in which the models are created and edited separately for each campaign.

The 1956, 1992 and 2008 DEMs corresponding to Almegíjar landslide are shown in the figure 4, in which the changes between the considered campaigns can be easily observed.

4.5 Comparison of models and calculus

The comparison between DEMs can be made in different ways:

- Vertical distances calculation between points of a DEM and the points of the reference DEM, subtracting the values of both models. Taking in account that both models are TIN format, the first points are the vertex of a TIN model and the second points belong to a side of the surface of the reference TIN model. These distances can be positives or negatives depending on whether the model to be compared is above or below the reference model.
- Absolute distances (defined as the minimum distances between DEMs) require more complex calculations algorithms and not are considered in this work.
- Volume estimation of material corresponding to DEM to be compared that is above or below regarding to the reference DEM. It allows estimate volumetric changes and losses, and it identifies the accumulation and depletion zones.
- Determination of longitudinal sections allows observe in detail the displacements of materials. If enough sections are available, the landslide cinematic can be reconstructed. In this way we can know if the movement has been planar or rotational around horizontal or vertical axes.

5. RESULTS

As first results, some qualitative aspects can be highlighted. As shown in figures 4 and 5, and in the 1956 images, the studied landslide developed after that year, although it is located in a global unstable zone, with some evidences upslope of older activity. This situation contrasts with the models and images corresponding to 1992 and 2008, in which landslide evidences such as a net main scarp, steps and terraces, minor scarps, accumulation zone in the toe moving on the river channel and open cracks are observed. Other features observed in the aerial images and in field examinations are the large extent of debris flow and gully erosion development.

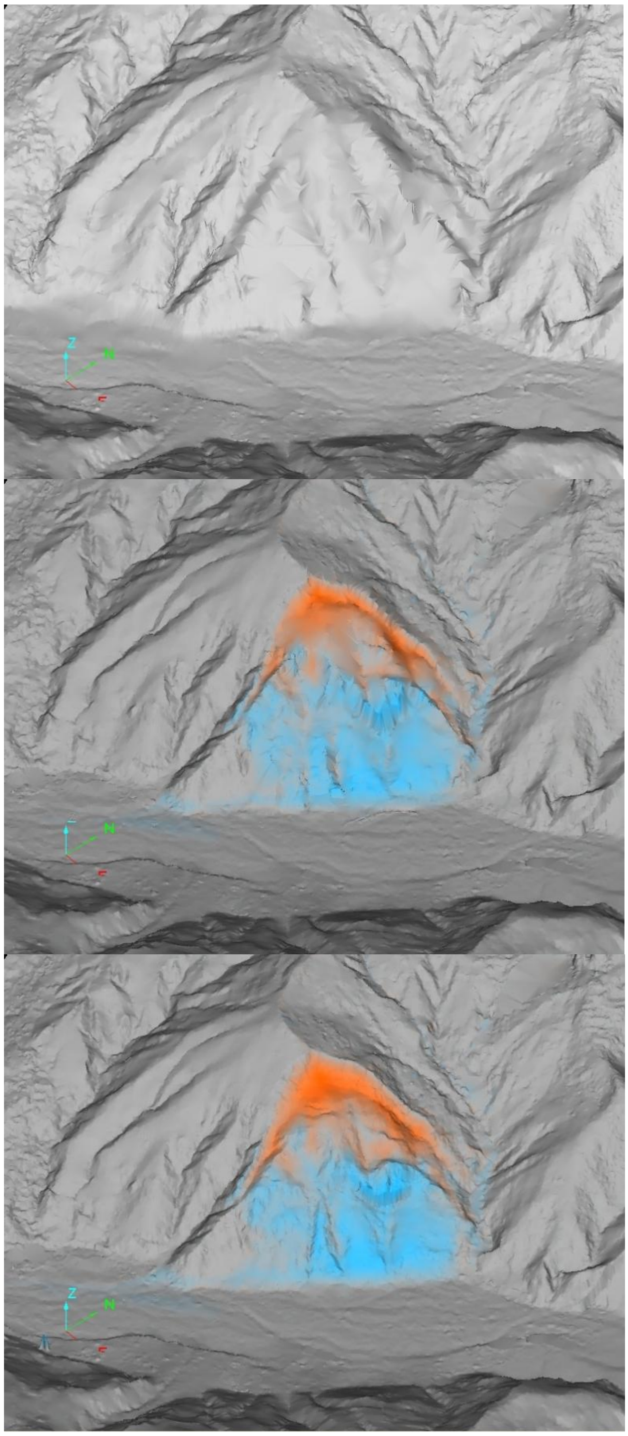

Figure 4. Digital Elevation Models: A. 1956; B: 1992; C: 2008. In orange: depletion zones; in blue: accumulation zones.

The comparison between the 1956 and 2008 DEMs –the whole considered period- shows two very different areas, the depletion zone in the upper part (under the main scarp) and the accumulation zone in the lower part; practically, there is not transitional zone from one area to another, as can be observed in the figure 5 and the profiles of figure 6.

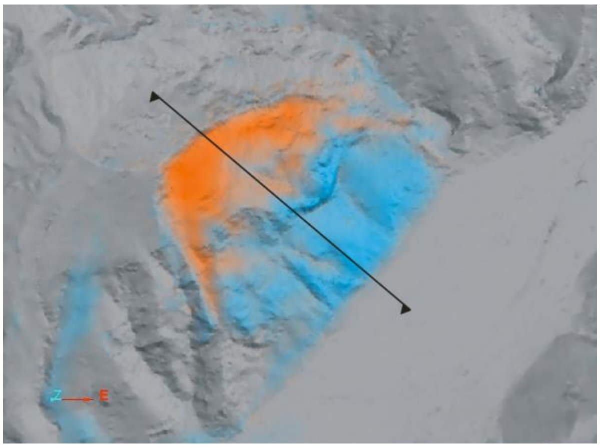

Figure 5. Comparison between DEMs (1956-2008). In orange: depletion zones; in blue: accumulation zones.

