Analysis of airborne laser scanning data and products in the Neusiedler See Project

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ABSTRACT. *The paper is a condensed presentation of the experimental part of my graduation project (Bitenc, 2006), which I carried out at the Institute for Photogrammetry and Remote sensing (I.P.F.) at the Vienna University of Technology during my Erasmus exchange program. The main topic is attractive, useful and advanced technology - airborne laser scanning, which was used in the Neusiedler See project in order to enable hydrological analyses. The aim of this project, which was part of the international SISTEMaPARC project in the framework of the transnational European project INTERREG IIIB CADSES, was refilling drained natural basins with water, so centimeter accuracy of digital terrain model (DTM) was required. Its high relative and absolute accuracy was obtained by using an appropriate post-processing method. The paper presents analysis of the DTM quality, which was accessed with local quality parameters. According to the results, the DTM of the Neusiedler See National Park reaches 4 cm accuracy in height. The second analysis, described in this paper, aims to investigate intensity values measured with laser scanner. Intensity is a side product of ALS, but could be very useful for recognizing the scanned objects, while it gives some semantic information directly to the 3D data. The possibility to use it for land cover identification and classification was investigated. Some land cover is separable with intensity data, but it was discovered that ALS data are not sufficient.*

KEYWORDS: *Aerial laser scanning, Neusiedler See Project, DTM, quality, local quality parameters, intensity, normalization, classification.*

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1. Introduction

A relatively new method of remote sensing - airborne laser scanning (ALS), has been recently greatly improved and developed, which makes it very useful in a wide range of applications. Firstly, better sensor technology sets up different systems, which provide users with a lot of data in a short time, and secondly, newly developed and improved post-processing methods enable more automated and exact calculation of results e.g. DTM, DSM, 3D city model. Therefore results are used in variety of different applications such as forestry, urban planning, hydrological hazards, archeology, coastal monitoring, roads, power lines and telecommunications survey, GIS and cartography, 3D cadastre etc. In the case of the Neusiedler See project, ALS was used to provide accurate and up-to date DTM for hydrological analyses.

In the 20th century an over-exploitation of groundwater and widespread artificial draining caused drastic changes in the natural park, so today only 25% of the water surface area still exists. In order to protect and restore the area, new research was done, based mainly on ALS data. Details on the first research within the transnational project INTERREG IIC can be found in Horvath, 2001 and Herzig, *et al* 2002 and the second, which was done within the discussed project, in Attwenger and Chalaupek, 2006; Attwenger, *et al* 2006 and Chaupelek, 2006. The exact location of the project area (the park), which is split between Austria and Hungary, can be seen in Figure 1-1.

After the data for the Neusiedler See project were acquired by the company TopScan, the post-processing started at the I.P.F. Home developed algorithms were used to contribute an accurately modelled DTM. While the DTM is used in most cases and is therefore the most important result of ALS, it is necessary to provide usera with information about its quality. According to the known quality, which consists of components like precision, accuracy and reliability, the optimal decision could be made. Those metadata could be given with different quality parameters. In this analysis of the Neusiedler See's DTM the **local quality parameters** were calculated with a step-by-step empirical stochastic approach, which gives grid point related quality parameters of DTMs. The method was developed at I.P.F. and is described in Karel, 2005; Karel and Kraus, 2006 and Karel, *et al* 2006.

The second analysis done on the Neusiedler See data aims to investigate inten-

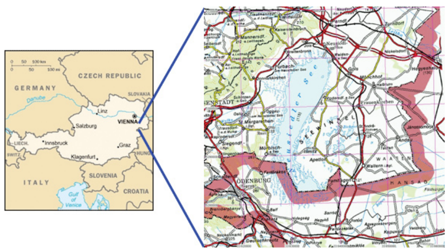

Figure 1-1. Overlap zone between the two clouds. b) The potential points and the extracted edge lines

