LAND USE CLASSIFICATION BASED ON THE INTENSITY VALUE OF THE REFLECTED LASER BEAM

KLASIFIKACIJA RABE POVRŠIN IZ VREDNOSTI INTENZITETE ODBITEGA LASERSKEGA ŽARKA

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ABSTRACT

Airborne laser scanning of a terrain results, in addition to polar coordinate measurements, in intensity measurement of the reflected laser beam. Because the 3D lidar point cloud itself does not include information about the object types on which points are located, intensity measurements provide the important data for identification of objects and phenomena in the physical space. This is confirmed by the colour coded intensity value image, where particular objects (asphalt road, grass, building etc.) can be recognized. The measured intensity values have been analyzed within the Neusiedler See project case, part of a transnational project SISTEMaPARC (Interreg IIIB). We have investigated the land use classes that could be differentiated on the basis of intensity values thus enabling the land use classification.

IZVLEČEK

Pri zračnem laserskem skeniranju terena se hkrati z registracijo polarnih koordinat beleži tudi intenziteta odbitega laserskega žarka. Ker sam 3D lidarski oblak točk ne vsebuje informacij o tem, na katerih objektih točke dejansko ležijo, so meritve intenzitete pomemben podatek za identifikacijo objektov in pojavov v prostoru. To potrjuje slika barvno kodiranih vrednosti intenzitete, na kateri lahko razločimo posamezne pojave (asfaltna cesta, trava, zgradba itd.). V raziskavi smo analizirali vrednosti merjene intenzitete na primeru projekta Neusiedler See, ki je del transnacionalnega projekta SISTEMaPARC (Interreg IIIB). Preučevali smo, katere vrste rabe lahko na osnovi vrednosti intenzitete razločimo in tako izvedemo klasifikacijo rabe površin.

KEY WORDS

airborne laser scanning, intensity, classification, normalization, land use

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zračno lasersko skeniranje, intenziteta, klasifikacija, normalizacija, raba površin

1 INTRODUCTION

Besides position, newly developed airborne laser scanning systems simultaneously record the intensity of each returned echo of the laser pulse. The position gives the morphology of the scanned terrain and the intensity holds potentially useful semantic information about the scanned features (reflectivity). The intensity joined with the 3D geometric data can be used for automatic identification and classification of different land uses. An indirect use of intensity for reconstruction of the ground reflectivity is impossible, because many influencing factors, originating from the laser scanner, the atmosphere and the target, may disturb a measurement.

In different experiments and analyses the experts are trying to find out, which factors, and in what way, influence the measurements, searching for an appropriate reflectivity model (Song et al., 2002; Lutz et al., 2003; Hasegawa, 2006). In our research described in this paper, we used the airborne laser scanning data of the Neusiedler See project. The scanned area covered the Neusiedler See national park, which lies on the border between Austria and Hungary. The aim was to experimentally normalize the measured values, so that they could be used for the classification of the predominant land uses like meadows, fields, vineyards and roads.

2 AIRBORNE LASER SCANNING

Airborne laser scanning (ALS), often called lidar – **li**ght **d**etection **a**nd **r**anging system, is a relatively new but fast developing technology of remote sensing, providing accurate and detailed 3D information about the surface and its objects. The data are captured with a laser scanner (LS), which is an active sensor mounted on the floor of an airborne platform (plane or helicopter), as shown on Figure 1.

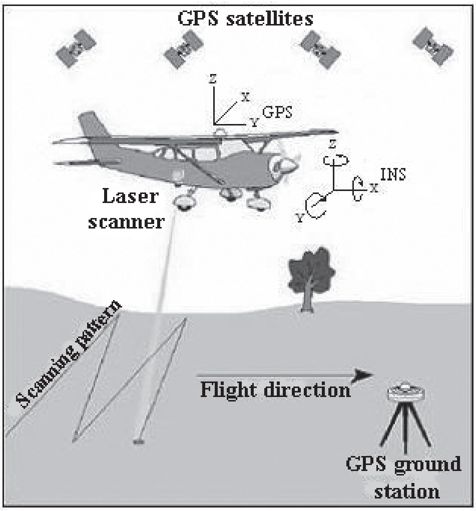

***Figure 1**: ALS data acquisition (ALTM).*

The laser emits narrow, monochromatic and coherent light towards a scanner that reflects it down to the ground in a common pattern. After hitting a target, the laser beam in most cases reflects in a diffuse manner and the returned part of a pulse (so-called echo) can be registered on the system's detector. As the laser light can be reflected from several targets (e.g. penetrating the vegetation) on its way down, it depends on the ALS system properties, how many echoes it registers. Usually, the first and the last echoes are measured. For each echo the travelling time of the light pulse, the scan angle and the intensity are measured. The time-of-flight of a light pulse is used in the equation to compute the double range laser–target–laser. 3D coordinates of the measured points can be determined in the reference coordinate system, if we know the position and the orientation of the laser scanner in the moment of transmitting the laser pulse. The position is defined with simultaneous measurements where the method of the differential kinematic GPS is used, and the orientation is defined with INS (Inertial Navigation System) where three rotation angles and angular accelerations of the platform in the space are measured.

