ASSESSMENT OF LIDAR AND DIGITAL CAMERA DATA IN THE CONTEXT OF RAPID CHANGE DETECTION METHODOLOGIES

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ABSTRACT:

Emergency mapping is one of the areas studied by the Centre of Topographic Information within the Emergency Mapping project of the Natural Hazards and Emergency Response Program of the Earth Science Sector, Natural Resources Canada. Rapid mapping, detection, and monitoring of the landscape changes are significant operations in an emergency mapping response program. Quick data acquisition using LIDAR technology, also known as laser altimetry, is a rapid way to generate dense accurate DEM of the topography and the various structures. The overall objective of the present work is to test and evaluate the acquisition, processing and handling of LIDAR DEM data collected simultaneously with optical data. This includes also the use of the intensity image captured by the LIDAR system as well as indicative examples for features extraction. LIDAR and digital camera data, airborne GPS and GPS field control were acquired for an area of approximately 5 square kilometers along a railway and watercourse in the Ottawa region. Additionally, independent GPS kinematic field survey where more than 300 points were collected as independent checkpoints. The Lidar data (direct measured DEM data and intensity) were evaluated towards optical (photogrammetric) data and the ground GPS measurements. The comparison analysis among the various datasets (e.g., LIDAR and photogrammetric DTM, LIDAR and GPS check points, LIDAR and GIS vector data) was performed using different approaches as point to point comparison, point vs surface, profile vs profile, surface (shape) vs shape, considering as well the in-flight GPS measurements and attitude data derived from inertial measurements. The potential of LIDAR data in contributing towards feature extraction and data visualization is also presented.

1. INTRODUCTION

1.1 Context of the present work

Current mapping applications such as generation of topographic information and geospatial database updating, require the implementation of rapid and economic processes due to the limitations in the available resources. Canada is no exemption to this, especially due to its vast territory and its aged National Topographic Data Base (NTDB). Various approaches were investigated at the Centre of Topographic (CTI) for the rapid change detection using imagery (raster) vs vector data comparison. The work focuses on the elaboration of tools for the automatic or semiautomatic extraction of topographic features from satellite imagery and the simultaneous change detection. Good results were obtained for the updating of lakes, the predominant topographic feature in the North of Canada (Armenakis et al, 2002, Armenakis et al. 2003, Armenakis and Savopol 2004)

In addition to their utility for current mapping operation, the change detection tools are even more critical for emergency mapping. Indeed, ***rapid*** detection, monitoring and tracking of landscape changes are essential tools for an emergency mapping response situation as the quick acquisition of new geospatial data, including DEM and digital imagery. The LIDAR, also known as laser altimetry is a rapid way to generate dense accurate DSM / DEM of the topography and the various structures. The use of the returned intensity signal and the addition of an imaging sensor (digital camera) could increase the utility of such a system.

The overall objective of the present work is to test and evaluate the acquisition, processing and handling of LIDAR data collected simultaneously with optical data and the extraction of urban and sub-urban features required for a rapid change detection system with possible application for emergency mapping.

The aim is to use existing (before the event) and current (after the event) geo-spatial data and to produce change information for the updating of the geo-databases and for monitoring and tracking the type and rate of the landscape changes.

2. ABOUT LIDAR

2.1 General use of LIDAR systems

The airborne laser scanning technology (Wehr and Lohr, 1999; Baltsavias, 1999a) also known as laser altimetry emerged in the last years as a leading technique for rapid collection of high accuracy, high density DEM. To be more precise, an airborne laser scanning system will produce a Digital Surface Model (DSM) and a Digital Elevation Model (DEM) can be derived using specific data process methods. The most common name for this technique was "airborne laser scanning" but in the last years the name of "LIDAR" from 'Light Detection And Ranging' became more popular. Same users prefer the spelling "LiDAR". Another name used is "Laser Range Finder" or "LRF" (Axelsson, 1999).

The LIDAR technology exists for at least two decades but in the last several years we see its wide use in topographic mapping because of the rapid, very precise generation of dense terrain elevation data. An extensive comparison between Photogrammetry and LIDAR mapping is given by (Baltsavias, 1999b).

LIDAR is used by diverse sciences sectors that were used to have their own, specific (non cartographic) measuring techniques. Such examples are:

- Detection and measure of individual trees (Persson et al, 2002)

- Measurement of snow packs depth beneath forest canopies (Hopkinson et al., 2004)
- Pipeline mapping and safety applications (Tao and Hu, 2002).

