



**ANALYSING AND MODELLING TERRAIN SURFACE CHANGES
USING AIRBORNE LASER SCANNING DATA**

Ana-Maria Loghin^{*1}, Valeria Ersilia Oniga² and Martin Wieser³

¹Ph.D. Student, Eng., Faculty of Hydrotechnical Engineering, Geodesy and Environmental Engineering, Gheorghe Asachi Technical University of Iași, Romania.

²Lecturer, Ph.D Eng., Department of Terrestrial Measurements and Cadastre, Faculty of Hydrotechnical Engineering, Geodesy and Environmental Engineering, Gheorghe Asachi Technical University of Iași, Romania.

³Univ. Ass. Dipl.-Ing., Department of Geodesy and Geoinformation (E120.7), Vienna University of Technology, A-1040 Vienna, Austria.

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***Corresponding Author**

Ana-Maria Loghin

Ph.D. Student, Eng.,
Faculty of Hydrotechnical
Engineering, Geodesy and
Environmental
Engineering, Gheorghe
Asachi Technical
University of Iași,
Romania.

ABSTRACT

In recent years, Light Detection and Ranging (LiDAR) technology has known an important evolution, being widely used for rapid and inexpensive topography measurements over large and complex areas. This article presents the potential of multi-temporal Airborne Laser Scanning (ALS) data sets in providing different and reliable digital elevation models of differences, used in detecting terrain surface changes. In order to obtain the results, two different ALS data sets from May 2013 and February 2015 were used. The necessary

processing steps start from an automatic classification of the acquired point clouds into terrain and off-terrain points, used for the Digital Terrain Model derivation. Therefore, for each of these two data sets, there was created a Digital Terrain Model, containing only the ground points. Finally, based on these two derived terrain models, the Digital Elevation Model of Differences (DoD), that reveals topographic relevant changes is obtained.

KEYWORDS: LiDAR, ALS, Digital Elevation Model of Differences (DoD), digital terrain modeling.

1. INTRODUCTION

Over the past decades, due to its accuracy and efficiency, Airborne Laser Scanning has become an important 3D data acquisition method used in remote sensing domain. Airborne laser scanning (ALS) - also referred to as LiDAR (Light Detection and Ranging) – became the standard method for acquisition of topographic data, especially for the reconstruction of digital terrain models (DTM)(Kraus, Otepka 2005).

Nowadays, as LiDAR technology knows a great evolution, the chances of multi-temporal LiDAR collections and data sets over the same area has increased. As a first result, using LiDAR to detect change has become more possible.

During last years, pixel-based change detection methods have been used for change detection in objects. Previous studies and research describe various change detection methods such as Change Vector Analysis (CVA), image rationing and image differencing, using an object-oriented classification (Domenech, Mallet 2014).

A digital terrain model is a topographic model, a mathematical representation, that contains all the ground points with their spatial elevation data, representing the terrain relief. Digital Terrain Models know a great importance in research domain, being used especially in civil engineering, geodesy, surveying, geophysics and geography for terrain visualization and analyses, parameter extraction (water flow, mass movement). Therefore, while Digital Surface Models describe the top surface of the terrains, Digital Terrain Models contain only the terrain surface, without vegetation, buildings or power lines.

2. MATERIALS AND METHODS

2.1 PRESENTATION OF THE STUDY AREA

The study area is located in Neubacher Au, near the Loosdorf village in Lower Austria (48° 12'50" N, 15° 22'30" E, WGS 84), at about 100 km west of Vienna. In order to determine the terrain changes, from the initial data, an area of 447 by 428 meters was selected. This territory has elevations between and 259 and 314 meters above sea level and includes a meandering region of the Pielach River, a pre-alpine river, right side tributary of the Danube and also vegetation represented by alluvial forest.