Since the ALS technology does not assure very accurate results in real-time, post processing is necessary. In the process of georeferencing the data of the laser scanner (polar co-ordinates) and measurements of integrated GPS and INS (position and orientation) systems are joined together at the same time, when the pulse is transmitted. To enhance the relative and absolute accuracy of the calculated 3D coordinates, additionally the calibration data of the used ALS system are considered. The results of georeferencing are the coordinates (X, Y, Z) for each registered echo in the reference coordinate system, which are further used for producing the final ALS products, e.g. digital surface model, digital terrain model.

3 INTENSITY DEFINITION OF THE REFLECTED LASER BEAM

The detector of the laser scanner registers the time-of-flight of the backscattered laser light, scan angle of the emitted laser beam and the intensity of the returned echo. It is not known how exactly the intensity in a certain ALS system is measured (the producers of the systems have no interest in providing this information), therefore its definition is rather unclear. In the literature the intensity of the backscattered echo is set to be a digital number, which is proportional to the number of photons impinging on the detector in a certain time interval (in physics: power). In case of the Optech systems, Jonas (2002) wrote that the measured intensity values corresponded to the strength of the returned signal. Intensity values go from 0 (weak return) to 8160 (very strong return) and are rather relative measurements, not necessarily absolute. Generally, the intensity (I_m) is defined from measuring the amplitude of that signal being reflected or emitted from the target, which returns from the target to the sensor and falls on the receiving element of the sensor inside its field of view. The measured intensity is defined as the maximum amplitude or as the average of the whole backscattered signal amplitude. If we consider the fact that intensity values do not have a unit, being relative measurements, then the definition of intensity in Song et al. (2002) is reasonable. It says that the intensity is a ratio between the received strength of laser light (P_r) and the strength from the laser system transmitted light (P_t).

3.1 Radar equation

With the so called radar equation, which is valid for all active sensors, the strength or power of the received signal can be calculated.

The laser evenly transmits its power P_t (referred to also as P_e) through the transmitting optics with a diameter D_t. The laser beam has a small divergent angle β, so it eliminates a small (individual) part of surface A_{laser}. If we consider loss of the laser beam energy, when it is travelling through the atmosphere, and the ratio between the size of footprint area A_{laser} and the size of target[1] dA, we obtain the total power intercepted by the target. Part of the signal is lost, because of the absorption on the target, and the rest is re-radiated in a diffuse manner (in various

[1] *Size of a target corresponds to the effective surface of an object, where the laser beam falls and is reflected from it.*

directions). The re-radiated power depends on the target's reflectivity ń, which is actually a property of the target material. The pattern of the reflected signal can be very complex. If the signal is reflected evenly distributed in the cone of solid angle and, after travelling the range R (target–sensor), this angle covers the field of view of the receiver, which has the aperture of the diameter D_r, then the power of the received signal can be calculated with the radar equation. After Wagner (2005) the final equation is written as in equation 1, where additionally the loss of the signal in the laser scanner system (η_{sis}) and in the atmosphere (η_{atm}) is considered.

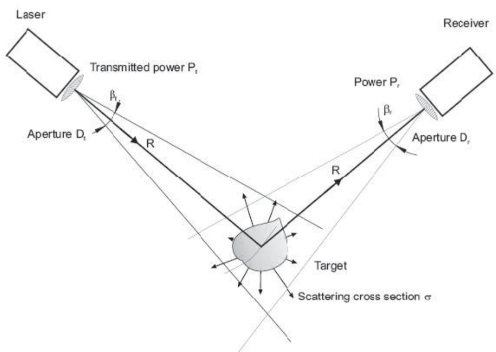

Figure 2: *Sketch of geometry of how lidar points are measured (Wagner, 2005)[2].*

$$P_r = \left(\frac{P_t \cdot D_r^2}{4\pi \cdot R^4 \cdot \beta^2} \right) * \left(\frac{4\pi}{\Omega} \rho \cdot dA \right) * \eta_{sis} \cdot \eta_{atm} \qquad (1)$$

Where:

Pr ... received signal power;

Pt ... transmitted signal power;

D_r ... diameter of received aperture;

R ... range from sensor to target;

β ... divergence of laser beam;

η_{sis} ... system transmission factor;

η_{atm} ... atmospheric transmission factor;

Ω ... solid angle;

dA ... area of the target;

ρ ... reflectivity.

[2] *For clarity, the transmitter and receiver are drawn at different locations. Otherwise the laser scanner has a monostatic construction.*

The factors in the first brackets are associated with the laser scanner and the factors in the second brackets with the target. The latter factors are difficult to measure individually, so they are combined into one single factor, the so called backscattering cross-section, which is further explained in subparagraph 3.2.1.

In the case when the beam falls perpendicular to the target surface (ξ = 90°) and reflects homogeneously ($dA = A_{laser}$), the size of a target is given by the equation:

$$dA = A_{laser} = \pi \frac{R^2 \cdot \beta_t^2}{4}. \tag{2}$$

If we consider that a laser beam reflects diffusely from most targets ($\Omega = \pi$), the power received by the laser scanner could be calculated as follows:

$$P_r = \left(\frac{P_t \cdot D_r^2}{4R^2} \right) \cdot \eta_{sis} \cdot \eta_{atm} \cdot \rho \tag{3}$$

It can be seen from equation (3) that the power of the received signal is inversely proportional to the square range (R) and is no more dependent on the divergence of laser beam (β).

