INTEGRATION OF AIRBORNE LASER DATA AND HIGH RESOLUTION SATELLITE IMAGES OVER LANDSLIDES RISK AREAS

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KEY WORDS: LIDAR, radiometry, high resolution imagery, data integration, DTM, landslides

ABSTRACT:

When areas interested by catastrophic events like landslides are investigated, it is important to have a great amount of information with a greater than possible detail.
It allows to evaluate the damages that occurred on the territory, to get a precise picture of post event situation and to understand the reasons and the effects of the event.
This work starts from the availability of a great amount of different information (satellite images, airborne LIDAR data, DTM from maps, DTM from laser, ground surveys) over an area of Southern Italy that was involved in a significant landslide event in 1998. Particularly, laser data have been used in order to improve the geometric and interpretative features of a satellite high resolution QuickBird image. In fact, laser data provide a double 'product': an elevation information, and, therefore, a Digital Terrain Model, and, at the same time, an intensity response. The DTM can be used to orthorectify the satellite images, the intensity response to create an intensity raster image as to increase the capability of analysis and interpretation of the images.
In the present work the laser DTM accuracy has been evaluated in order to study the influence of different problems occurred during the laser survey, particularly problems with GPS signal acquisition. Furthermore, the work evaluates the accuracy of an orthoimage generated with a DTM obtained from the integration of height LIDAR data and a map derived DTM and analyses the use of intensity data to integrate the satellite image.

1. INTRODUCTION

Present work starts from the availability of a great amount of data over an area in the South of Italy (Sarno, Quindici and Bracigliano towns) hit in May 1998 by a catastrophic series of landslides that interested a wide and densely inhabited area. After the events, because of the lack of updated maps and data over the territory and in order to study the landslide phenomena, to prevent new disasters and to plan interventions and defensive works, different survey methodologies have been applied. Particularly, high resolution satellite images from different sensors (QuickBird and Ikonos) have been collected, ground surveys with traditional techniques (total station) and GPS over the landslide bodies and their surroundings and a LIDAR survey have been performed.
The aim of the present work is to integrate and use different data in order to describe with the best accuracy the territory and the changement happened to the ground topography due to the event. Particularly a satellite image and laser data, both height and intensity, have been used. An orthoimage has been created using a Digital Elevation Model derived from the integration of a pre-event DTM and LIDAR DTM carried out over the most changed area. An evaluation of the accuracy achieved has been performed either using check points or trajectories obtained through kinematic GPS survey or comparing the landslide boundaries and other significant features achieved by the digitalisation performed over the intensity laser data. Moreover, an integration of image and intensity data has been performed in order to obtain a better description of the study area.

2. STUDY AREA AND MATERIALS

The study area is a mountainous area wide, approximately 75 km^2, with strong slopes, height up to 1000 m a.s.l. and almost completely covered by a dense vegetation. As said, over this area a great amount of data from different sources is available. A panchromatic QuickBird image, laser data and ground control points from GPS survey have been used in present work.
The study area is represented in the white rectangle in figure 1.

1.1 High Resolution Image

In order to frame the study area we have chosen to use a QuickBird image. It is a panchromatic image (BASIC) with a nominal spatial resolution of 0.6 m, collected over the entire area in January 2003.