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sity values of the reflected laser light. ALS technology gives accurate 3D data of the scanned surface, but the information about a type of scanned objects is questionable. Time-consuming post processing algorithms help us to identify terrain, buildings and other objects. To make it faster and easier the objective of this analysis was first to identify land cover types that occur within the scanned area like fields, meadows, roads and vineyards and then to (automatically) classify laser points regarding intensity values. The main obstacle using intensity directly is the fact that the measured values are a complicated function of many influencing factors. State of the art experimental analysis on the intensity values can be found in Song *et al*, 2002; Lutz *et al*, 2003 and Hasegawa, 2006. From now on, the intensity values are primarily used for visualization of scanned area (colour coded image), but in the future applications like searching for homologues features, improving the classification and the extraction of features, use in the forestry etc. will be developed.

The sensors used for ALS data acquisition and their properties are summed up in Table 2-1. Some parameters about flying mission have to be defined beforehand and considered during flight, so at the end, the desired data is available for post-processing.

At the same time as the flight mission, GPS measurements with the frequency 1 Hz were done on 4 ground points – KT602-79, KT460-79, KT441-78A2 and KT135-109.

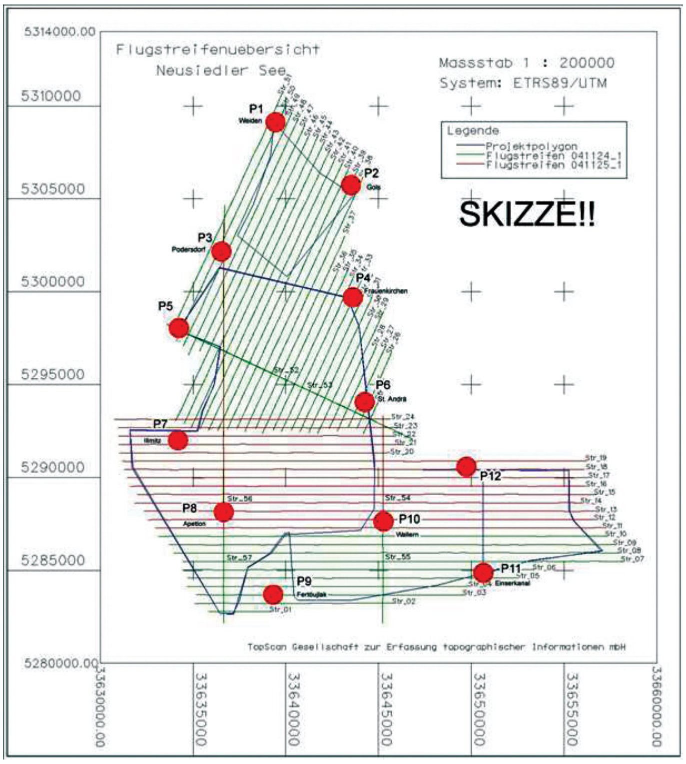

Figure 2-1. Laser scanner strips - red and green lines and the control areas - red dots (Attwenger, 2005)

2. The project neusiedler see

2.1 ALS data acquisition

The aerial mission was done on 24. and 25. November 2004. The scanned area of the Neusiedler See/Seewinkel national park is 340 km^2 big and consists of 57 strips. Six of them are cross strips, which should be scanned at ends of the block. Actually, two are missing on the southern and eastern part of the project area (see Figure 2-1). Cross strips are essential for joining strips together in one model and help to improve relative orientation. The point density, which greatly influences the accuracy of ALS products, is 1,5 points per square meter.

2.2 Terrestrial measurements

For the Neusiedler See project terrestrial measurements were done in August 2005. They are essential for more precise fitting of ALS strips together and help to improve absolute orientation. The best solution is obtained, if the control area has a minimum of three tilted planes with different aspect (Kager, 2004). In the case of the project 12 control areas were measured with tachometry on the basis of GPS net. Because of a lack of tilted planes in the south-eastern area of the project, two horizontal planes and additionally height points were measured (Figure 2-1).

Table 2-1. Parameters of planned flight and used sensors (Laserscannermessung ..., 2005.)