If the inclination angle (ξ) of the laser beam is different than 90°, the equation (2) for the size of the footprintchanges and the received power after Hug in Wehr (1997) is:

$$P_r = \left(\frac{P_t \cdot D_r^2 \cdot \cos\xi}{4R^2} \right) \cdot \eta_{sis} \cdot \tau_{atm}^2 \cdot \pi \cdot \rho \tag{4}$$

3.2 Values of the measured intensity

Intensity values measured for each returned laser beam are a complicated function of many variables like:

- Power of the transmitted laser beam (Pt);
- Range sensor–target–sensor ($2R$), which depends on the height of the terrain and flying height;
- Above see level of the area scanned – it influences the characteristics of the material (e.g. soil moisture changes according to the height);
- viewing angle of the ALS sensor;
- inclination angle (ξ) of the laser beam;
- type of laser light reflection (diffuse, specular) on a target;
- reflectivity of a target;
- size of a target in comparison to the size of the footprint;
- atmospheric condition – impact of clear or hazy air (depends on the quantity of the steam

and aerosols) on the air attenuation and diffraction;

· radiation from surroundings, which has a similar wavelength to the one of the laser light (sunlight reflected from the ground and from small parts in the atmosphere, thermal radiation from the Earth's surface).

These influencing factors disturb the measuring of intensity, so it is impossible to use them directly for the identification or determination of the target's material. The model must be simplified and checked with different experimental analyses.

Considering the definition of intensity, being defined by the ratio of the received and transmitted light power, and supposing that the reflection is diffuse and homogeneous, and the inclination angle is perpendicular to the target, we can simplify the equation (3) to equation (5). It is valid for the same measuring system and for equal atmospheric conditions (one ALS mission).

$$I_m \approx \frac{P_r}{P_t} = \frac{\rho}{R^2} \cdot const. \tag{5}$$

Where:

$const. = \frac{D_r^2}{4} \eta_{sis} \cdot \eta_{atm}$ ... constant.

The values of the measured intensities depend on the target's material (reflectivity ρ) and get smaller with the range squared. Equation (5) shows that for the same surface, which is illuminated and observed with the same ALS active sensor, but from different distance (R), the detector records different intensity values (I_m). While the incidence angle is mostly around 90°, its influence on intensity measurements could be neglected. It is considered only in case, when a high accuracy of measuring the reflectivity is required.

Therefore values of the measured intensities do not depend on variables like transmitted power, atmospheric condition, radiation from surroundings, sensor's field of view, but mostly depend on the range R and the type of the target (according to its reflectivity, orientation and size). Range R is known, while it is measured for each returned laser beam. More complicated is the influence of the target, which is presented with various variables in the second brackets of equation (1) and is called backscattering cross-section σ (Wagner, 2005).

3.2.1 Backscattering cross-section

The backscattering cross-section ó of the laser beam depends on the target's reflectivity (dielectric properties), the orientation of a target regarding the incidence angle and the angle of reflected beam and, finally, on the size of the target regarding the size of the footprint. As we can guess from the name, the backscattering cross-section gives the effective area for collision of the beam and the target, where the directionality and the reflectivity of the target are considered (Jelalian, 1992, after Wagner, 2005). The understanding of variables, which determine the backscattering cross-section and which are important when calculating the power of the received signal, is essential for analyzing the intensity values and defining influences on intensity measurements.

First, the influence of the target's directionality on intensity depends on the way, how the laser light is reflected from a target (diffuse, specular or no reflection). While the wavelength of the laser light is small (λ = 1 μm) in comparison to the surface height variations of most targets, we consider the Lambertian scattering law: the beam reflects diffusely, homogeneously in the solid cone Ω, which is $\Omega = \pi$ (Lambertian target) (Wagner, 2005). In this case the influence of the target's directionality regarding the direction of the beam reflection is negligible. Rarely, there are some exceptions like areas covered with snow and ice, where the beam reflects specularly (the surface appears smooth) and so we have to consider the direction of the beam reflection in the intensity analysis (Lutz et al., 2003). Nevertheless the angle between Lambertian target's normal and the direction of the beam reflection (towards the sensor) does not influence the received power (P_r), it depends on the angle between target's normal and the direction to the source of light, i.e. incidence angle. The bigger the incidence angle, the larger the laser footprint size and the smaller the power density on a target. Therefore the power of the returned light, which is detected in LS, is smaller. In reality (for e.g. leaves of trees, mountain areas) it is difficult to calculate the incidence angle. But if we have the information about the LS system orientation, which gives the direction of the laser beam, and the digital elevation model (DEM), which defines the inclination and the orientation of a target, we can compute the incidence angle with the equation in Lutz et al. (2003).