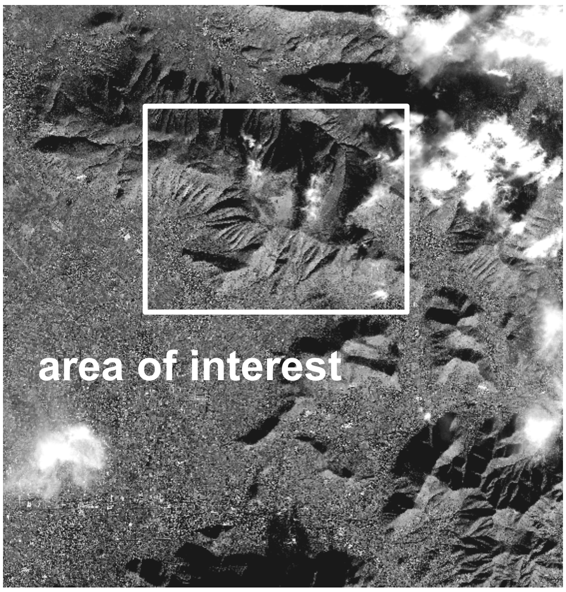

Figure 1. QuickBird scene and area of interest

The capture is not nadiral but it presents a rather high off-nadir angle equal to 15.04°. However, this feature is not too sensible for the aim of the study, but it could be important in case of study of urban areas with high buildings and artefacts (problems of shadows, perspective views, etc.) for which the nadiral view is fundamental.
The area of interest is the mountainous part of the QuickBird scene. Unfortunately, because of the season and the hour of the day during which the image has been collected (mid morning in January), it is affected by strong shadows, especially in the most interesting areas, along valleys and gullies and, in some cases, over the landslide detachment areas. On the contrary, capture during the winter season, allows the recognition of some features usually covered by tree canopies. Furthermore, even if the visual quality is good on the whole, the presence of clouds (percentage equal around to 16%) right over landslides areas prevents a clear visibility of study features.

1.2 Airborne Laser Data

Two different areas, included in the QuickBird scene limits, have been scanned through the Airborne Laser Scanning mounted aboard the helicopter. Both LIDAR surveys have been performed by the TopEye System, that allows to record two echoes and the intensity for each points in the near infrared wavelengths.
Over the largest area, around 21 km^2 wide, the eight of flight, equal to 400 m has brought to a density of 1 point to 1 m^2; instead, over the other area, around 2 km^2 wide, the lower height of flight, equal to 200 m, has led to a higher density of points, equal to 4 points to 1 m^2. In the whole, thirty million points have been collected.

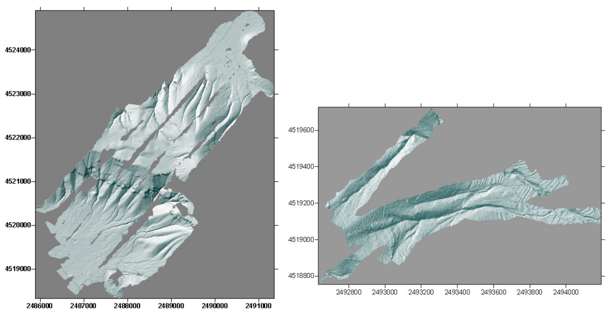

Figure 2. LIDAR DTM over two areas

As the results of the present work have to be framed in a national contest and have to be used from different users in a local contest, all data have to be expressed in the Italian Cartographic System Gauss-Boaga. For this reason, from the original reference system, WGS84, laser data have been transformed in Gauss-Boaga system through a Molodensky transformation with a precise estimation of parameters through ground points of a local reference network.
Data have been processed thanks to TerraSolid package. First of all, they have been checked in order to eliminate outlier points, then, through a TIN densification algorithm (Vosselman, 2000) they have been filtered and, finally, classified in three classes: vegetation, ground and buildings. The ground class points have been thinned up to three million points and, finally, they have been used in order to create the LIDAR DTM.
Moreover, because the LIDAR survey is composed by several strips, it has been necessary to join them together (Barbarella, 2003). The result of the strips adjustment is shown in figure 2, where it's also evident that strips don't cover the area with continuity but several holes among different strips are visible. For this reason the necessity of integrate data where they lack has risen.
As regards the intensity data, the infrared image derived from reflectivity of laser points has been utilised for the integration with the satellite image.

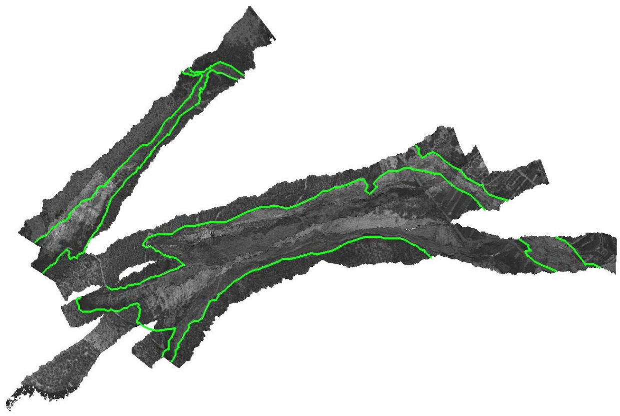

Figure 3. LIDAR radiometric response over Bracigliano landslide. In green the digitalisation of the landslide boundaries

