INFLUENCES OF VEGETATION ON LASER ALTIMETRY – ANALYSIS AND CORRECTION APPROACHES

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KEY WORDS: Laser scanning, texture, vegetation influence, digital terrain model

ABSTRACT
The influences of low vegetation on airborne laser scanning are studied. High vegetation is removed by filtering, but low vegetation causes systematic errors in digital terrain models. Many researchers have reported that the measurements are too high. The investigation of influences on the laser range measurement improves the understanding of the technology in use and gives explanations for the observed errors. The possibilities of correcting the data with information on the vegetation type are studied, using ground truth data from terrestrial measurements as reference. An alternative approach using texture measures, which does not require information on the land cover type, is presented. Texture has previously been defined for digital images and its equivalent for point clouds is presented here.

1 INTRODUCTION

Airborne laser scanning has become a standard method for obtaining elevation information over open landscape and in forests alike. Laser scanning is used to determine digital terrain models (DTM) in areas covered with trees, shrubs, grass of varying height and other vegetation types. The terrain models are determined with one or more applications in mind, e.g. orthophoto production, hydrological modelling or planning purposes. Demands on modelling scale (point density), accuracy (currently more attention is paid to vertical accuracy, whereas lateral accuracy is less investigated) and reliability (certainty/propability that an error can be detected) are growing steadily. The question arises if laser scanning technology and data processing algorithms keep pace with the growing demands.

Accuracy studies are frequently published (Torlegård and Nelson 2001), (Maas, Vosselman, and Streilein 2003), but a closer look on the *method* of laser scanning is necessary, yielding a better understanding of the obtained accuracies. A generally observed phenomenon is, that laser measurements are too high compared to check points (see Fig. 1), with the exception of break lines, where a laser derived DTM can also be lower than the check points[1].

It has been shown that DTM accuracy depends on the type of vegetation covering the ground. In (Pfeifer, Stadler, and Briese 2001) DTM accuracy has been investigated, which can be higher than laser measurement accuracy due to elimination of random errors in the modelling process. Within one flight and using roughly 800 terrestrial check points, the results obtained were in a street without cars: ±1.0cm, street height below parking cars: ±3.7cm, in an open park area (grass): ±4.5cm, park with few trees: ±7.8cm, and park with dense tree stocking: ±11.1cm. Additionally, there is a systematic shift of the DTM above the check points, growing in the same manner as the accuracies. In (Ahokas, Kaartinen, and Hyyppä 2003) the land cover classes investigated are asphalt, gravel, and grass (flying height 550m), and forest ground (flying height 400m), and comparison to roughly 3500 ground points[2] lead to ±10cm, ±4cm, ±11cm, and ±17cm, respectively, but a less systematic behavior in the upward shift of the laser points compared to the ground points. (Bollweg and de Lange 2003) investigated horizontal areas and found an upward shift of 8cm on long dense grass, and 4cm on solid ground, and the standard deviation of the laser measurements increased from ±7cm on solid ground to ±14cm on low vegetation, whereas standard deviations of the terrestrial control measurements showed an increase from ±3cm to ±7cm. In (Oude Elberink and Crombaghs 2004) it is shown that upward shifts occurred up to 15cm on low vegetation areas (creeping red fescue, thrift). A relation could be seen between the density of the vegetation coverage (and height) and the systematic error: 0% coverage meant no upward shift, 100% coverage showed a 15cm shift.

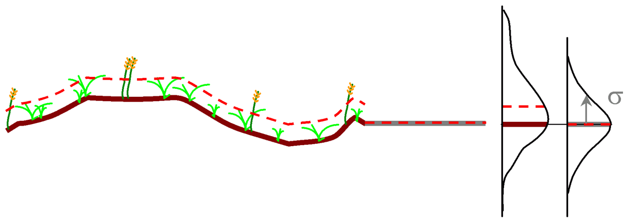

Figure 1: Over low vegetation laser measurements have a systematic upward shift compared to the ground surface, the dashed line shows the expectancy of the observed height values (assuming a stationary vegetation influence, i.e. the distribution of points relative to the ground does not depend on the location). Over a flat surface the expected height of the laser measurements is identical to the surface elevation. The standard deviation σ of the distribution of the measurements around it is the standard deviation of one laser scanner measurement (right histogram).