So far LIDAR surveys have been done over small areas because of their high cost.

3. TYPICAL EMERGENCY MAPPING NEEDS

3.1 Emergency situations and geo-spatial data sets

There are many situations that can be considered as an "emergency". In the last decade in Canada, most of these situations were generated by natural disasters as the flooding in Manitoba and in the Saguenay region (Quebec), the ice storm in Québec and Eastern Ontario, large forest fires and the hurricane in Atlantic Canada. Other natural disasters are possible as earthquakes, tsunamis and massive landslides. Environmental accidents are also possible and there are so many possible scenarios, from a 'classical' oil split to the worst toxically chemical or nuclear contamination.

The number of 'emergency possible scenarios' will be dramatically multiplied if we consider all the possible trigger - events such as a traffic accident, a human error, a natural disaster (as a earthquake damaging a chemical plant) or an 'act of war' or a sabotage. In addition, the emergency services will have to take in consideration the specific local conditions such as the spatial distribution of the human population, the meteorological conditions, the availability of medical services, the access roads that are in service, availability and location of possible shelter places, etc. It appears that a large variety of situations could result from all these possible emergency situations and the specific needs could be different from case to case. However, some general trends can be seen.

For the needs of the present paper, we will use the term of "emergency services" for the authorities in charge to deal with an 'emergency situation'. From the point of view of a geomatics professional, it appears that in almost all situations, the emergency services will have to deal with:

- a variety of geo-spatial data sets (as the city plan, evacuation routes; map of electrical & water networks, etc.) that have to be consulted repeatedly
- Almost all the new information received as result of the emergency situation has a direct or indirect geo-spatial component (examples: location of the accident/disaster, location and extension of damages, location of victims, position of traffic obstacles, closed road segments, collapsed bridges, location of shelters, etc, etc.)
- The geo-spatial component has to be considered and integrated in order to conduct the recovering operations.

The emergency services will have to be trained to use modern geomatics tools for the manipulation and the integration of the geospatial information described above.

An 'Emergency Mapping' group should exist at the governmental level for the preparation of typical 'emergency mapping products', for the training of local emergency services about the use of 'emergency mapping products' and the integration of other geospatial products and information.

3.2 Typical emergency mapping needs

The emergency services will use maps and a variety of geospatial information for their main tasks. We can consider the following list of typical mapping / geo-spatial data needs in the case of an emergency situation triggered by a (simulated) chemical accident:

3.2.1 Reconnaissance purposes:

- *Emergency situation acknowledgement and primary localization:* The first communication about the accident could be just a phone call but it will already contain a geospatial component with the location of the accident (example: "It was an explosion followed by a fire at the chemical plant at the address 123 on Acid Street").
- *Disaster understanding and primary damage evaluation:* The fire department will locate the fire on their map (or GIS system). The fire department will evaluate the situation ad will trigger the Emergency Services and will give the first estimation about the dangers for the local population. In some situations it could be very useful for the situation understanding to get some airborne digital imagery. Some police departments are already equipped with visible and infrared digital cameras (video or frame based) and are using them onboard helicopters.

3.2.2 Monitoring purposes:

- *Disaster evaluation and dynamic estimation of the danger for human population:* The emergency services will have to integrate a variety of information from specialists about the toxicity of the released substance, from the meteorological services (wind direction, intensity and forecast) for the definition of the evacuation area and from the own topographic data for the distribution of residential areas, schools, hospitals, potential shelters etc inside the evacuation area and in the neighbourhood region. Alternative road access should be defined. Airborne or satellite high-resolution imagery could be very useful for these tasks. Important decision will be made after the integration of all those pieces of information, all having a geospatial component.
- *Supervision and monitoring of rescue/recovery operations:* As the situation can change continuously with possible extension of the evacuation area, the Emergency Services have to update again and again the information. There is a need for a kind of 'dynamic map' to keep track of all these changes.

3.2.3 Damage assessments and reconstruction planning:

Damage assessment*:* there is a need of detailed mapping of the disaster area and change detection operations by comparing with the situation just before the event. It could be very important to record digital pictures over the disaster area from the beginning and during the rescue / recovery operations as by their nature, such operations could include the demolition of the damaged buildings and/or industrial facilities. The same images could be used for others tasks (disaster understanding, monitoring of rescue operations, and others). For an immediate use in '*Disaster understanding and primary damage evaluation' for example*, immediate access to the data is important and no precise geo-referencing is mandatory. However, true ortho-images will help for recovery operations and other tasks as 'post mortem' precise damage assessment.