1.3 IGM DTM

A digital terrain model provided by the Italian Military Geographical Institute (IGM) was also available over the whole area corresponding to the QuickBird scene. This DTM has been derived from the digitalisation of contour lines of 1:25000 maps in the Italian Cartographic Reference System Gauss-Boaga. Maps obviously date back the landslide event, so the DTM doesn't correctly represent the real and present morphology of the terrain along the mountainsides, from which a large amount of soil and mud teared away.
The IGM DTM over the scene is composed by four files for a total amount of 1 million points regularly gridded with a spacing of 20 meters.

3. INTEGRATION OF TERRAIN MODELS

The availability of the two digital terrain models with different resolution, allows to exploit advantages and quality of both of them, that is the greater detail of the laser DTM and the extension of the IGM DTM over the whole scene, needed for a correct orthorectification of the entire QuickBird image. Therefore, the two available DTMs have been integrated together.
For this aim, in order to integrate the raw data, and not interpolated data, an automated procedure has been created on purpose with Matlab package. Regular gridded data of the IGM DTM, corresponding to the area in common with the laser strips, have been removed from the file and replaced with laser points belonging to the relative gridding cells. The final result of the operation is a file composed by around 4680000 of sparse points, with a gridding space variable from 20 to 0.3 meters, denser over landslides and impervious areas where it's clearly necessary to have a great amount of details to describe the earth-bare, and a less density in the plain area and over the mountainous area not hit by landslides.

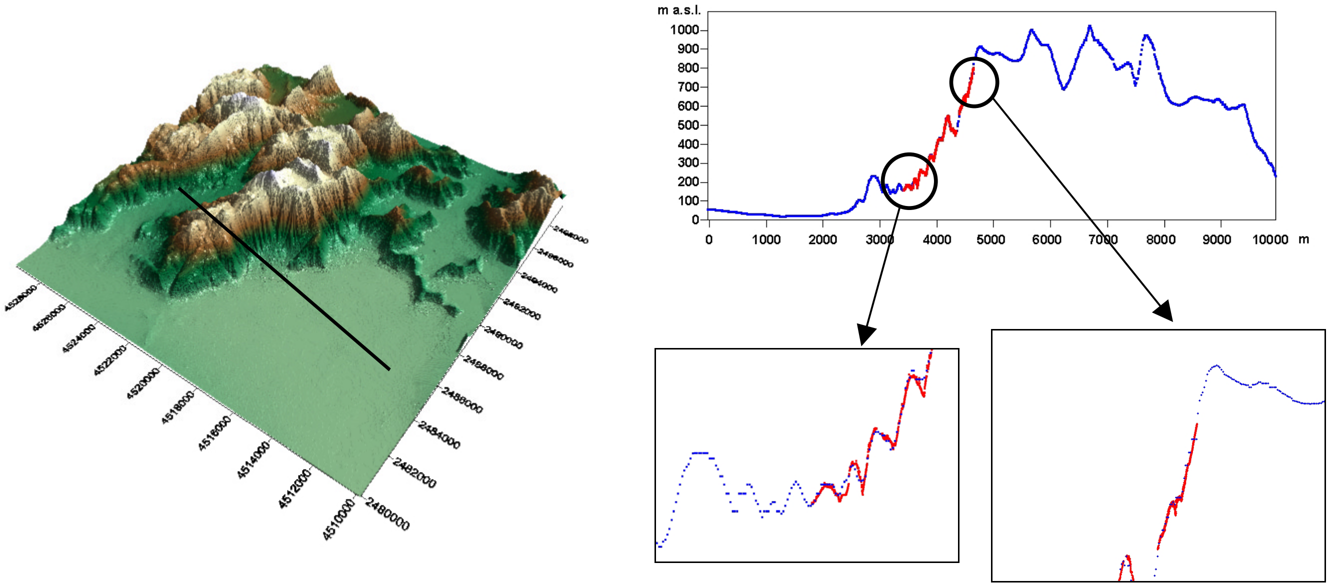

Figure 4. Integration of LIDAR and cartographic DTM. The transect shows the coherence between the two models. Blue dots represent the IGM DTM, red dots the laser data

Before integrating the different models, a pre-processing has been indispensable in order to get the suitability and coherence of elevation data. Each laser strip has been compared with the GPS-RTK ground survey and, for each one, it has been determined the height shift with respect to the ground truth. It has emerged that the shift is not constant between adjacent strips because of problems in GPS signal reception at the flight moment. Each strip has been corrected of the proper elevation and all the strips have been adjusted together so as to obtain a coherent final model .