Realizing that there are systematic errors of laser scanner derived heights, the next logical step is trying to *detect* the quality automatically and *improve* the accuracy, i.e. eliminate the errors caused by the different vegetation covers.

In Section 2 the laser scanning technology and characteristics of the vegetation relevant to laser ranging, eventually leading to the height measurement, are studied. Section 3 studies possibilities to remove the disturbing influence of vegetation.

2 INFLUENCES ON LASER RANGE MEASUREMENTS OVER VEGETATION

Obtaining one ground point measured from laser scanning is a product composed of many individual measurements and events: direct geo-referencing, determination of the angle of the emitted beam, emission of the laser pulse and travel through the atmosphere, interaction (i.e. specular and diffuse reflection and absorption) with the ground and vegetation, travel back, and eventually signal detection and time measurement. All these processes have an impact on the obtained ground point.

Geo-referencing of the laser data is usually performed by the data

[1]This effect can be explained by the random sampling of surface points by laser scanning, providing no edge information. The interpolated surface therefore underestimates the true terrain elevation at break lines.

[2]The 3500 ground points were used for 6 study areas, where only 4 are quoted here.

providers. Errors in the control points (e.g. the GPS reference stations) and in the control or calibration areas (e.g. horizontal sport fields, the air strip) influence the entire orientation of the laser scanner point cloud. As calibration is usually performed over asphalt or areas with sparse, very low vegetation laser ranging over other surface types cannot a priori be expected to have the correct heights.

Flying height influences on the overall accuracy, and systematic vertical shifts of the points measured by laser scanning have been reported by (Ahokas, Kaartinen, and Hyyppä 2003). Larger flying heights result in larger footprint size due to the *beam divergence*.

Footprint size refers to the area illuminated by the laser light. For terrain capturing missions the footprint size is usually in the range of 50cm to 1m. This means that all objects within this area contribute to the backscatter. Over vegetation the returning echo is therefore a mixture of ground (i.e. soil) reflections and the leaves of the vegetation (e.g. grass). Because of this the measured range lies systematically above the terrain. With smaller footprint sizes the probability of having more than one surface within the footprint drops, but smaller footprints are harder to establish optically. A very small beam divergence and low flying height put an additional restriction on the emitted energy (eye safety), and lower energy leads to less precision in ranging due to a decrease in signal-to-noise ratio.

Pulse width has an impact on the ability to discriminate between two echoes. The pulse width is usually a few nano seconds, with 1ns corresponding to 30cm of length. If two surfaces (e.g., upper side of a shrub and the ground) are within one footprint only two distinct echoes are generated, if the pulses are at least half the pulse width apart (see e.g. (Wagner, Ullrich, Melzer, Briese, and Kraus 2004)). In (Löffler 2003) it is specified, that for the TopoSys laser scanner the “two successive echoes must have a significant larger distance than the pulse duration of 5ns”(!), corresponding to 1.5m one-way travel distance.

Echo selection in the case that more than one returning echo is detected has to provide the last echo, if the ground surface shall be reconstructed. Otherwise subsequent filtering becomes unnecessarily complicated as more point in the higher vegetation have to be removed. As explained above, echo selection has no impact on recording low vegetation (e.g., 1m above the ground) versus recording ground reflections.

Echo detection method refers to the way the returning echo is recognized and time counting, started upon emission of the laser pulse, is stopped. The arrival time can be measured with different methods ((Wagner, Ullrich, Melzer, Briese, and Kraus 2004), (Fox, Accetta, and Shumaker 1993), (Katzenbeisser 2003), (Jutzi and Stilla 2003b)): threshold crossing (measure the time when the signal power is larger than a threshold), threshold crossing with dynamic adaptation to signal amplitude, signal peak detection, constant fraction (an inverted and time delayed copy of the signal is added to the original received echo and the first zero-crossing of this compound signal is detected), signal center of gravity detection, and average time value detection (detection time is reached after a certain portion of the return energy has been received).

In general, it is not known, what type of echo detection is applied by different laser scanning systems. For airborne laser scanning, there are no studies that investigate the influence of the different techniques on the measured range, and if there are systematic differences for different surface and vegetation types. However, the study by (Jutzi and Stilla 2003a) provides evidence for such influences.

