

ESTIMATION OF THE LIDAR HEIGHT OFFSET IN COASTAL VEGETATED AREAS

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ABSTRACT:

Authorities operating in the field of coastal management require reliable area-wide height information for their responsibilities regarding to the safety of the coastal area. In this context the lidar technique replaces more and more traditional methods, such as terrestrial surveying, and is now the most important source for the generation of digital terrain models (DTM) in this zone. However, coastal vegetation interferes with the laser beam, resulting in a height offset for the lidar points depending on different vegetation types occurring in this region and their phenology. Various filter algorithms were developed for lidar data in vegetated areas, which are able to minimize this offset. But in very dense vegetation and hilly terrain these algorithms often fail resulting in certain residuals. In a previous approach the height offset was estimated based on grid data. In this algorithm the offset was linked to suitable features in the remote sensing data. A segment based supervised classification was performed using these features to partition the lidar data into different accuracy intervals. A major problem of this method arises from the fact that the accuracy intervals do not correspond to distinct and easily separable clusters in the feature space. Considering a single vegetation type the height offset exhibits a rather continuous characteristic. In a new approach this issue is tackled by modelling the offset with respect to the features using continuous functions. Additionally, feature extraction and classification are performed on raw data, in order to maintain the significance of the features by avoiding transformation artefacts and to increase the accuracy of the classification. On the basis of test data a comparison between the two methods is conducted to emphasize the problems and their solutions.

1. INTRODUCTION

Digital terrain models (DTM) of high accuracy are vital geographic information sources for various applications in coastal areas. For example, reliable height information is necessary for the calculation of flood risk scenarios, change detection of morphological objects and hydrographic numeric modelling. In former times traditional methods, such as terrestrial surveying, were used to acquire the data. However, in coastal areas with dense vegetation and frequently flooded terrain such measurement campaigns are very costly and time consuming as well as difficult to perform. Therefore, lidar technique is more and more used to collect the required amount of 3D points for the generation of the models. The advantage of this contactless remote sensing method leads on the other hand to an information loss about the measured objects (e.g., type and material). A serious problem for the generation of accurate DTM from lidar data is the influence of vegetation. The laser beam is not always able to fully penetrate the different layers of dense vegetation. Some echoes are produced by a mixed signal from vegetation as well as the ground and others are generated entirely in the canopy. This results in a positive height offset, because the laser beam is reflected before hitting the bare ground. In order to derive a DTM of high accuracy, these elevated points have to be eliminated from the dataset. Many filter algorithms were developed to remove such points. However, if there are only a few ground points, for example caused by dense vegetation, or points within low vegetation not significantly higher than the surrounding terrain present in the analysed area, the filter methods usually fail. Figure 1 visualizes a region in the dunes on the East Frisian Island "Langeoog" with standings of Japanese Rose, Beech Gras, Creeping Willow and Sea Buckthorn. The digital surface model (DSM) derived from unfiltered lidar data is illustrated on the left side (a) and the second picture (b) shows the DTM. Obviously, after the filtering process some height variations caused by vegetation still remain in the dataset. These considerations motivate efforts to determine the height offset of the lidar points depending on the vegetation type on the basis of different features.

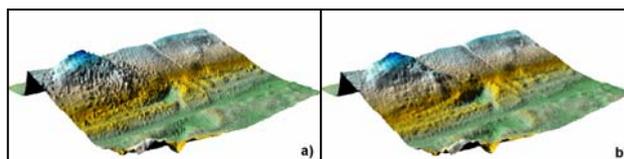


Figure 1. a) lidar DSM, b) lidar DTM

In preliminary studies the dependencies between the height offset of the lidar points and vegetation attributes (type, density and height) were investigated. In a next step the influencing factors had to be connected to features extractable from the available remote sensing data. These features were used for a supervised classification of the lidar data into different accuracy intervals.

In this paper, a new approach for the estimation of the height offset in the lidar data depending on the vegetation type is presented. While the previous classification algorithm was based on lidar data interpolated to a grid, now features are extracted directly from the 3D lidar raw data, in order to increase their significance with regard to the height offset. Another major problem of the former method arises from the aspect that the accuracy intervals, which represent the desired classes, do not correspond to distinguishable clusters in the feature space. The features describing the height offset show a rather continuous appearance. Thus, in this paper a relation between features and the height offset is established by continuous functions using reference data. Subsequently, the offset of each laser point can be determined on the basis of its related features and the connecting functions.