Second, the influence of the target size on intensity in comparison with the laser footprint size was described by Wagner (2005) for four different types of targets: small target (e.g. leaf on a tree), linear target (e.g. power line), extended target (e.g. road) and volume target (e.g. tree crown). If we presume that the target intercepts the entire beam with a divergence β, its size is equal to the laser footprint size. For flat terrain and for an arbitrary incidence angle the footprint size could be calculated with equation in Baltsavias (1999). The size of an extended target influences the intensity by the variable *incidence angle* (ξ).

The reflectivity (ρ) for targets with diffuse reflection is defined with a ratio between the reflected and received power. The reflectivity changes according to the light used and the properties of the target material. Table 1 lists typical reflectivity values for different target materials and for laser wavelength 1 μm, which is commonly used in commercial LS systems. As the measuring conditions are not well known, these values must be treated with care (Wagner, 2005).

Material	Reflectivity
Aluminium foil	0.8–0.9
Asphalt	0.2
Cement	0.4
Chromium	0.6
Copper	0.9
Maize leaf	0.9
Maple leaf	0.4
Platinum	0.45–0.6
Sandy soil – wet	0.15
Sandy soil – dry	0.3
Silty soil – dry	0.6
Snow	0.25
Stainless steel	0.2–06
Water – normal incidence	< 0.01
Water – grazing incidence	up to 0.3
Wheat stalks	0.9
Wheat heads	0.65
White oak leaf	0.65

***Table 1**: Reflectivity values for different target materials at the wavelength 1 μm (Wagner, 2005).*

The influence of the reflectivity ($\rho_{tarča}$) on the intensity is the biggest and the most important among other factors mentioned, as it is evident from the intensity definition (see equation (5)). While disturbed by the influencing factors, the measured intensities do not correspond to theoretical reflectivity values, but they follow them relatively. It is possible to separate different materials, so the registered intensity of the returned beam could be used to distinguish different surfaces. The condition is that the reflectivities and therefore the measured intensities of surfaces differ enough among themselves. Researches on this topic are explained in Hasegawa (2006) and Song et al. (2002).

4 INTENSITY ANALYSIS IN THE NEUSIEDLER SEE CASE PROJECT

Airborne laser scanning of the Neusiedler See National Park, which lies on the border between Austria and Hungary, was done in the frame of international project SISTEMaPARC as part of the Interreg IIIB project. The prime objective was to renaturalise the park, since in the 20th century the inappropriate water and land management caused a drastical increase in the number of natural wetlands. While the surface is relatively flat, even height differences of a few centimetres are significant for the planned hydrological analysis. This accuracy could be achieved with the ALS acquisition system and with certain post-processing methods. The results of the hydrological analysis are discussed in the graduation paper by Chlaupek (2006). Additionally, the Neusiedler See measurements were used for the analysis of intensity of the returned laser beam (hereafter intensity), which is the core research of the graduation paper by Bitenc (2007). The aim of this analysis was to find out whether it is possible to use intensity for the classification process. Within the area covered by the project, we tried to classify land use, distinguishing between fields, meadows or other low vegetation, roads (asphalt and gravel) and vineyards.

4.1 The data for intensity analysis

For the intensity analysis we could use the lidar data of the southern part of the Neusiedler See project area. The data were in the UTM projection system and the heights were related to the ellipsoid. The 3D coordinates of lidar points, which were computed in the process of fine georeferencing, were used for interpolation of the digital terrain model (DTM) and digital surface model (DSM). In the entire area, the DTM changes by 15 m only, meaning that the terrain is relatively flat. The DSM is interpolated from all measured points and its texture shows the position of features like buildings, vegetation (trees, bushes and vineyards), and other objects (e.g. cars). It is used as an underlying layer for intensity data – adding the representation of height perception. Additionally we could make use of raw digital images.

ALS mission was done with the Optech ALTM 2050 system, which measures intensities for the first and the last pulse. For intensity the following properties could be written:

- The measured intensities display a traditional "bell-shaped histogram".
- The range of intensity values is between 4 and 255 if flown at an average height of 1100 m.
- The lower the flight of the plane, the higher the magnitude of the intensity returns.

In fact intensity values were coded with a 12-bit amplifier used in the ATLM 2050. Maximum values (up to 4096), which were recorded for points with strong reflectivity (e.g. water and mirror surface, glass), disturb the visualization of the intensity image. Therefore in the TopScan company they reduced the range until a value of 255, so that the intensity data could be visualized in a 8-bit colour scale. Points with highest intensity values were assigned the value of 255, without any scaling. Returns with very low/small intensity value have to be omitted, while range measurements are not accurate enough (the signal is too weak). In this case returns with intensity less than 4 were excluded. To show intensity images, first the intensity values were interpolated, using SCOP++ software, with a simple »Moving Planes« method, and then colour coding with black and white palette was performed (Figure 3, right).