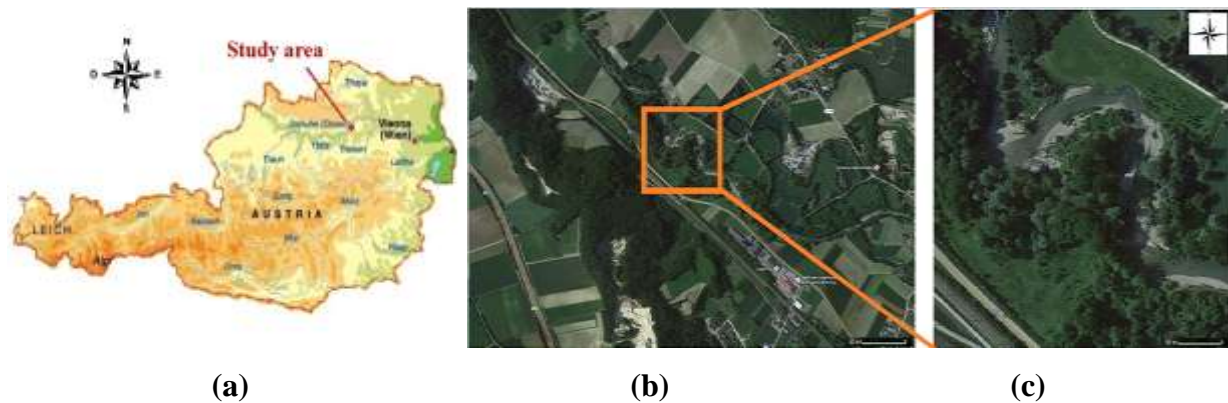


Fig. 1. Neubacher Au, Lower Austria; (a) Overview map of Austria; (b) location of the study area; (c) Study area Neubacher Au

2.2. MATERIALS AND EQUIPMENT

The airborne laser scanning data used in this study was provided by the Department of Geodesy and Geoinformation, from Vienna University of Technology.

The ALS data of the first epoch took place at the 24th of May 2013 using a V-Line Airborne Laser Scanner RIEGL VQ-580, with a narrow near-infrared laser beam and a fast line scanning mechanism. The second data acquisition took place on 26th of February 2015 using a RIEGL LMS-Q1560 scanner, characterized by a high laser pulse repetition rate up to 800kHz, laser wavelength in near infrared, allowing operation at various flight altitudes.

2.3 DATA PROCESSING

The main principle of LiDAR technology is to emit a laser pulse in a known, controlled direction and measure the time from emission until receiving of its echo, scattered back from surfaces within the instantaneous field of view. Direct georeferencing provides the position and orientation of the measurement platform. Together, this is used for 3-dimensional location of the echoes, thus providing a georeferenced 3D point cloud (Otepka, Ghuffar, Waldhauser, Hochreiter, Pfeifer, 2013).

Surveying riparian areas represents a challenge for remote sensing domain, due to vegetation, that is most presently along the river channel.

For the first flight mission from May 2013 the mean echo point density is in the range of 10 points per square meter whereas for the second one, the value of point density increases to 57 points/m², due to leaf-off conditions.

The details of these two ALS datasets are shown in the following Table 1.

Table 1. Summary of data capturing

Fligh Date	Sensor	Point Density [points/m ²]	Total number of points	Foliage
24 May 2013	VQ-580	10	1958483	leaf-on
26 February 2015	LMS-Q1560	57	12227601	leaf-off

The following figure shows a short overview of the processing steps applied to derive the two Digital Terrain Models of the same area and finally the Digital Elevation Model of Differences, providing reliably determined deposition and erosion areas between the two analyzed epochs.

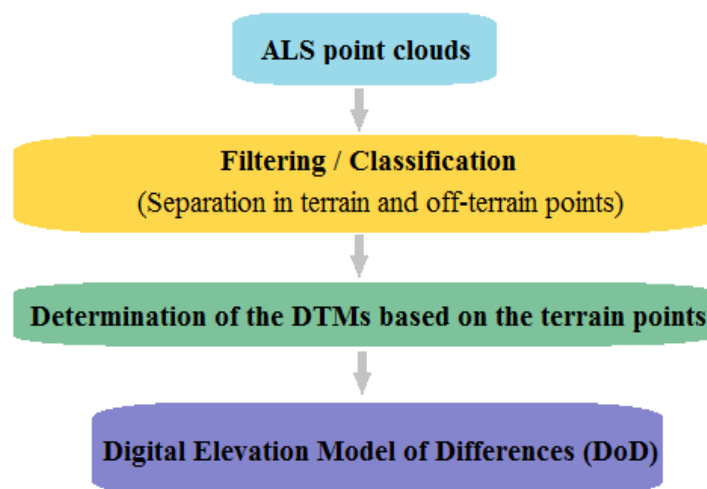


Fig. 2. Overview of the processing steps for the proposed method

Preprocessing of the LiDAR point cloud was performed with the Riegl ALS software suite RiProcess (direct georeferencing, strip adjustment) and the following steps for digital terrain models derivation, laser scanning software OPALS (Orientation and Processing of Airborne Laser Scanning data) developed by the Technical University of Vienna, was used (Pfeifer, Mandlbürger, Otepka, Karel, 2014).