Flying parameters	
Planned flying speed	65 m/s ~ 126 Kn
Planned flying height above the ground	1000 m
Planned strip distance	450 m
Measurement system – ALTM 2050	
Laser repetition rate	50.000 Hz
Max scan angle	20 deg
Scan frequency	25 Hz
Planned strip width	725 m
Planned strip overlap	275 m (30%)
Digital metric camera – Emerge DSS	
Array size	4.092 x 4.077 Pixel
Pixel size	0,009 mm
Filter array	True colors
Lens	Zeiss Distagon 55,0 mm, 36° FOV
Planned disposition distance	325 m
Quantization	16 bit
Resolution on ground	0,17 m x 0,17 m

2.3 Processing of the data

The first processing steps, done in Topscan (see Laserscannermessung ..., 2005), are joining the ALS data of three main technologies (GPS, IMU and laser scanner) and georeferencing the data. The results were 3D coordinates of laser points in the reference coordinate system WGS84, which were then transformed into ETRS89 and Gauss-Krüger M34 coordinate system and interfered to the I.P.F. Vienna for DTM computation. Further next steps followed (see Attwenger and Chalaupek, 2006; Attwenger *et al*, 2006):

1. quality check
2. fine georeferencing
3. height correction for geoid undulation
4. calculating the digital surface model (DSM)
5. calculating the digital terrain model (DTM)
6. joining the Austrian and Hungarian DTM
7. transformation from ETRS89 to national coordinate system MGI

Computer programs used for processing were SCOP++, Orient and other program modules developed at the I.P.F. Vienna.

3. Analising the quality of dtm

3.1 Local quality parameters

In contrast to global quality parameters, which are valid only for a certain measuring technique and provide only one value for the whole area (see Karel and Kraus, 2006),

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the local quality parameters give much more detailed information about DTMs' quality. In order to consider all the factors that influence DTM computation and modeling, and to obtain detailed estimation of DTM quality, I.P.F. Vienna developed a method for the derivation of the height accuracy of each grid point. This approach has the following properties:

- It may be used to analyse DTMs existing beforehand.
- It is independent of the interpolation method.
- In the computation of quality parameters, the original data are used.
- Quality parameters have the resolution of the used grid.

The factors that influence on the accuracy of the DTM are according to the I.P.F. Vienna approach:

- The number and alignment of the neighboring original points.
- The distance of original points to the respective grid point.
- The terrain curvature in the neighborhood of the grid point.
- The accuracy in height of the original points.

They form the input of a simple interpolation method for the estimation of the accuracy at each grid point (see the equation in Kraus *et al*, 2005). The final results (DTM quality) as well as intermediate results (influencing factors or so-called quality parameters) are easily and clearly visualized. In such a manner the precision of DTMs is confidence-building for end users.

3.2 Calculation and results

The calculation of local quality parameters for Neusiedler See DTM was done with the program *sigmaDTM.exe*, developed at the I.P.F. Vienna. Input files are **.dtm*, with the DTM's grid points, and **.xyz*, with original terrain points. From the whole project's area I chose 5 squares with a side size of 2 km. Each of them has a different prevailing feature like rush, village, vineyards, fields and wood. Besides the computation of DTM quality, the objective was to compare quality parameters between different features.

The following five models show local quality parameters computed at each grid point. Visualization was done with the program SCOP and is shown only for the *Village* area.

The model of minimum distance between each grid point and its nearest original point (Figure 3-1) shows areas without data (marked red on the Figure 3-1, as well