4.2 Intensity analysis for certain features

The intensity image (Figure 3, right) clearly shows different land uses. To actually define the different features of land use, we used, simultaneously to laser scanning, the digital images made with a non-metric digital camera. In this way we could separate and identify features given in Table 2. Typical intensity values (or the range of values) for a certain feature was estimated in the GVE program, where colour coded presentations are done and the intensity for each lidar point can be inspected. To identify objects above terrain and estimate their intensity values, the DSM was laid under the lidar points. DSM gives the type of an object (e.g. house, vegetation, car

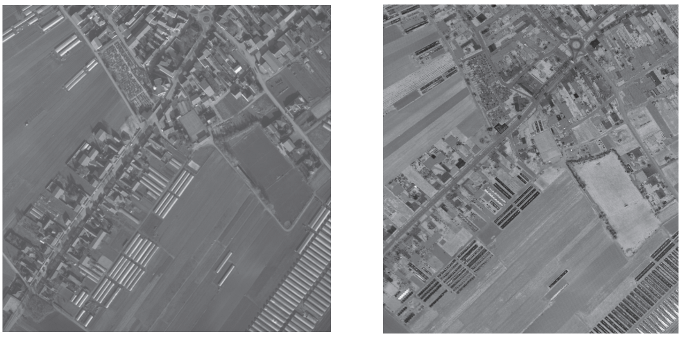

***Figure 3**: Example of a digital photo (left) and an intensity image (right) for the same area.*

Feature		Estimated intensity values
Grass		76–107
Fields	green	56–96
	brown	35–52
Vineyards		**4–134**
Roads	asphalt	14–47
	gravel	50–68
Roofs		**4–146**
Objects – greenhouse		**4–255**

***Table 2**: Different features (objects, land use) and estimation of their intensity values.*

etc.) and its position on the intensity image (e.g. outline of vegetation or house). The type and the position of features lying on the terrain were defined with the help of digital images and intensity itself. A more exact estimation of the intensity values was not possible in this case, since we should use additional data (e.g. orthophoto) to directly locate features in the intensity image. This would facilitate a more accurate extraction of intensity values for a certain feature

The intensity changes most and has the widest range of values for objects (houses and greenhouses) and in the area of vineyards. This confirms the influence of the incidence angle ($\hat{\imath}$) on the measured intensity. While the surfaces are inclined (roofs) and their orientation, inclination is changing (curved roofs of greenhouses, trelliswork for vines), the intensity varies fast. The fast and disorderly changing of intensity values of the returns from greenhouses is also the consequence of the transparent material used (plastic). The laser beam partly penetrates the greenhouse roof and reflects from the objects inside. The range of intensity values is therefore from 4 to 255. Isolated high intensity values occur on roads. The beam may reflect from a car, a white sign on the road surface (middle line, pedestrian crossing), or a manhole cover. These materials have a high reflectivity (Table 2). The estimated intensity values for the features on the terrain also have (too) big intervals, which overlap.

The comparison of intensity images of different strips in some cases shows significant differences among them. Although the images cover the same area and the objects shown are the same (returns of the laser beam come from the same material, feature), the values of the measured intensity differ. An empirical analysis of the intensity in identical areas, but from different strips, gives the answer: the shift in intensity values is the consequence of different heights of flying.

4.3 Analyzing influences on the measured intensity

The measured intensity depends on range (R), incidence angle (ξ), which is a parameter in the equation of the target size, and reflectivity (ρ). Analyzing the data, we are looking for a correlation between these variables.

$$I_m = f(R, dA(\xi), \rho) \qquad 6$$

Variable R is known for each lidar point, since the original observations of polar coordinates are at our disposal. To consider the influence of dA, we presumed that:

1. When we wish to classify different land uses, we take into account the intensity of terrain points only. The incidence angle for those points is the same as the scan angle, because the terrain of the Neusiedler See area is relatively flat (according to the DTM). For the ALTM2050 measuring system the scan angle changes from 0° to ±20° and is given with polar coordinates for each lidar point. Therefore the incidence angle is $\xi = \Theta = [0°, 20°]$.
2. The laser beam was reflected from a homogeneous surface, i.e. from an extended target, so the target size is always the same as the footprint size. Therefore the target size.

The changes of the incidence angle modify the target size, but its influence on the measured intensity is very small in comparison with the range influence. We also take into consideration the fact that in the case of flat terrain the incidence angle is a parameter of the measured range. Therefore in further analysis the influence of the incidence angle (or scan angle) on the intensity is neglected.

The biggest influence on the measured intensity values is that of the reflectivity of the target, which is not known. Also, we could not use the theoretical values (Table 1) that would apply for a certain feature, since we were not able to extract or acquire the intensity value for this feature (the extraction of I_m for e.g. a field is not possible). Equation (6) can be written as:

$$I_m = f(R, \rho) \tag{7}$$

Since in the discussed area different land uses appear with different reflectivities, there is no direct correlation between the intensity of the returned beam and the range. The function *f* in equation (7) could not be determined. In this case we take into account the fact, that the reflectivity is a property of the material. Therefore the reflectivity of points with the same position (i.e. lying on the same feature), but measured in different strips, should have the same value ρ ($\Delta\rho = 0$). When analyzing the difference of measured intensities for identical terrestrial points from two strips $(\Delta I_m, \Delta R)_{\mathrm{IDT}}$, we tried to find out how the intensity changes (for a certain feature) with the change of the sensor–target range.