Even the IGM DTM, that has a nominal height accuracy equal to 7-10 m, has been compared with the GPS-RTK ground survey. The average shift between the two data, equal to 3,50 m, has been applied to the DTM.

The reliability of Lidar DTM is lower than the nominal accuracy of the system (about 0.3 m), due both to the morphology of ground (slopes up to 45°) and to the applied corrections; however its accuracy, around 1-2 m, is higher than that one of the DTM obtained from the IGM.

The final result of these adjustment is a correct and uniform model over the whole area. Figure 4 shows the entire model and a profile over the integration area (black line over the DTM).

4. ORTHOIMAGES GENERATION

Orthorectification of the QuickBird image has been performed using PCI Geomatica OrthoEngine v8.2 software. The software adopts different geometric correction models; among them, the parametric rigorous model and the rational polynomial model are the most accurate.

It should be noted that the rigorous model can be applied to the entire scene and not only to a little part of it. Moreover, from previous studies performed by our group, it has been found that at least 20 ground control points evenly distributed over the whole scene are needed for an accurate orthorectification with the rigorous model. On the contrary, QuickBird image is delivered together with Rational Polynomial Coefficients (RPC), that, theoretically, allow an accurate orthorectification without ground control points.

Because of the availability of points from a RTK-GPS survey not over the entire image but only over the study area, we chose to ortorectify the image using the Rational Polynomial Model with coefficients delivered with metadata.

Actually, previous studies performed using PCI Geomatica showed that the software, when GCPs are not used, applies erroneous transformation parameters from UTM-WGS84 to Gauss_Boaga system, that leads to a shift of several tens of meters from the correct position, both in East and North coordinates.

For this reason, in order to eliminate the shift and the little rotations it is necessary to use some ground control points placed around the study area.

The orthorectification tests have been performed using different DTMs to evaluate the influence of the morphology change on the orthorectification procedure. First test has been carried out with the IGM DTM, the second one with the integrated DTM.

For both tests the geocoding procedure has been led with four ground control points placed as shown in figure 5.

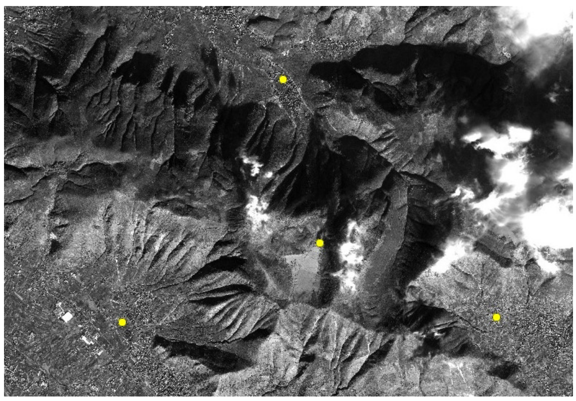

Figure 5. Subset of the study area of an orthorectified image. Yellow dots represent the GCPs location

5. ORTHOIMAGES ACCURACY EVALUATION

Orthoimages obtained from the two different processing have been compared through digitalisation of significant features located in areas where both DTM were available.

It was not possible to evaluate accuracy through ground check points because of the lack of a significant amount of points univocally recognisable on the image. In fact the GPS survey was performed just after the emergency when QuickBird images were not yet available