3.3 Typical problems for the Emergency Mapping Group

From the point of view of the Emergency Mapping Group, all the needs described in the previous section could be described as two main mapping problems:

.A.- The need for up-to-date topographical information showing the situation ***just before the emergency situation****;*

B.- *The need to acquire as quickly as possible heterogeneous geospatial data from the disaster area* ***after the emergency*** *situation in order to understand and monitor the situation, to evaluate the damages and the risk for additional damages and injuries, to plan and monitor the rescue/recovery operations. Same data (as high resolution imagery) should be recorded repeatedly over the same area for monitoring needs.* In addition, the team has to address the problem of integrating these layers of data from divers origins, not necessary homogenous, having different resolutions and precision.

In a real life situation, the separation between these two main cartographic problems is not so clear. In many areas the existing topographic information is not updated on a regular basis and some important changes for examples for the local road network (such as access roads to industrial facilities) are not included in the last version of the topographic database. The Emergency Mapping Group will face the challenge for example to use the new imagery layers recorded after the disaster for 'situation understanding' purposes and in the same time for the updating of the old topographic information. Same confusions and errors could happen.

Another possible issue is the delivery of geomatics outputs to the main group of users, the emergency services, in order to help the understanding of the ongoing changes. This issue is not discussed in the present paper.

4. OUR TESTS IN OTTAWA SOUTH

4.1 Description of the test

The Centre of Topographic Information (CTI) began to investigate in 2001 the development of rapid mapping and rapid change detection systems for current mapping operations and for emergency situations. A contract was granted in 2002 to Mosaic Mapping Systems Inc. of Ottawa for an airborne survey of a test area of about 5 square kilometres (1.5 km x 3.5 km). The contractor had to provide a turnkey airborne survey, complete with data acquisition of LIDAR and digital camera data, and GPS field control.

The overall objective of this project was to test and evaluate the acquisition, processing and handling of LIDAR DEM data collected simultaneously with optical data and their contribution to a rapid change detection system.

Flight and LIDAR Parameters:

Flight Altitude:	apprx. 300 m AGL (Above Ground Level)
Swath Width:	apprx. 300 m
Laser Wavelength:	0.9 µm
Scan Angle:	up to +/- 30 degrees
Flight Overlap:	40 percent
Flight line Spacing:	apprx. 140 m
Point Density:	0.4 m x 1.0 m (approximate and adjustable)
Scan Rate:	34 hz (approximate and adjustable)
Data rate:	10 MHz
Beam Divergence:	3.0 mrads (90 cm spot size at 300 m)
Collection Mode:	Last Pulse and Intensity

Digital Camera Data:

Image size:	2300 x 3500 pixels,
Resolution:	about 8 cm, at 300 m
Image Swath Size:	apprx 400 m x 260 m, at 300 m

A second flight (recording optical images only) was flown at 900m above ground.

The test area was chosen in the South of the City of Ottawa along the Rideau River, close to the Ottawa Airport. One of the selection criteria was to have a variety of topographic features and land use categories: roads, railways, two important bridges over the Rideau river, residential and industrial areas with buildings of different sizes, lakes, some vegetation spread across the residential area, a more dense forest area along the river and some terrain height variation.

4.2 Reference data

Landscape change detection analysis involves the comparison of two or more spatio-temporal datasets and the identification and location of differences in the patterns of two spatio-temporal datasets. For change detection operations it is important the have a good spatial registration between the two data sets. In order to test the change detection operations and other mapping operations needed for emergency mapping as merging/fusion of heterogeneous geospatial data sets, more imagery and digital topographic data were acquired for the test area:

- National Topographic Data Base (NTDB) data set 31G05;
- Colour aerial photography from 1999 at 1:15 000 scale.

In addition, for the evaluation of the LIDAR data and the associated digital camera, a data set of over 230 check points have been measured by the Mapping Services Branch personnel using the GPS kinematic technique. This data set was used only as independent checkpoints and was not communicated to the contracting company. A number of 6 points were signalized.

Part of the GPS check points were recorded as profiles over different slope shapes: across and along a railway track, along a country road with moderate, constant slope, across a 5 levels building and its attached flat parking lot, etc.

4.3 Results of Ottawa tests

4.3.1 A priori accuracy estimation:

The expected accuracy was estimated a priori using the manufacturer specifications of all the components of the Mosaic Mapping LIDAR system and taking in account the company's experience in operating the system in standard terrain conditions and in processing the data.