Vegetation type has an influence on the returning echo, leading to a distorted returning wave from, and generally larger random errors, compared to terrestrial check points. From the studies available so far, no conclusion can be drawn between systematic height differences and vegetation type and state. The *flying time* has a well-known impact on the measurements, but concerns more the higher vegetation. During the leaf-on season more points on the canopy are measured, which means that fewer points are available for the reconstruction of the ground.

Intensity of the return signal is known to have an influence on the measured range if it is very high, which can be caused by e.g. retro-reflective materials. This does not apply to vegetation. One explanation for this effect is that the detector is not calibrated for these high return energies and yields unreliable results.

The above list leaves open questions, and indicates that the ability to determine the ground (i.e. soil) elevation directly from laser ranging is not straight forward.

3 CORRECTION OF THE VEGETATION INFLUENCE

The analysis in the previous Section was system driven (i.e. investigating the ‘elementary’ influences on laser ranging), improving our understanding of the technique and the cause of errors, but did not lead to a correction approach yet. In this section a data driven approach is taken, investigating the possibilities to correct systematically too high measurements over vegetation.

Generally two approaches can be taken: using meta information (e.g. type of vegetation) or trying to look for cues how to correct the measurements solely in the data. Before treating these two approaches, the role of filtering (i.e. applying algorithms to remove ‘vegetation-points’) will be analyzed shortly. The data for the experiments have been provided by Rijkswaterstaat.

3.1 Description of test data

Ground truth and very dense laser data have been captured over a number of test sites in the Netherlands. These data sets are used to study the influence of vegetation on a phenomenological basis.

This test area covers two regions, “Afferdensche en Deestsche Waard” and “Duursche Waard”. Laser altimetry data has been captured by Fugro-Inpark with the FLI-MAP system. This system is mounted in a helicopter and provides data with a density of 10 points per m^2. In the same period of time, terrestrial measurements (RTK-GPS) have been performed at 24 sites in this area. Each site contains approximately 25 points with point distance of 2.5m. These measurements are so-called ground measurements: the height is supposed to represent the ground level. Various sorts of low vegetation have been discriminated, among others long dense grass, young forest and old willow forest.

3.2 Role of filtering

The first applications of laser scanning were related to DTM reconstruction. For wooded terrain, where not all laser measurement ‘reach’ the ground but are reflected in the vegetation so-called filter algorithms have been developed. These filters remove – more or less reliably (Sithole and Vosselman 2003) – high vegetation and houses. The low vegetation cannot be removed with these filters, because no real ground points are available (see Section 2). Tuning the parameters of these filters it is possible to prefer lower points measured over low vegetation to higher points in the low vegetation. Assuming that the measurement over low vegetation have a systematic upwards shift and a random distribution around it (see Fig. 1), the filters select those points with a random component of the opposite sign as the shift. This approach brings the reconstructed DTM closer to the ground surface in a practical way, but the quantity of this “correction” depends on the (unknown) size of the upwards shift and the (unknown) distribution of the measurements around it.

Table 1: Analysis of laser scanning measurements over different vegetation types. The column ‘mean’ gives the average offset of laser points above the terrestrial check points in [mm], the column ‘std.’ the standard deviation of signed distances from the control points to the laser measurements in [mm], and ‘min/max’ shows the minimum and maximum height below/above the control points in [mm].

vegetation	area	#pts.	mean	std.	min/max
long dense grass	A2.1	614	101.1	73.6	-67/376
	A2.2	2368	60.3	77.6	-235/351
	A2.3	1811	104.7	94.3	-139/554
	D2.1	1471	77.3	75.8	-193/365
	D2.2	2189	50.0	79.2	-248/446
long dense grass	all	8453	73.1	84.1	-248/554
young forest	A10.1	386	79.9	91.0	-173/344
	A10.2	642	86.2	94.0	-189/409
	D10.2	543	146.0	98.2	-80/473
	D10.3	542	61.8	102.1	-148/376
young forest	all	2113	94.2	101.7	-189/473
old willow forest	A11.1	355	68.1	137.8	-355/524
	A11.3	189	175.9	96.8	-153/449
	D11.1	133	160.2	108.1	-29/482
	D11.2	539	116.4	93.7	-107/490
old willow forest	all	1216	116.3	116.5	-355/524

3.3 Vegetation type approach

For measuring the influence of the low vegetation the 24 control point areas were used to study if there is a systematic relationship between vegetation type and offset of laser measurement above the ground surface. The control points were triangulated to form the DTM. The laser points were selected from the entire laser data set in an area centered in the middle of the control points, but nine times larger than the control points areas. The larger extent is necessary to insure that during filtering no boundary-effects occur in the region of the control points. Filtering was performed to remove points measured in the high vegetation. The results of this step were checked visually, and filtering with the slope based approach (Vosselman 2000) worked correctly.