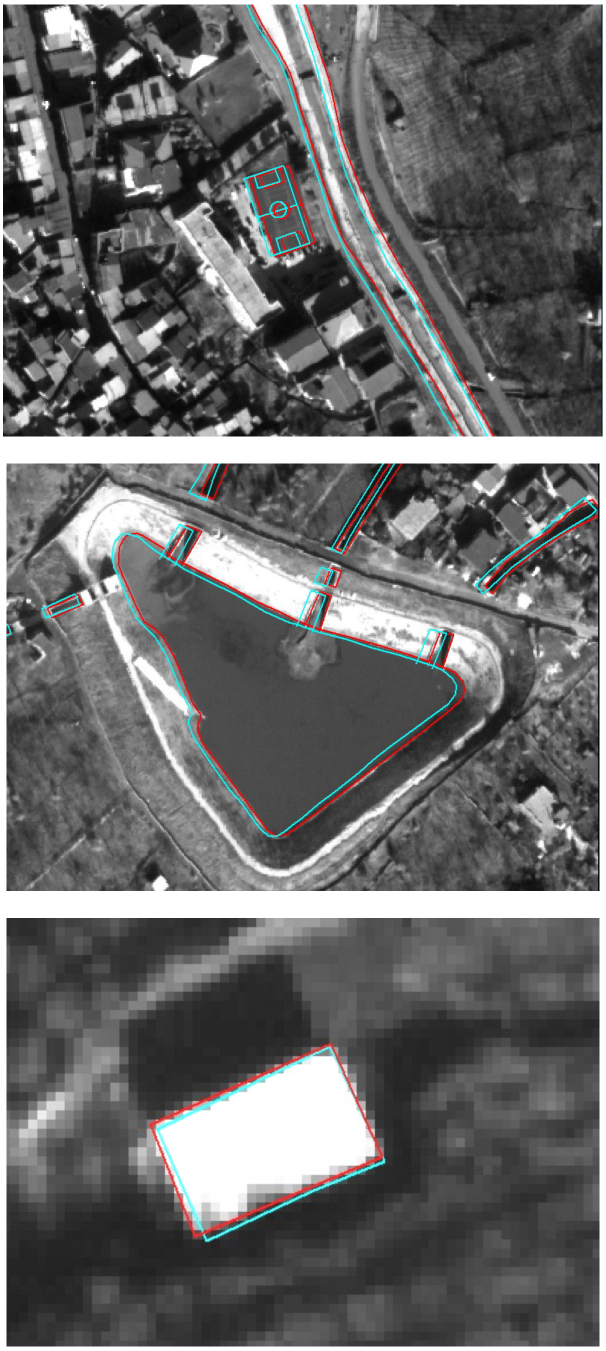

Figure 6. Features digitalisation over the orthoimages. Red lines are relative to orthorectification with integrated DTM, the cyan lines to orthorectification with IGM DTM. The base image is obtained from integrated DTM.

Figure 6 shows a visual comparison between the orthoimages obtained. The evaluation has been carried out by digitizing features in three different areas of the images: in the plain area, both in Quindici village (top image in the figure), and in Episcopio (central image), and in the mountainous area (bottom image). The displacement between the orthoimages is very variable over the whole area: in the plain areas it is around 4 - 5 pixels (around 3 meters), in the mountainous area it decreases to one pixel (around 60 cm).Actually, the lack of recognizable features in mountainous zones doesn't allow to have significant elements to compare.

6. INTENSITY LASER DATA INTEGRATION

As previously said, laser scanning records both the height and the intensity data of the hit points. Intensity LIDAR data are collected in the near infrared part of the electromagnetic spectrum. The value of intensity is normalized so it depends only from the reflectance of the object and not from the reflection angle.

LIDAR intensity is expressed in percent value; in the first LIDAR survey the intensity values of all points varies about from 0% to 45% (Bracigliano), while in the second one about from 0% to 25% (Sarno). This is caused by the different height of flight, different foot-print size, different scan angle and unfavourable atmospheric conditions.

In the area of landslide of Bracigliano, the intensity of first echo, that represents most of all canopy mass, ranges from 0% to 25%; while the intensity of last echo, that mostly represents the terrain, varies from 0% to 50% as the histograms show in figure 7.