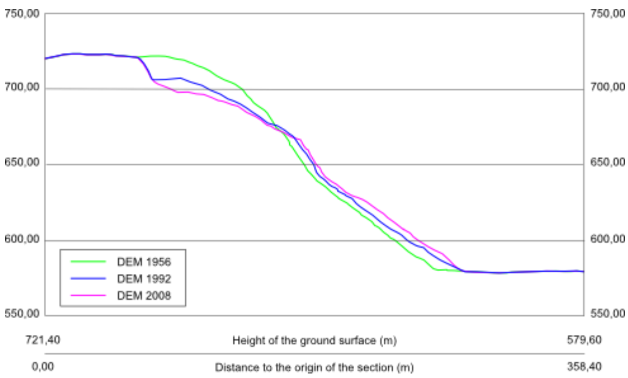

Figure 6. Longitudinal sections obtained from DEMs.

DEM subtraction reveals important vertical displacements. In the depletion zone there is a decrease of ground surface of 8,25 m average value, reaching maximum values of 23 m; in annual rate terms, this means 0,16 m/year. Meanwhile, in the accumulation zone the vertical distances between DEMs present an average value of 6,72 m with peaks of 27 m, that translated to annual rate gives an average value of 0,13 m/year.

Respect to both analyzed periods, the vertical distances between DEMs in absolute terms are higher in the first period (1956-1992) than in the second (1992-2008) (table 2). However, if we compared annual rates, we can observe very similar values between both periods and those calculated for the whole period.

Time period	Depletion		Accumulation	
	Average	Maxim.	Averag	Maxim.
Absolute mobilized masses (m)				
1956-1992	5,92	19,25	4,90	21,98
1992-2008	3,08	8,74	2,48	18,46
1956-2008	8,25	22,81	6,72	26,54
Relative mobilized masses per year (m/year)				
1956-1992	0,16	0,53	0,14	0,61
1992-2008	0,19	0,55	0,16	1,15
1956-2008	0,16	0,44	0,13	0,51

Table 2. Calculation of vertical distances between DEMs.

From the volume estimation shown in table 2, we observe that in the whole period (1956-2008) a depletion process occurs in the upper part with 190675 m^3 of material involved; meanwhile in the accumulation zone, the mobilized material is 177583 m^3, so the losses of material represent 13093 m^3, that are evacuated by the river. The annual rates show values of 3667 m^3/year of depletion, 3415 m^3/year of accumulation and 252 m^3/year of losses, being very similar in both periods.

Time period	Depletion	Accumulation	Wasting
Absolute mobilized masses (m^3)			
1956-1992	137629	128609	9020
1992-2008	62677	58605	4072
1956-2008	190675	177583	13093
Relative mobilized masses per year (m^3/year)			
1956-1992	3823	3572	251
1992-2008	3917	3663	255
1956-2008	3667	3415	252

Table 3. Estimation of volume differences between DEMs.

6. DISCUSSION

The presence of landslide evidences in addition to other features such as gully erosion or ravines formed recently –after landslides- reports about an important geomorphologic activity in this area that is also confirmed by the important losses of material that the river evacuates. This activity is not only recent but dates back hundreds or thousands of years as indicated by the presence of dormant and relict landslides.

The similar values of annual rates in the two considered periods of time may suggest that the landslide evolution are constant and uniform in time; however other qualitative observations suggest that this activity are not uniform and the movements are of a diachroneity degree of VII that define movements with an irregular activity alternating phases of low activity with reactivations, mainly due to heavy rainfalls that occurs in the region every 10-15 years. This statement should be checked with more data and analysis that will become soon.

From calculations, longitudinal sections and other evidences, the landslide can be considered as translational with a slide surface close to a plane and a thickness of a few tens of meters that partially flows in the front and is evacuated by the river. Evidences do not suggest a rotational slide of a large thickness.

7. CONCLUSIONS

Digital photogrammetry techniques and DEMs building and editing are proved again as a very useful tool to study landslide and its temporal evolution. The accuracy and consistence of these techniques allow detect small features and modifications.

In this work, we propose a methodology based firstly on the orientation of flights being the more accurate the reference flight; this processing way ensures a consistent data integration in the same reference system. Besides, the use of second order control points –extracted from the reference flight- to orient the other two flights allows to have well identified and accessible control points, and the orientation process is better warranted. Meanwhile, the building of DEMs taking as reference the model corresponding to the more accurate flight –obtained from LiDAR data- reduces the time to DEM Edition and avoids the noise introduced by the stable zones in the automatic correlation process, focusing in this way in mobilized zones.

Regarding results, the followed methodology allows identify and quantify depletion and accumulations zones with average values around 7-8 m and maximum values higher than 20 m in both signs. Besides, some ideas about landslide description (translational slide) and its evolution (diachronic movement with an annual rate of about 10-20 cm/year) can be deduced.

Nevertheless, current and further researches must give more information about the movement; in this way, more flights have to be used (they are available, especially in the last ten years). In the other hand, other techniques must be introduced, such as the determination of displacement vectors in significant points or the calculation of absolute distances reporting better about landslide cinematic. Finally, regional studies of landslides activity to mapping hazards will be addressed.

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9. ACKNOWLEDGEMENTS

This research was funded by CYCIT project CGL2008.04854, the ISTEGEO project RNM-06862 funded by the Andalusian Research Plan, and Research Groups TEP-213 and RNM-221 of Andalusian Research Plan.