In the next step the signed distances from the terrestrial control DTM to the filtered laser points were computed, yielding a positive distance, if the laser measurement is above the control points. The average value (1st moment, also called *shift* in the following) and the standard deviation (2nd central moment) of these distances were computed. Results for vegetation types with more than four test fields are given in Table 1, the full data can be found in (Pfeifer, Gorte, and Vosselman 2003).

This table shows that the laser scanner measurements are systematically too high. Including all 24 test areas upward shifts range from 1cm, found in one control area close to a forest border, to 18cm (A11.3). If the ‘mean’ is subtracted from all the measurements in one test field, the modified laser measurements are free of the systematic error. Assuming that the terrestrial check points are free of error and that the triangulation is the ‘true’ form of the terrain, the ‘std.’ becomes the accuracy of the laser measurements for this vegetation type.

One tendency can be observed in the table of all 24 areas. Higher offset values can be found, where the standard deviation is higher, too. However, within one vegetation group the values vary strongly (e.g. offset between 5cm and 10cm for long dense grass), so that a dependency on the offset on the vegetation type cannot be demonstrated with this data.

One approach for correcting the data would be to specify the vegetation more precisely, e.g. find a measure for the density of the grass, and make more experiments of this kind in order to demonstrate a dependency of the offset value on the vegetation type. If successful, the result would be a table with detailed vegetation characteristics and the corresponding offset value. Also the foot print diameter (and other system characteristics, see Section 2) can have an influence on the necessary offset value.

For improving the laser data (i.e., applying a height correction) this approach is not very practical, because this additional information on the vegetation type has to be collected, too. Land usage maps or remote sensing data do currently not allow to retrieve this kind of information.

3.4 Texture for correction

The questions arises, if there are other strategies to correct the laser data – without external knowledge on vegetation type, but on the basis of the data itself – and obtain improved ground heights in this way.

Our approach is based on texture, a measure defined for digital images. After finding a corresponding definition in the point cloud domain, the texture can be measured in the sample areas and correlated with the offset between a measured laser point and its ground height in the TIN.

The hypothesis is that when different vegetation classes have similar texture, they also have similar influence on laser measurements, and therefore require similar shifts. For example, rough vegetation (shrubs, bushes) has “more” texture than short grass, and most probably requires larger shifts as well.

In the following, we will briefly introduce image texture and extend it into the vector (point cloud) domain. After that, we will elaborate on two strategies to estimate shift from texture.

Texture features Texture features are known from image processing and are considered helpful when attempting to distinguish between (for example) materials that have similar gray value distributions, but show them in different spatial patterns (textures). The aim of textural feature extraction is to numerically characterize different textures.

Image texture Texture is defined in terms of patterns, i.e. regular repetitions of spatial phenomena. The value of a textural feature at a certain position in an image cannot be derived from a single pixel value. It is necessary to consider a neighborhood in the image around the desired position, large enough to contain one complete instance of the pattern.

A very widely used class of textural feature extraction algorithms is based on co-occurrence matrices. To compute texture at any point in the image, gray level co-occurrences in pairs of pixels at fixed displacements (i.e. a distance in a certain direction) from each other within the neighborhood at hand are recorded in a co-occurrence matrix. From this matrix, different statistical features can be easily computed, such as entropy, contrast, angular second moment and inverse difference moment (Haralick 1979)

Point cloud texture A possibility to characterize texture in a laser altimetry point cloud would be to interpolate the points into a regular grid, treat this as an image, and perform the above-mentioned procedure. But since we prefer to stay in the vector domain, we present an alternative algorithm.