3. RESULTS AND DISCUSSION

3.1 DTM GENERATION

The most important product that was derived from the point cloud (LiDAR data) is the Digital Terrain Model, containing the bare-earth surface with all ground points. In order to achieve this, a separation between ground points and non-ground points was made.

Over time, scientists and researchers developed different automatic methods that can be applied for ground points filtering. For example, most of the algorithms are based on the

usage of mathematical morphology (Vosselman, 2000), weight iteration (Briese, Pfeifer, 2001), or data points gridding (Wack, Wimmer, 2002).

For the present study, in order to automatically determine the DTM of the Neubacher Au territory, there were used robust filtering methods, that allow the elimination of off-terrain points and the modelling of the terrain surface within one process.

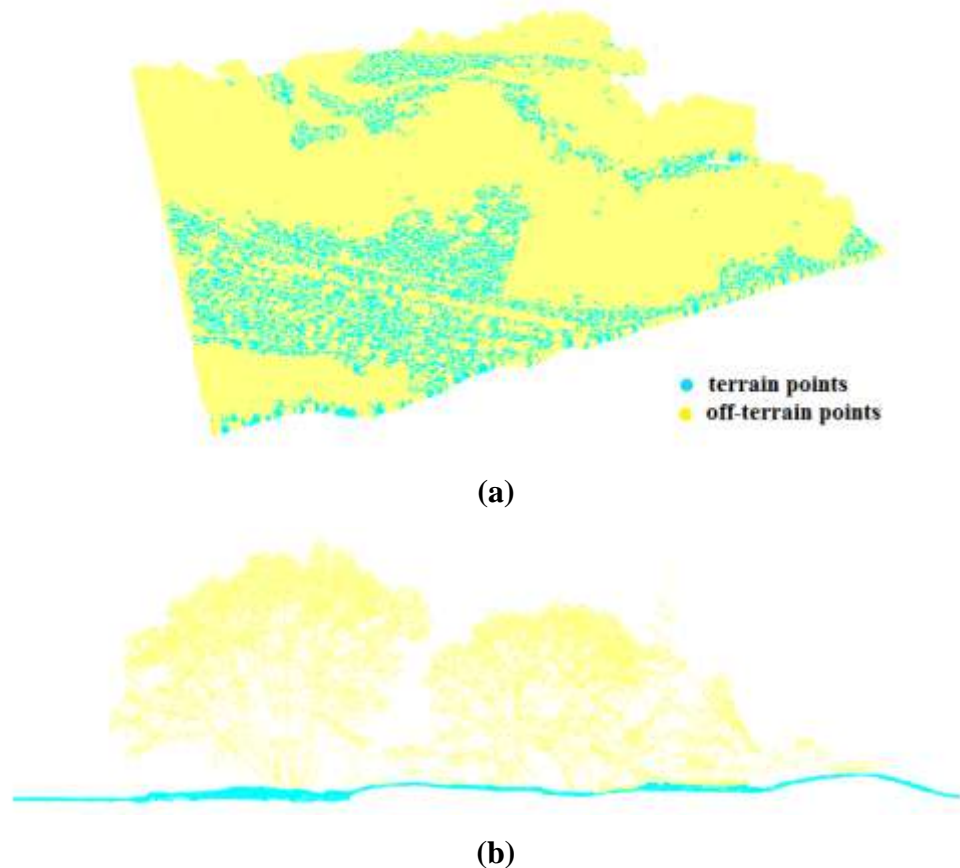


Fig. 3. ALS point cloud classification (a) 3D view of the classified points, (b) profile view

The applied algorithm for robust DTM generation consists of the following steps (Kraus, Pfeifer, 1998):

1. Interpolation of an initial surface with points having equally individual weights
2. Calculate filter values, based on vertical deviations of the ALS points to the surface
3. Taking into account the new point weights, a new surface is calculated.
4. Steps 2 and 3 are iterated until a good approximation of the terrain.
5. The last step is the identification of ground points.

The flight in spring (May 2013) was made in leaf-on conditions, the complex and dense understory within the alluvial forest affecting the obtained DTM quality. In the Digital Terrain Model of the study area (Fig. 4a), it can be easily seen that due to the presence of

trees, the chances for the laser pulse to make it to the bare ground are quietly reduced. Therefore, the accuracy and reliability of the derived surface, are lower in vegetated parts, than in clear and open ones.

In contrast to the first data acquisition, the second flight was made in leaf-off conditions, enabling a good penetration of the laser beam through the vegetation (Fig. 4b).