Considering a confidence level of 95% (2 sigma), the expected accuracy of the LIDAR data was as following:
a.- For the absolute Vertical Accuracy: +/- 0.15 to 0.25 meters on Hard Surfaces; +/- 0.25 to 0.40 meters on Soft/Vegetated Surfaces (flat to rolling terrain); +/- 0.40 to 0.75 metres on Soft/Vegetated Surfaces (hilly terrain).
b.- For the absolute Horizontal Accuracy: +/- 0.75 to 1.0 meter on all but extremely hilly terrain.

4.3.2 Evaluation of the LIDAR DSM and DEM:

The LIDAR data was delivered in two versions:
- The 'original' data set containing all the laser signal returns called 'all-returns' was used to produce the digital surface model (DSM),
- The filtered data set produced using 2 automatic filtering processes and an interactive editing, intended to eliminate all the noise, the buildings, the trees an all objects above the

ground. It was used to produce the digital elevation model (DEM) called also digital terrain model (DTM). This data set is named “bald-earth”.

Visual evaluation:

A first general visual evaluation was done by displaying the LIDAR DSM and DEM as 3D perspective using the ArcGIS software from ESRI. For a better visualization, the Z dimension (highs) was exaggerated by factors 3 and 5. Both the DSM and DEM give a general good image of the terrain and its general morphology due their high resolution (1m cells). However, the DSM produced from the “all-returns” data set contains a large number of ‘spikes’. The DEM produced from the ‘bald-earth’ data set has no more nosy spikes but is less useful in the emergency mapping context where it is important to visualize the terrain surface with all man made objects on it as buildings, bridges and all infrastructures. Bald earth only is not interesting for this user group.

A comparison was made between the LIDAR DSM and a photogrammetric DSM produced from the 1:15 000 scale aerial photos with a planimetric resolution of a 5 m grid. The photogrammetric DSM is very smooth and has practically no spikes and gives a better general image of the nature of the terrain. However, due to the important difference in the spatial resolution (5 m cells vs 1 m cells), it is almost impossible to identify small buildings on the photogrammetric DSM without further information and the bridges and the water bodies have to be edited manually. On the LIDAR DSM most of the buildings are recognizable, except some houses in a residential area having mature, high trees. Bridges are easy to identify as most of the railway due to the high resolution of elevations values allowing to recognize practically all embankments. Due to the less interest for the ‘bald-earth’ DEM in the emergency mapping context, it was decided to use the ‘all-returns’ data for the other tests.

Some of the spikes generated probably by noise have an elevation value over 200 m, out of the range of the terrain inside the test area (between 75m and 120m) even considering the existing buildings. A threshold was used for cutting off all the elevations values outside a range of 74 m to 120 m and was applied to the row data creating a separate data set names ‘Range cut-off’. For noise reduction, the DSM data was filtered using two simple median filters with a window size of 3 x 3 and 5 x 5. The results were fair but the differences in noise reduction between the 3 x 3 median filter and the 5 x 5 median were not significant. However, it seems that same valuable elevation information might get lost using the 5 x 5 filter and the recognition of small objects and buildings will be compromise. Only the 3x3 median filter was used for all further analysis.

Evaluation of the LIDAR vs GPS checkpoints

a. Direct comparison with GPS check points:

A set of 203 GPS check points were used to evaluate the precision of the elevations values from the DSM generated from the ‘all-returns ’LIDAR data set after applying the above described filtering methods: the out of range cut-off and a 3 by 3 median filter. The results are presented in Table 1.

With a value of 1.82 m for the standard deviation of the ‘Out-of-range cut-off” data set, the precision seems to be far from the expectations. However, it should be remembered that the two data sets have still some noise like we can see from the Min. and Max. values for the differences. After eliminating the 3 highest differences, the standard deviation dropped to 0.64 m, a value closer to the expectations. Comparing with the ‘bald-earth’ data set was not possible as a number of GPS check points are located on the top bridges and industrial buildings that were eliminated by the filtering process used to generate the ‘bald-earth’ DEM. It appears that there is no significant bias with a mean value of 5 and 6 cm.