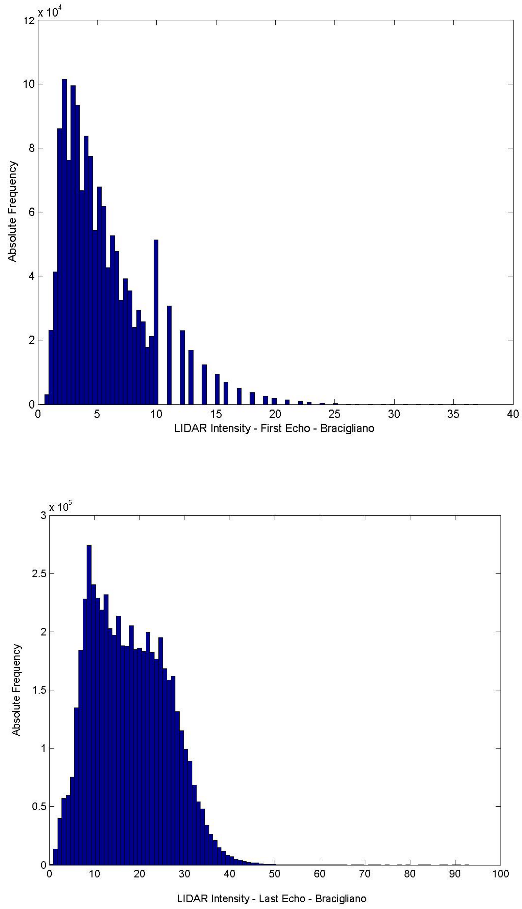

Figure 7. First and Last Echo Laser Intensity Histograms

LIDAR intensity data have been processed to produce a georeferenced 8 bit grey scale raster. Laser data with a density of 4 points/m^2 have been interpolated to give a 20 cm pixel resolution image (fig. 8), while from data with a density of 1 points/m^2 a 1 m pixel resolution image has been obtained (fig. 9).

Figure 8. Detail of laser intensity raster 20cm pixel resolution

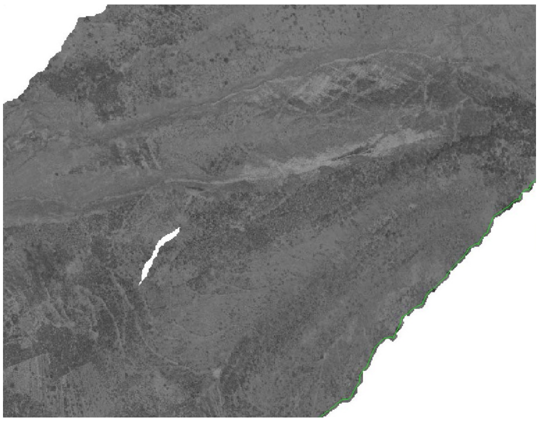

Figure 9. Detail of laser intensity raster 1m pixel resolution

Raster images obtained from last echo, in areas covered by vegetation, have low intensity values of pixel because the strength of laser power has been lost during several multi-reflection of laser beam. So rasters represented only with last echo are not useful to identify objects or entities, but they could be used to evaluate the vegetative state according to the loss of laser power passing through the canopy.

As the raster pixel varies according to the point density, the infrared image obtained from the less dense LIDAR survey results noisy because the dimension of footprint and the distance among the laser points make the raster grid size under-sampled.

However, most of features are clearly recognisable, particularly detachment surfaces of landslides, roads and fields are clear and identifiable. This raster image provides a support to understand ground surface state. The intensity image can be seen as a secondary product to supplement the primary elevation models rather than a purely stand-alone product.

The intensity image, thought having similarities to panchromatic images, does not provide the radiometric resolution of the satellite orthoimage that is achieved as 16 bit raster.

The raster images from laser data have been used to integrated the QuickBird orthoimage over that areas that are not clearly visible because of presence of shadows and clouds (fig. 10).

In the QuickBird image the landslides, particularly the detachment surfaces, are not identifiable, while, on the contrary, these objects are clearly visible trough the Lidar intensity. Moreover the pixel size of lidar intensity image is more detailed than the pixel size of QuickBird image over Bracigliano area. So we can integrate QuickBird image with intensity lidar data and eliminate shadows and clouds over the areas that have to be studied. At present a simple overlay of the two images has been performed, but a procedure of fusion is under study.