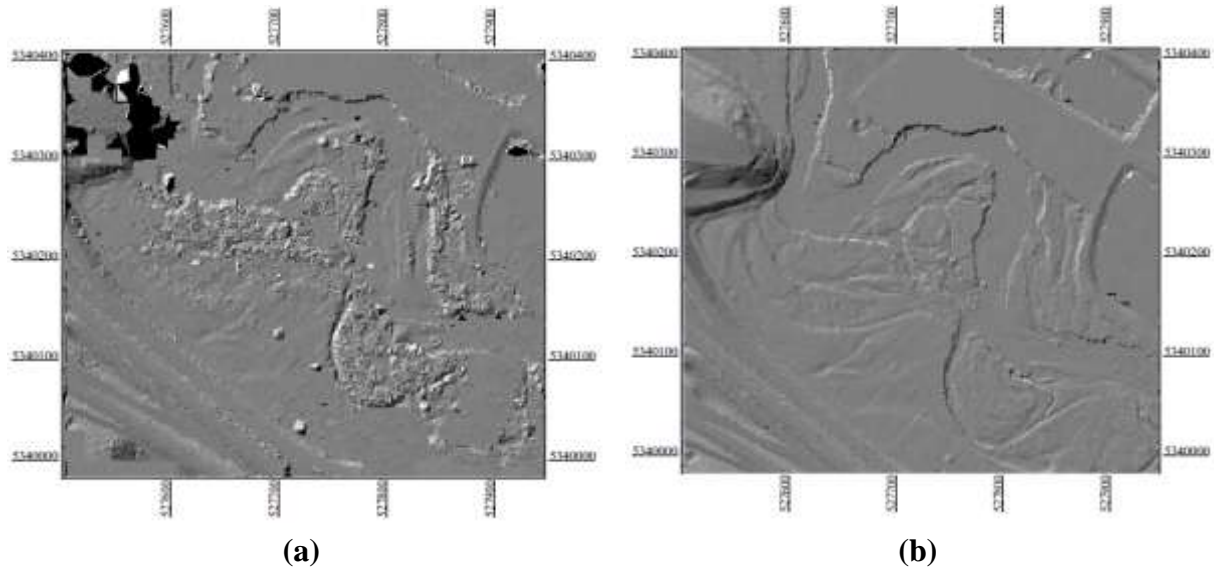


Fig. 4. DTM raster derivation

- (a) DTM raster corresponding to the first data acquisition with the Riegl VQ 580 laser scanner, using “robmoving planes” interpolation (with 0.05m gridsize, 500 neighbours, 20 meters search radius and selmode quadrant)
- (b) DTM raster corresponding to the second data acquisition with the Riegl LMSQ 1560 laser scanner, using “robmoving planes” interpolation (with 0.25 gridsize, 200 neighbours, 2 meters search radius and selmode quadrant)

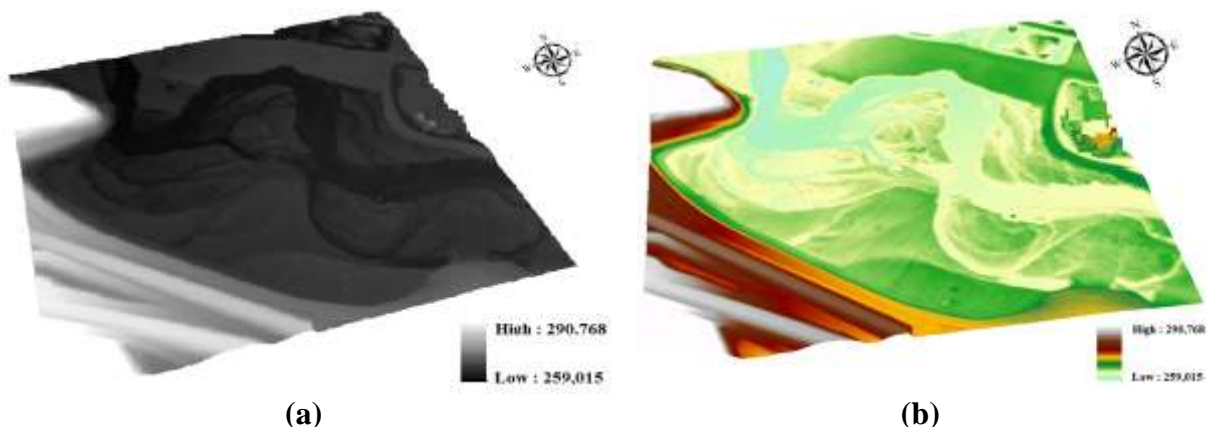


Fig. 5. Digital Terrain Model - 3D visualizations in “ArcScene” software (a) using shaded grey color ramp; (b) using standard color ramp

3.2 TERRAIN CHANGE DETECTION

Based on the multi-temporal ALS data sets, the digital terrain model can be analyzed and changes can be revealed. For this case study, using two different airborne laser scanner collections from May 2013 and from February 2015, there are presented the main changes (erosion / deposition) of the terrain topography along the Pielach River, in Neubacher Au territory.