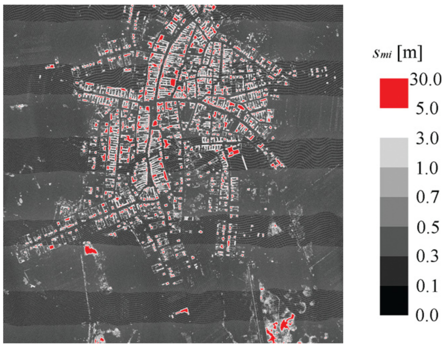

Figure 3-1. The colour-coded model of minimum distance

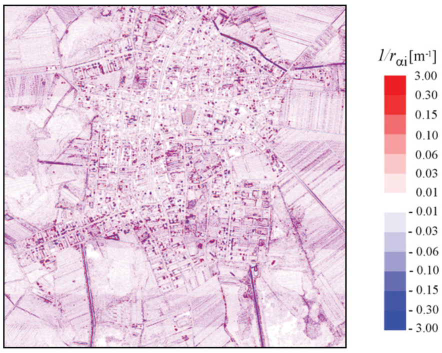

Figure 3-2. The colour-coded model of maximum main curvature

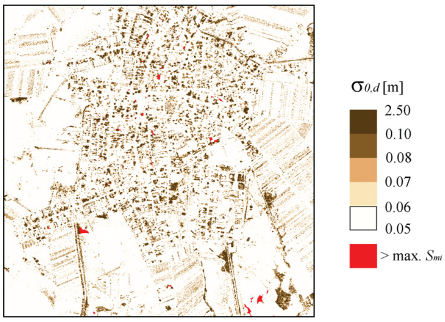

Figure 3-3. The colour-coded model of RMSE

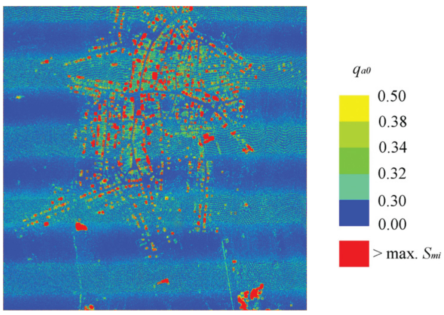

Figure 3-4. The colour-coded model of weight coefficient

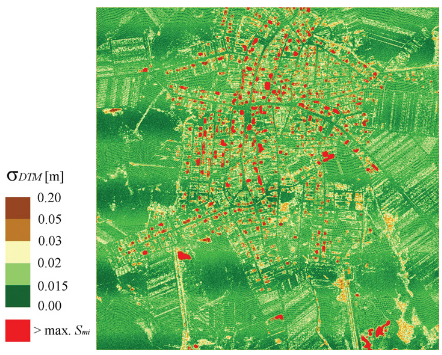

Figure 3-5. The colour-coded model of sigma DTM

as on the Figure 3-3, Figure 3-4 and Figure 3-5, the threshold used is 5 m). These areas are useless and must be pointed out to users. They most often occur in areas with big buildings and dense vegetation.

The model of maximum main curvature at each grid point (Figure 3-2) shows tiny terrain characteristics like the not eliminated low vegetation, outlines of buildings, ditches, furrows etc. Red casts show relatively higher areas (DTM goes up) and blue casts relatively lower areas (DTM goes down).

The model of height accuracy of original points (RMSE, see Figure 3-3) has an a-priori defined lower limit, which is in this case 5 cm. It is determined regarding the post-processing steps, whether the quality check and fine georeferencing of ALS strips were done. The best accuracy is reached where the terrain is flat and without vegetation or big buildings (area with fields).

The model of weight coefficient (Figure 3-4) has values lower than 1. It means that the accuracy of DTM will be higher than the accuracy of the original points, which is actually our aim.

The model of height accuracy of the DTM (Figure 3-5) is the most important result and shows the spatial variation of sigma DTM. The computation employs the reference standard deviation (Figure 3-3) and the weight coefficient (Figure 3-4). In this analysis the sigma DTM varies from 0 cm to ±4 cm.