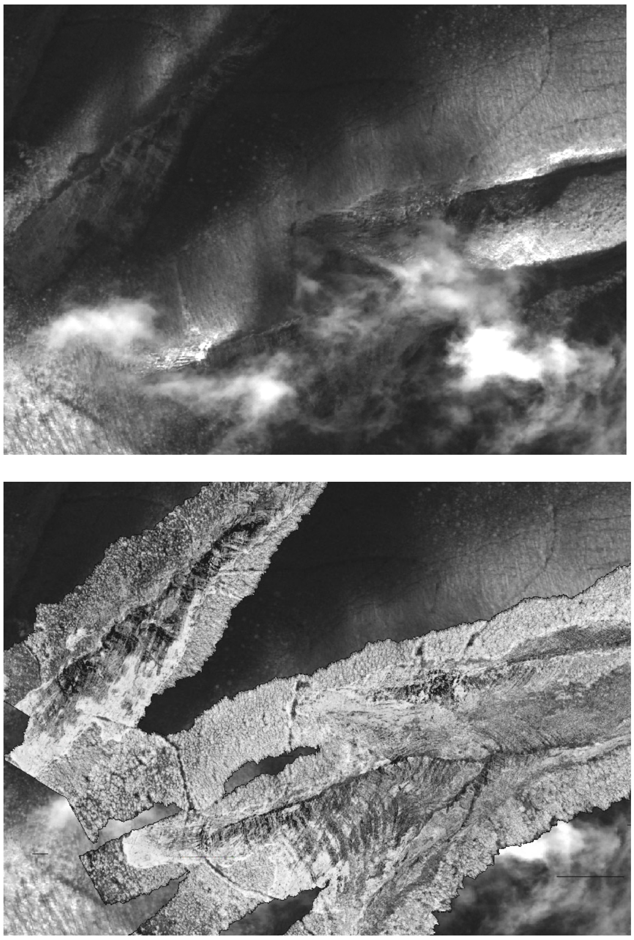

Figure 10. Particular of an orthoimage and overlay with the intensity laser data over a landslide detachment surface

A procedure to verify the planimetric differences between the images is to compare the vectorials of landslides and other objects obtained from intensity LIDAR data and the other ones obtained from the different QuickBird orthoimages.

Moreover, the vectorials that describe the shape of landslides obtained from digitalisation of intensity raster, can be compared with the contour lines that represent the same value of intensity. These ones derived from resampling the raster in a new grid composed by 64 classes of grey scale in accordance with the belonging to areas with the similar radiometric characteristics (fig.11). Particularly, around the landslide bodies these contour lines identify the changement of materials between the bare rock (sliding surface of landslide) and the undamaged soil and vegetation.

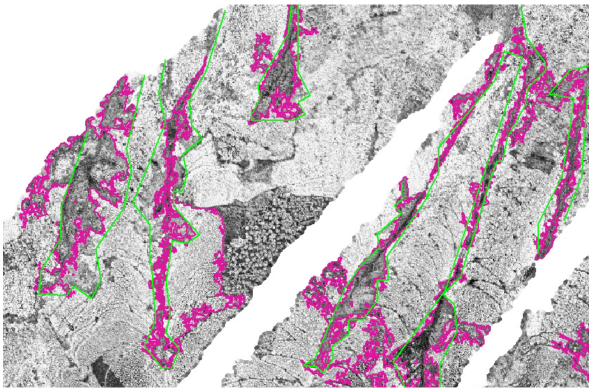

Figure 11. Vectorials of landslides; in green from manual digitalization, in pink from automatic digitalization

7. CONCLUSIONS

The attempt of integration of DTM that present different characteristics of grid spacing or extension requires automated procedures that are still under development. In fact, before integrating data, it is necessary to check and remove the offset among the different DTM in comparison with reference data.
Tests of orthorectification performed with the two DTM showed an improvement in metric accuracy of the orthoimage, but not so significant as it should be expected from the use of a more detailed DTM. Probably it has to be due to problem with GPS signal reception that compromised in such cases a good LIDAR survey (and, therefore, the generation of DTM).
The use of intensity data from LIDAR survey allowed a better interpretation of the territory, above all in those areas that in the satellite images are covered by shadows and clouds. A further work will be directed to perform a real automated integration and fusion of lidar intensity values and satellite images in order to make a complete and detailed description of the study area.

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ACKNOWLEDGEMENTS

A special thank to Prof. Salvatore Troisi (Istituto Navale of Naples) for providing the QuickBird image and to Mr. Claudio Abbondanza for his valuable contribution.