Within May 2013 and February 2015 when the two data sets were acquired, two flood events occurred at the Pielach River. The first one in June 2013 and the second one in May 2014. These events had an important impact on the terrain topography along the river, and also on the riparian area (Mandlburger, Hauer, Wieser, Pfeifer, 2015).

By analyzing and comparing the derived Digital Terrain Models from the two epochs, that were obtained in the previous step, it can be obtained the Digital Elevation Model of Differences (DoD), revealing topographic relevant changes.

The method used in this study, for detecting the topographic terrain changes, is a pixel-based method, using difference imaging, where each pixel value in the raster - image corresponding to the Digital Terrain Model of May 2013 is subtracted from its corresponding pixel value in the raster - image of the Digital Terrain Model of February 2015.

The figure shows the Digital Elevation Model of Differences (DoD) of the study area represented in raster format, erosion having a yellow to red color tone, whereas deposition is represented in green to blue color tones.

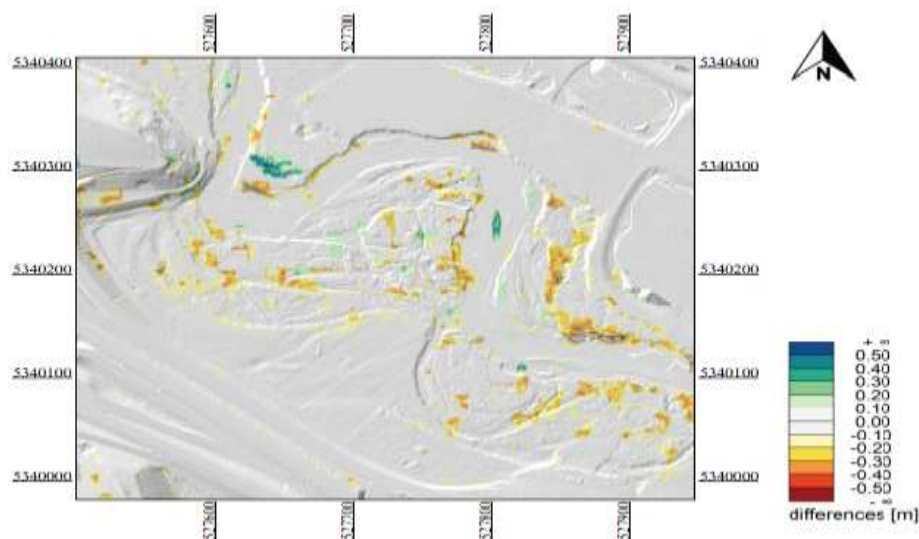


Fig. 6. Digital Elevation Model of Differences (DoD) with relevant topographic changes

As it can be seen, the differences are ranging between -0.5 m (corresponding to erosion) to +0.5 m (corresponding to deposition) and they are especially located along the Piellach riverbed.

4. CONCLUSIONS

Airborne laser scanning (LiDAR), using near infrared pulses for point clouds acquisition, has been proved to be a suitable method for the 3-dimensional structure of vegetation analysis and also for the terrain surface assessment.

An important advantage of airborne laser scanning is represented by the large areas that can be analyzed within a single project. For example, Digital Terrain Models can also be derived using terrestrial laser scanning data, offering more detailed and accurate description of the ground surface. Whereas terrestrial acquiring covers only small areas of about 1 km² and below, airborne laser scanning is being used to collect topographic information over larger areas of more than 10,000km².

Nowadays, with LiDAR evolution, the number of LiDAR collections and data sets over the same area increased, fact that makes possible the change detection operation and the technology of airborne laser scanning has proved to be very efficient in obtaining the information of relevant topographic changes.

An important aspect that must be taken into account is the flight time of data acquisition. For example, in spring or summer, due to the leaf-on conditions, the chances for the laser pulse to reach the bare-ground and penetrate the vegetation, are quietly reduced. This fact affects the accuracy of the processed digital models, that is lower in vegetated parts than in clear and open ones. But, like all the other technologies, LiDAR is a measurement tool, that has its own strengths and weaknesses.

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