The new point cloud texture algorithm computes texture either for a laser point, or for an arbitrary position anywhere in between the laser points (such as at a control point). In both cases, first the k nearest neighbors (laser points) around the wanted position are found. If the position is a laser point, it will be one of those k points. Now, for each pair of points, which means $k*(k-1)/2$ times, the two z values are retrieved, establishing a height co-occurrence, which is then recorded in the appropriate matrix within a set of co-occurrence matrices. The matrix is selected on the basis of the displacement between the two points. In the current version, displacement is defined by distance only. It would be easy to take different directions into account as well, but we decided that orientation is not an important characteristic of natural vegetation. The number of distance intervals (the number of co-occurrence matrices) and the size of the intervals are parameters in the process. Other parameters are k, the number of neighbors, and the number of height intervals, which determines the size of the co-occurrence matrices. After filling the matrices, from each one the different textural features can be computed in the usual manner (Fig. 2).

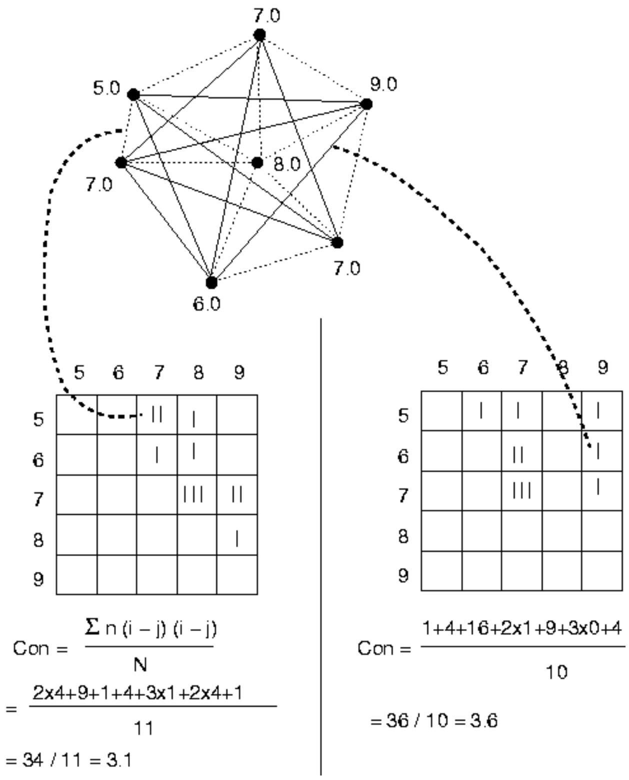

Figure 2: Point cloud texture computation using 7 neighbors, 2 distance intervals and 5 height intervals

Laser point based approach We apply the above algorithm to investigate how shift correlates with texture. We limited the experiments to only one textural feature, the contrast feature, based on 40 neighbors, using one distance interval between 0.65m and 1.3m, with height intervals of 0.1m.

Analogous to before, the shift for a laser point is determined by projecting it vertically onto a TIN defined by the control points and calculate the height difference between original and projected point. Laser points that are not inside any triangle still participate in texture computations, but no shift can be computed for these points.

Having a shift and a texture for each point, we can see the relationship between these quantities either per individual point or aggregated over an entire field. This is shown in the two graphs of Fig. 3 and 4. It can be seen from the regressions that the relationship is rather similar in the two cases. However, it also appears that the relationship is very weak. The correlation coefficient $R^2 = 0.09$ in the first case, and $R^2 = 0.36$ in the second.

Control point based approach An alternative way to evaluate the accuracy of laser points with respect to control points is to start form the latter ones. The purpose of laser measurements can be formulated as the attempt to obtain z values equal to terrestrial measurements by surveyors, and the purpose of data processing as correction of the remaining differences. Therefore, we will first estimate the heights at the control point locations from the laser data, and then investigate how the difference between these estimates and the actual control points heights relate to laser point texture. It should be noted that the selection of (x,y) locations of control points was still based on the surveyor's judgment, also when z values are derived from laser measurements.

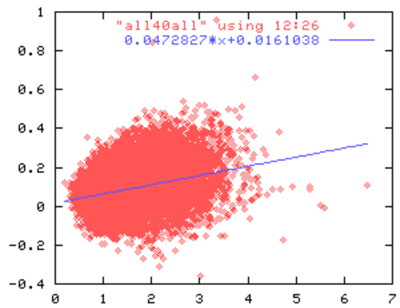

Figure 3: Relationship (regression) between contrast (x-axis) and shift (y-axis) for all laser points .