	Min (m)	Max (m)	Mean (m)	Std. dev. (m)
Out of range cut-off	-19.0	10.7	-0.05	1.82
Med 3	-3.2	10.6	0.06	1.25

Table 1: Differences between GPS and LIDAR DSM

b.- Comparison of terrain profiles

An other set of evaluations was done using the a set of profiles recorded using the GPS kinematic technique across some typical features of the test area: across and along a railway track, along a country road with moderate, constant slope, over a 5 levels building and the attached flat parking lot. These profiles were compared with filtered ‘all-returns’ LIDAR data set and a set of two DSMs created from the digital aerial images using the Leica Helava DPW. A typical profile evaluation is shown in Figure 2. It appears that the LIDAR DSM is very close to the GPS profile. The standard deviation is 0.21 m computed over all GPS recorded points of the profiles and the mean value is 0.14 m.

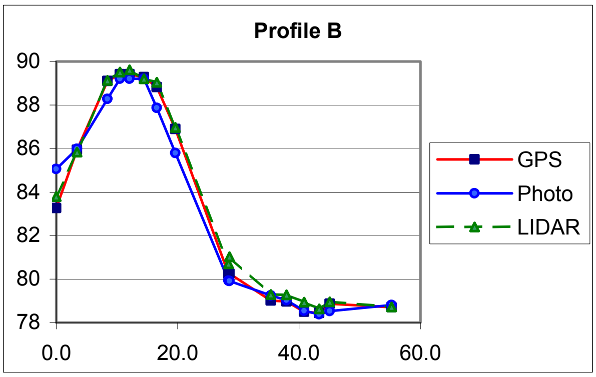

Figure 2. A profile across a railway embankment

4.3.3 Evaluation of LIDAR intensity data

The LIDAR system used for the test recorded also the intensity of the signal for each measured point. The intensity value can be used to produce an image of the terrain that has the advantage to be recorded in the same time as the LIDAR elevation data and to have theoretical the same metric proprieties as an ortho-image produced using the LIDAR DEM. The main difference with an image recorded by a standard digital camera is that the LIDAR recorded points do not have a regular distribution. The quality and the true resolution could be variable across the recorded area as it is the almost random distribution of the LIDAR recorded points. For the present test, the intensity values were used to produce an image with the resolution of 1m by 1m. The resolution is significant lower than the digital image recorded simultaneously but has an important advantage for the emergency mapping: it can be produced in the same time as the LIDAR DSM with no more human intervention.

As a result of the wavelength of the LIDAR laser signal of 0.9 µm, the intensity image is an infrared image.
It was considered that the evaluation of the planimetric precision of the intensity image is important for two reasons:
- to evaluate its one spatial precision;
- to evaluate the planimetric precision of the LIDAR data.

A set of points representing well defined points on the intensity image and on an ortho-photo used as reference. The 'reference' ortho-photo was produced from the digital images recorded by the Mosaic Mapping LIDAR system using a set of GPS check-points as control-points and the LIDAR generated DEM using the Leica Helava DPW. Its ground resolution is 25 x 25 cm. The results of this evaluation are shown in Table 2. It seems that the planimetric precision of the intensity image is determinate mainly by its resolution of 1x1 m.

	Std. dev. (m)
X	**0.50**
Y	**0.65**

Table 2: Planimetric precision of the intensity image

4.3.4 Rapid production of orthoimages

Taking into account the needs of emergency mapping users, an evaluation was done about the rapid production of geo-spatial data from the on-board digital camera with out using ground control points. The goal is to use only the data produced by the LIDAR system and its coupled digital camera. A test was done using 6 digital images from two adjacent flight lines and the 'direct orientation' (DO) values computed from the GPS + inertial sensors of the LIDAR system and the LIDAR produced DSM. Two possibilities were explored, the stereo-compilation and the production of ortho-rectified images. For this reference, the same digital photos were used following the standard method (relative and exterior orientation) using the Leica Helava working station and the GPS recorded control points.

a.- Stereo-compilation: The stereo compilation was not possible because the residual y parallax was much to important. Comparing the values of the photogrammetric computed values of the exterior orientation angles with the 'direct orientation' values it appears that these last values have errors of some minute of arc. The differences for the Omega and Phi angles were in a range of 1 minute to 16 minutes of arc with a mean value of 8.25 minutes. For Kappa the differences were smaller, between 2 and 4 minutes.

b.- Ortho-rectification: A digital ortho-photo mosaic was produced using the same data set with the 'direct orientation' values. As expected, planimetric errors in order of some meters were observed. The relative errors, measured between the position of the same terrain detail present on two successive photos were in the range of 2 m to 4 m. These errors are easy to observe on the ortho-image at the seam line, where the image of a linear detail as a road will appear as 'cut'. On the example shown in Figure 2, the road on the left of the image appears to be cut in the middle indicating a relative orientation error between the two images. The red lines are the GPS measured road centre-lines and their offset to the East of the ortho-image shows an absolute error in the East-West direction. The absolute error, measured between a detail position on the ortho-image and the GPS position measured for several points had values up to 6 m.