$$\Delta I_m = f(\Delta R)\,,\ \Delta\rho = const. \tag{8}$$

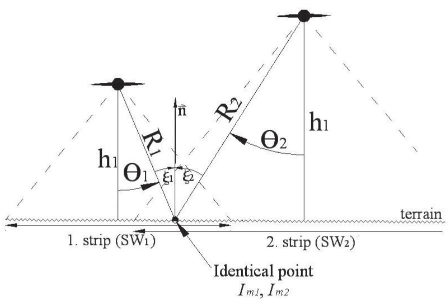

Figure 4: *Geometrical relation between variables for identical points.*

4.4 Correction of measured intensity for identical points

The corrections of (measured) intensity values, which correspond to the identical points from the first and second strips ($I^n_{IDT,1}$ and $I^n_{IDT,2}$)should meet the requirement that the differences of normalized intensity values for those points are zero.

$$I^n_{IDT,1} - I^n_{IDT,2} = 0 \tag{9}$$

The diagram below shows the steps of the empirical analysis, where we studied the connections between the differences of variables and calculated normalized values.

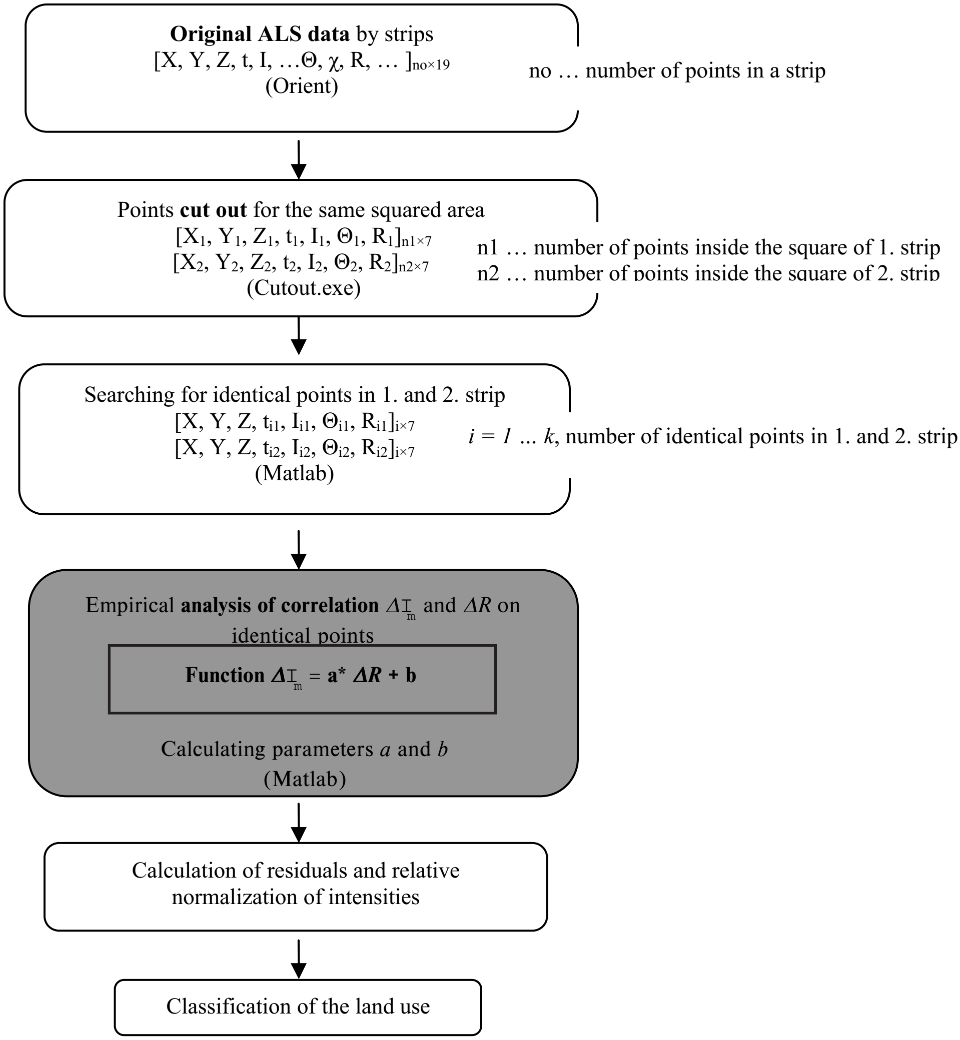

***Figure 5**: Flow chart of the empirical analysis for intensity normalization.*

Preparing the data of lidar points

The original data of lidar points (range and scan angle) were not available. For our analysis they were calculated with the ORIENT program by Prof. Helmut Kager from I.P.F Vienna (Institut für Photogrammetrie und Fernerkundung Wien). The Cutout.exe program (author Maria Attwenger, I.P.F.) was used to cut out lidar points inside the same squared area of size 420 m × 420 m, but from two overlapping lidar strips. The comparison of intensity images, made from those two sets of points, showed different values (Figure 6).