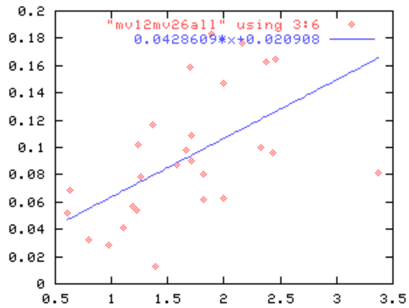

Figure 4: Relationship (regression) between contrast (x-axis) and shift (y-axis) for laser points averaged per field.

As an estimate of the height in a control point from the laser data we used the average height of k nearest laser points. As it appears from comparison with terrestrial leveling measurements, the influence of vegetation causes the estimates to be shifted "up" (and even in non-vegetated reference fields a positive shift occurs).

Similarly to the laser point based approach above, shifts can be estimated from texture (contrast) either in each control point (Fig 5), or averaged in each field (Fig. 6). Both shifts and contrasts are based on 50 nearest neighbor environments. The correlation is stronger than above ($R^2 = 0.35$ for the correlation in points, and $R^2 = 0.47$ for the correlation in fields).

4 CONCLUSION

In the first part of the paper the influences of the laser scanning system and the mission parameters on the obtained heights over vegetation have been investigated. Not for all components (pulse shape, flying height, ...) their influence on measurements over vegetation is currently known in the airborne laser scanning community. Further investigations are necessary to increase the understanding. With the upcoming full waveform capturing laser scanners new possibilities to investigate the return signal and therefore the ground characteristics will be given.

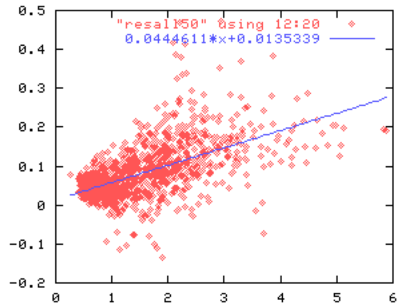

Figure 5: Relationship (regression) between contrast (x-axis) and shift (y-axis) for all ground points .

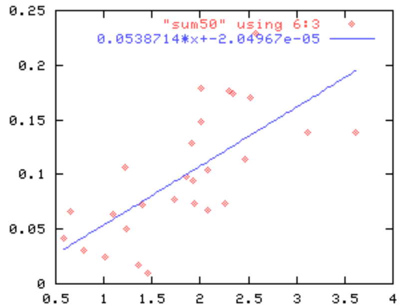

Figure 6: Relationship (regression) between contrast (x-axis) and shift (y-axis) for ground points averaged per field.

In this paper the quality of laser scanning has been assessed. The results are in line with observations made by other research groups, mentioned in the introduction, that laser scanning measures a height above the ground level for vegetated surfaces. Upwards shifts of the terrain elevation from laser scanning reached from 5cm, the lowest observed shift for long dense grass, to 17cm, the highest shift for old willow forest. Within this study is was not possible to identify a strong relation between ground surface coverage type (i.e., vegetation) and the systematic difference between true ground height and observed laser surface.

An alternative to the correction of the laser measurements with vegetation type knowledge, is an approach based on the texture of the laser scanner point cloud alone. We derived four instances of shift as function of texture (contrast), which gave four quite similar, positive regressions. This is qualitatively conforming to expectations, since rougher vegetation will simultaneously cause more "contrast" as well as larger shifts. In the control point based approach we found better correlation (larger R^2) than in the laser point based approach. This suggests that shifts can be estimated better in the former case, probably because the "true" heights at the control points are more accurate than at the laser points (where they are interpolated using a TIN). We come to the preliminary conclusion that texture can be used to correct shifts caused by vegetation. However, we are not yet able to fully quantify the effect. Partly this is caused by the data at hand. They were recorded in quite difficult areas, with very rough terrain and diverse, natural vegetation.

For Rijkswaterstaat the potential of the texture-based approach is reason to extend this research project with other data sets. The new data sets will have to show a more homogeneous type of vegetation.

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