It is understood that for this 'first shot', automatically produced ortho-image, the absolute planimetric precision could only be estimated from the 'a priori' precision estimation of the exterior orientation parameters delivered by the GPS / inertial sensors of the LIDAR system.

These ortho-images can be very useful for emergency mapping operations despite the much higher errors versus the normal acceptable values for this category of image scale. In fact, for the firs step of situation understanding and preliminary damage evaluation after en emergency event, the value of a new, quick delivered, very high-resolution colour ortho image is very high despite an absolute positioning error of about 2 to 6 meters.

In second iteration, the orientation operations can be done again using additional information and more precise ortho-image can be produced in a few hours.

Figure 2: Ortho-image produced automatically

5. RECOMMANDATIONS AND CONCLUSIONS

5.1 Recommendation for the use of LIDAR data and rapid change detection for emergency mapping

While in the imagery the unit is the 2D pixel in image space, in the LIDAR data the unit is a 3D point in the space of the reference coordinate system. The LIDAR data is a high-density point sampling of the terrain. These data are processed either as TIN elevation surface model or interpolated into a regular elevation surface model (DSM). The LIDAR DEM data can be also converted into a raster image. In addition certain LIDAR systems capture also the intensity of the response signal corresponding to the LIDAR ground point. The intensity is a function of the reflectivity of the ground material and the intensity changes form a georeferenced grey level image like output.
In emergency situations, where the time factor is crucial, LIDAR data can be used for mapping, modelling, change detection and monitoring and visualization tools for knowledge-based decision-making.

In mapping, LIDAR data contributes to an accurate recording of the elevations (shape/morphology) of the terrain surface, the generation of a DEM (bald earth, contours) by separating man-made objects and vegetation from the ground surface, the calculation of terrain information (slope, aspect, volumes, profiling), the ortho-rectification of imagery, the extraction of planimetric features (i.e., buildings, Figure 3 and 4) in fusion with other data sets, and the use of the georeferenced intensity image for mapping (e.g., roads) and the detection of high reflective objects.

Figure 3: Delineation of buildings using shaded relief on the LIDAR elevation data

Figure 4: Delineation of buildings using Canny edge detector on the LIDAR elevation data

In modelling, LIDAR data contributes to the creation of 3D city models and modelling simulations, such hydraulic modelling during flooding. In management of an emergency situation, the 3D visualization of the area data contributes to the better understanding, planning and decision –making for damage assessment and mitigation. For example, intensity image can be draped over the LIDAR DSM (Figure 5).

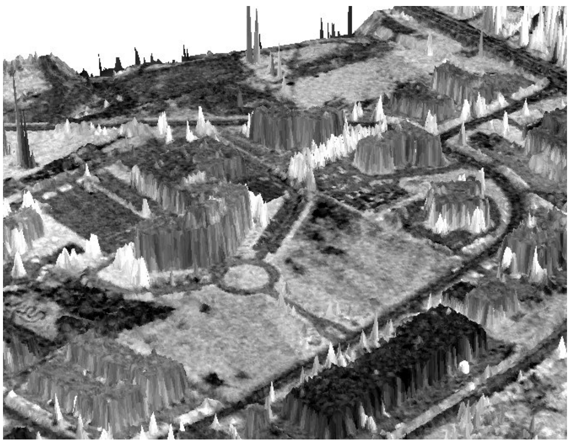

Figure 5: Intensity image draped over LIDAR DSM

If previous data is available or if multi-temporal data are acquired following an event, then the LIDAR data can be used for change detection and for monitoring of the situation. The changes can be detected either from temporal image type LIDAR generated data, for example differencing of two elevation data sets to determine volumetric differences, or from temporal features using feature based approaches (Armenakis and Savopol, 2004).

Concerning the use of 'direct orientation' values delivered by the LIDAR system in order to produce automatically ortho-images for emergency mapping situations, it is recommended to continue the investigations and to do an incremental improvement of the orientation on a digital photogrammetric station that will permit to have a normal stereo visualisation ant to do stereo compilation.

5.2 Acknowledgements

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