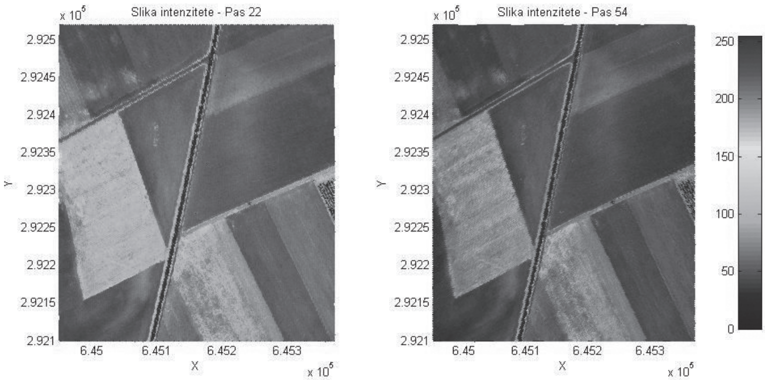

Figure 6: Comparison of intensity images of the same area but from different strips (Left – strip 22, right – strip 54).

Finding the identical points and analyzing the differences of the variables

The Matlab program package code finds the identical points in both lidar strips. Their position (X, Y) is not more than 10 cm apart (the radius of the footprint size changes from 10 cm to 12.5 cm) and it can be presumed that a pair of identical points lies on the same feature (meadow, field). Therefore the identical points have the same reflectivity and should have (theoretically) the same measured intensity values. In fact this does not hold true, proven by the comparison of intensity images, made for the same area but measured in two strips. As we can see in the histograms below, the intensity from strip 1 is shifted according to the values in strip 2.

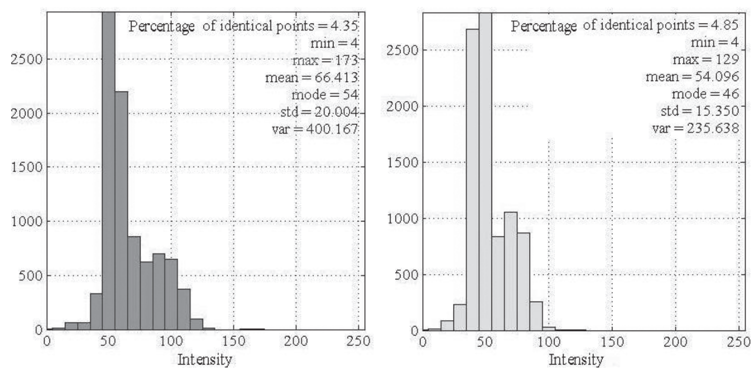

Figure 7: Histograms of intensity values for identical points (left – strip 22, right – strip 54).

We calculated the differences of measured variables for identical points and empirically analyzed their correlation.

Where:

- *Difference of intensities*: $\Delta I_i^m = I_{i,2}^m - I_{i,1}^m$ $\quad i = 1, \ldots, k$ (10)
- *Difference of ranges*: $\Delta R_i = R_{i,2} - R_{i,1}$ *(11)*

k ... number of identical points for a strip pair;

ΔI_i^m ... *Difference of intensities* for identical point *i*;

$I_{i,1}^m$ or $I_{i,2}^m$ ... intensity value of identical point *i* in strip 1 or strip 2;

ΔR_i ... *Difference of ranges* for identical point *i*;

$R_{i,1}$ or. $R_{i,2}$ ... measured range of identical point *i* in strip 1 or strip 2;

Definition of the function

While the differences of intensities from two lidar strips and for the identical points are not zero, as was expected, we search for its functional dependency from ΔR_i (equation 8). The function is shown on the figure below (Figure 8).

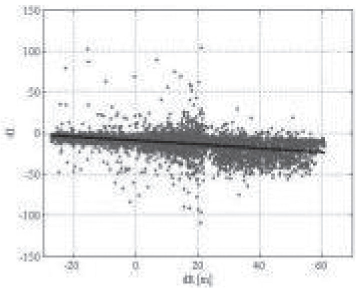

***Figure 8**: The linear dependency of intensity differences on range differences.*

While there is no correlation between variables of *intensity* and *range*, the *differences of intensities* and the **differences of range** are linearly correlated (Figure 8). Equation (8) could be rewritten as:

$$\Delta I_m = a * \Delta R + b \tag{12}$$

Because the differences ΔI_m in ΔR were calculated from identical points, the unknown *a* in *b* could be estimated with the realization of the sample from identical points using the least-squares method. Calculated coefficients $\tilde{a}$ in $\tilde{b}$ are called regressive coefficients and the straight line $\overline{\Delta I(\Delta R)} = \tilde{a} * \Delta R + \tilde{b}$ is called regressive straight line (black line in Figure 8). The values of parameters *a* in *b* define the influence of ΔR on ΔI_m more exactly and enable to calculate the corrections of measured intensity values.

4.5 Intensity normalization

With parameters a in b, which were calculated from identical points and are valid for a used strip pair, we calculated the corrections for measured intensity $\overline{\Delta I(\Delta R)}$. The corrections are relative, since they are based upon the distance difference, thus the intensity of the basic strip (called also master strip) does not change, but the intensity correction of the other strip (called also slave strip) is added or subtracted.