4. Analising the intensity data

4.1 Intensity measurements

Because the 3D lidar point cloud itself does not include information about the object types on which points are actually located, intensity measurements represent important data for identification of objects and phenomena in physical space. Colour-coded intensity value image confirms this, as particular objects (asphalt road, grass, building etc.) can be recognized on it. Intensity values have no unit and are relative measurements. While the definition in Song, 2002 says, intensity is a ratio between the received and transmitted strength of laser light, the equation for received power in Hug and Wehr, 1997 can be used and simplified, so measured intensity can be calculated as,

$$(1) \quad I_m \approx \frac{P_r}{P_t} = \frac{\rho \cos\xi}{R^2} konst.$$

Where

I_m … measured intensity
P_r … strength of received signal
P_t … strength of transmitted signal
R … measured range

ρ … reflectivity
ξ … angle of incidence

Therefore intensity depends on measured range, angle of incidence, which depends on the normal of terrain and scan angle, and reflectivity that is defined for a certain material for the laser light wavelength (see the table in Wagner, 2005). The measured intensity must be normalized for these factors in order to be used for identification and classification of the scanned features.

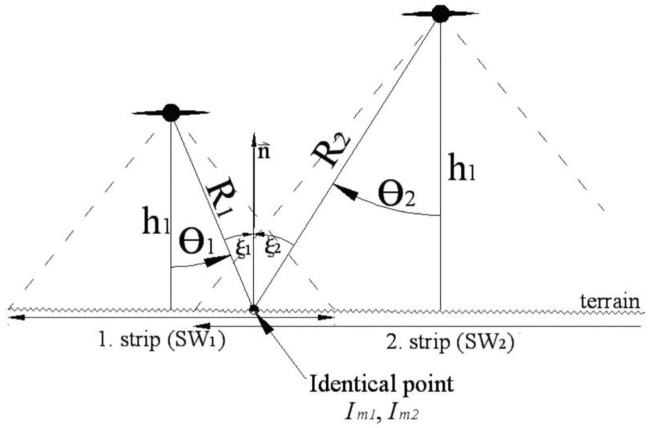

Figure 4-1. Geometrical relation between variables for identical points

4.2 Data

Data available for the analysis were strips of lidar points (position and intensity) and raw digital photos, made simultaneously during laser scanning. From 3D coordinates of lidar points the DTM and DSM were calculated. The first one gives information on how the terrain is changing and shows relatively flat area – heights are changing for only 15 cm. The second model was used as an underlying layer, which adds the height perception to the intensity data, so we can separate vineyards, objects, vegetation etc. For the research of an eventual correlation between intensity and main influencing factors (equation 1) additionally polar coordinates (which are actually row output data from the ALS system, but we did not have them) were recalculated in the program Orient.

4.3 Analysis and corrigenda of measured intensities

The objective of the analysis was normalizing the intensity values to use them for identifying land use, so we were looking for a function *f* from equation 2.

(2) $$I_m = f(R, dA(\xi), \rho)$$

The range (R) is known for each lidar point from previously computed polar coordinates. The footprint size (dA) influences intensity indirectly as a function of the incidence angle (ξ). While we analyse intensity only for terrain features (fields, meadow; roads and vineyards) and while in the case of the Neusiedler See project the scanned terrain is relatively flat, it can be simplified that incidence angle is equal to the scanned angle. Furthermore, the scanned angle is a parameter of the measured range, meaning they are tightly correlated, so we can neglect their influence. Reflectivity has the biggest influence on measured intensity. Theoretical values, which are typical for certain materials, cannot be taken into consideration, until we are able to extract intensity values for a certain feature like. the fields from our data. But since the reflectivity is the same for one material or at least similar for one land use, we presumed that points from two overlapping strips, lying less than 10 cm apart, had the same intensity value (Figure 4-1). The footprint has a minimum 20 cm in diameter.

The identical points were computed in several areas of overlapping strips with the program Matlab. While the measured intensities for identical points are not the same, we analysed the difference of measured intensities ΔI_m according to changes in range ΔR (equation 3).

(3) $$\Delta I_m = f(\Delta R), \Delta\rho\text{=konst.}$$

The empirical analysis of different areas showed linear dependency between variables ΔI_m and ΔR (Figure 4-2).

The equation (3) can be rewritten as,

(4) $$\Delta I_m = a\Delta R + b$$

Here we compared parameters *a* and *b* with the least-squares method and computed corrections $\overline{\Delta I(\Delta R)}$ of the measured intensity for the rest of lidar points in corresponding two strips. Because the correction is relative, since we used variable ΔR, intensities of one strip do not change (master) and intensities of another strip (slave) are increased or decreased for the correction values.

If $\Delta I_m = I_{m,2} - I_{m,1}$, then the normalised intensities can be calculated as:

1. possibility I_2 (2. strip is master)

(5) $$I_1 \rightarrow I_1^n = I_{m,1} + \overline{\Delta I(\Delta R)}$$

2. possibility I_1 (1. strip is master)

(6) $$I_2 \rightarrow I_2^n = I_{m,2} - \overline{\Delta I(\Delta R)}$$

4.4 Classification

After normalizing the intensity values for the range, as described above, we continued with the classification process. But unfortunately it turns out to be unsuccessful. Figure 4-3 shows an example of extracting a relatively small range of intensity values (form 90 to 106), which experimentally presents meadows (comparing the intensity values to the digital image). Along with meadows, roads and other areas and points that lie on fields were classified.

The described method of relative normalization with the help of identical points gives a more homogeneous and clearer intensity image, but the intensity within certain land use does not change much. Normalized intensities of slave strips are just shifted according to intensity values of the master strip. But finally the ranges of intensity values for different land uses are still too large and moreover they overlap between each other, so classification of certain land use is not possible.

5. Conclusion

This is the first analysis intended to evaluate the quality of computed DTM for the Neusiedler See project. While the area is relatively flat and the DTM was calculated from fine georeferenced lidar points, which means that systematic errors were eliminated, we expected to get high quality DTM. The expectations were confirmed when calculating the local quality parameters. The worst DTM accuracy occurs reasonably in the forest and village area and goes up to 4 cm.

The described method of grid point related quality parameters gives promising results and fulfills requirements for clear and understandable information on DTM quality. In the future, that kind of information should be interfered to the end user together with a DTM, the better like quality layers. The most important layer is the standard deviation model, which gives information about the relative accuracy.

The conclusion of the second analysis of measured intensities is that the data itself includes very important information about the scanned surface and objects on it, but

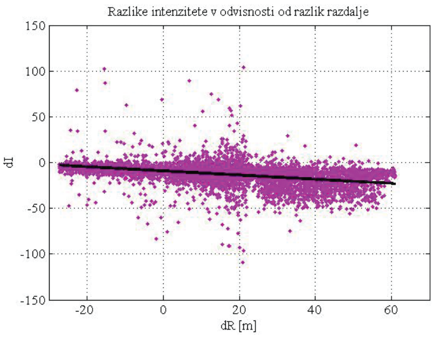

Figure 4-2. The linear dependency of intensity differences and range differences.

many influencing factors make it direct use impossible. Therefore normalization is necessary. In the case of the Neusiedler See project relative normalization of the measured intensity was done on the basis of identical points. According to several presumptions and simplifications we corrected measured intensities for the influence of the range. The mentioned relative normalization can improve the intensity image to be more velar and homogenous, but the ranges of intensity values for a certain feature do not change. Therefore, the classification is not successful. Improvement of the described analysis requires research on how the intensity values are changing inside the outline of certain feature. In this way the correlation between the intensity and range could be defined directly (not trough differences) and more accurately. That would result with better corrections and finally enable (automatic) classification. For the extraction of intensities that belong to the feature, additional data would be needed, like digital ortofoto, cadastral data or terrestrial measurements.

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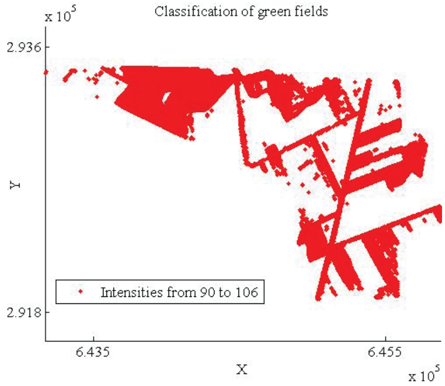

Figure 4-3. Example of intensity image extracted for values from 90 to 106

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