Examples below are valid when the differences of range *ΔR* are calculated as ranges from the second strip minus ranges from the first strip (strip 2 – strip 1).

possibility 2 I_1 (master strip is strip 2)

$$I_2 \rightarrow I_2^n = I_{m,2} - \overline{\Delta I(\Delta R)} \tag{13}$$

possibility 1 I_2 (master strip is strip 2)

$$I_1 \rightarrow I_1^n = I_{m,1} + \overline{\Delta I(\Delta R)} \tag{14}$$

ΔR for identical points is calculated using equation (1), and for other points (in a slave strip) as:

possibility 1 $$\Delta R = \overline{R_2} - R_1 \tag{15}$$

possibility 2 $$\Delta R = R_2 - \overline{R_1} \tag{16}$$

Where:

$\overline{R_1}$ or $\overline{R_2}$ ... average range of lidar points in strip 1 or strip 2;

R_1 or R_2 ... measured range of lidar points in strip 1 or strip 2.

Both relative normalized intensity images for identical points are now more similar and the difference of (normalized) intensity values is zero. Actually the normalized values of the slave strip are shifted according to the measured values, so that their difference with the master strip is zero. This can be explained with the size of parameters *a* and *b*, where *a* determines the influence of the difference of range and is much smaller than the constant part (e.g. parameter *b*).

	strip 1: 22	strip 2: 54 (master)
Average flying height	1122.19 m	1137.01 m
Size of a square	420 m × 420 m	
Number of points inside the square	204,518	183,660
Number of identical points	8902	
Averaged measured intensity $\overline{I}_i^m$	66	54
Difference of intensities ΔI_i^m	–12 ± 10 (average ± standard deviation)	
Parameters a and b	(–0.2278, –9.0596)	
Difference of relatively normalised intensities ΔI_i^n	0 ± 9	
Averaged relatively normalised intensities	54	54 (the same)

***Table 3**: Results of relative normalization for strips 22 (slave) and 54 (master) – for identical points.*

5 CLASSIFICATION

To compare the measured intensities between different strips it is necessary to normalize its values for the average range (Katzenbeisser, 2002). The described method of relative normalization, with the help of identical points, gives the corrected values for differences of range ΔR and the result is a more homogeneous and clearer intensity image. But the intensity within a certain land use does not change much. Since the interval of intensity values for a certain land use (i.e. for grass) is still too large and these overlap, the classification is not a successful one.

The figure below (Figure 9) shows an example of classification of grasslands – besides meadows, there are also roads and other smaller areas and points lying in the fields.

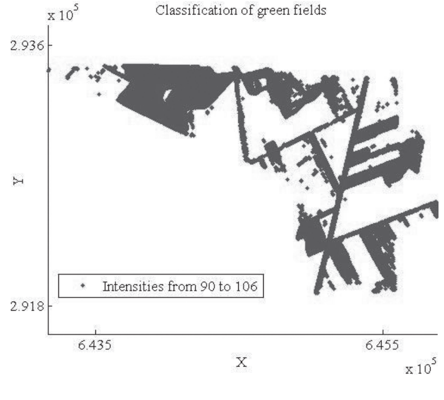

***Figure 9**: Example of intensity image extracted for values from 90 to 106.*

Even though features such as grass, fields and gravel are separable according to the results provided in the literature (Hasegawa, 2006), we should use additional data for a more accurate and successful classification. On the other hand, remote sensing with the multispectral camera, where many spectral channels are used, assures enough information for an automatic classification.

6 CONCLUSION

The registering of intensity and the measured intensity values themselves depend on different factors like the way the returned laser beam is registered in LS, conditions of the atmosphere, through which the beam is travelling, the type of target material and its position, measured polar coordinates (range and scan angle) etc. For these influences the intensity values must be normalized. The best way is to perform laboratory experiments or else one uses the data available for a certain project. According to the studies, performed by the authors discussed, the intensity mostly depends on the measured range sensor–target, reflectivity of the target material and incidence angle. We checked the influence of these factors with the data of the Neusiedler See project.

While the terrain of the area discussed is relatively flat, we presumed that the incidence angle is the same as the registered scan angle. We found that it had a negligible effect on the measured intensity. We did not have any information about the materials of the targets, i.e. about the reflectivity, which have a strong impact on the intensity values. Therefore we used the measurements of identical points from two overlapping strips. The results of the linear regression function showed that the more or less constant differences in the measured intensities between the points from two strips are the result of the different height of flying. The intensity values from different strips are mutually shifted by a certain constant value.

The relative normalization of the intensity values described above could be done for all parallel strips (slave strips) regarding the cross strip (master strip), as they were acquired for the Neusiedler See project. This helps the intensity of the image to become clearer and more homogenous, however, the range of intensity values for a certain feature does not change. In the future we should study the change of intensity values that belong to a certain feature (not just relatively regarding the master strip). In this way the correlation between the intensity and range (depending on the scan angle, when the terrain is flat and the flight height is constant) could be defined directly and more accurately. This would result in better calculations of corrections and finally enable the (automatic) classification. For the extraction of the intensities that belong to a certain feature, additional data would be needed. We would need to know the position of the feature in the lidar point cloud, provided by the digital orthophoto, cadastral data, terrestrial measurements etc. Lidar data only do not suffice.

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