2. STATUS OF RESEARCH

In order to investigate the influence of different vegetation types on the accuracy of lidar measurements, understanding of the physical principles is essential that govern the interaction between the laser beam and different illuminated targets. Based on the radar equation Jelalian (1992) described the fundamental relations between the emitter, the reflecting object and the receiver applied to the lidar technique. Sensor and target

dependent parameters are separated and an object dependent cross section is defined. Additionally, Wagner et al. (2006) pointed out the dependencies between the spatial variations of the cross section and the amplitude as well as the width of the reflected echoes. Pfeifer et al. (2004) considered the influence of different parameters such as flying altitude, footprint size, echo detection and selection method as well as pulse width on the laser measurement in vegetated areas.

In addition, ground truth measurements can be used in comparison to the lidar data to estimate the height offset caused by the vegetation. In this manner Oude Elberink and Crombaghs (2004) found a systematic upwards shift of up to 15cm for low vegetated areas (creeping red fescue). Pfeifer et al. (2004) investigated the influence of long dense grass (+7.3cm), young forest (+9.4cm) and old willow forest (+11.6cm) on the accuracy of lidar data. In (Göpfert and Heipke, 2006) a positive offset for different coastal vegetation, such as Beach Grass (+19,3cm) and Sea Buckthorn (+18,4cm), was observed, too.

In the approaches described above the investigation of vegetation parameters influencing the lidar accuracy was limited to certain vegetation types. However, in the research of Hopkinson et al. (2004) the following relationship between the standard deviation of pre-processed laser heights (the ground elevation was subtracted from the first and last pulse measurement) and height of low vegetation in general (<1,3m) was given:

$$\text{vegetation height} = 2.7 * \text{standard deviation.}$$

The RMSE of the predicted vegetation heights was determined to be 15cm. Pfeifer et al. (2004) and Gorte et al. (2005) described the variation of the laser heights with texture parameters and showed their potential for correction of the height shift caused by low vegetation. Göpfert and Heipke (2006) linked vegetation attributes to features, such as echo intensity, in order to classify the lidar data into different accuracy intervals.

Many filter algorithms were developed to separate terrain and off-terrain points using geometric criteria exclusively, such as slope or height differences in a defined neighbourhood. Some methods are based on single lidar points, for example Axelsson (2000). Other approaches (e.g., Sithole and Vosselman, 2005), group the points to segments, which are classified afterwards. In contrast radiometric features of the lidar points are not very often included in standard filtering processes, if we distinguish between filtering and classification of objects. For example, in (Moffiet et al., 2005) the capabilities of the different returns (ground and vegetation, first, last, and single pulse) as well as the returned intensity were investigated to classify diverse tree types. Tóvári and Vögtle (2004) used the intensity values among other features, in order to discriminate buildings, vegetation, and terrain. In different studies a combination of height and multispectral data was proposed in order to detect and classify vegetation types. For instance, Mundt et al. (2006) explored the potential of this combination for mapping sagebrush distribution.

3. DATA

The research and tests are based on data of two flight missions. A detailed description of the reference and lidar data can be found in (Göpfert and Heipke, 2006). The first flight covering the East Frisian island Juist was conducted by the company TopScan with an ALTM 2050 scanner from Optech in March 2004. At a flying altitude of 1000m the system provided an average point density of 2 points/m². Unfiltered last pulse data

with intensity values, CIR-Orthophotos, ground and vegetation points were delivered. Simultaneously, 696 reference points with ground and vegetation heights, situated within a mixed habitat of rose and willow, were surveyed using tachymetry and GPS.

The data for the second measurement campaign were collected by the company Milan-Flug GmbH on the East Frisian island Langeoog in April 2005. The used LMS Q560 system of the company Riegl operating at an altitude of 600m realised an average point density of 2.9 points/m² and illuminated a footprint of 0,3m diameter. Raw data with up to three echoes per emitted pulse as well as the related intensity values, RGB-Orthophotos, ground and vegetation points were acquired. Supported by biologists several control areas of different vegetation types were surveyed. The results of this paper focus on coastal shrubberies including five test sites with Japanese rose and creeping willow.

Finally, a biotope mapping performed on aerial photos taken in 2002 and 2003 with a HRSC-AX and a DMC camera was used for the distinction of different predominant vegetation types.

4. METHODS

On the basis of previous research (Göpfert and Heipke, 2006) this paper introduces a new method to determine the height shift of lidar points in areas with typical coastal vegetation, where due to dense plant population no or only a few ground points exist and therefore standard filter algorithms usually fail.

Initially, section 4.1 explains briefly the characteristics of vegetation with respect to the lidar measurement and the connection between vegetation attributes and features generated from the remote sensing data. In section 4.2 the feature extraction method based on irregularly spaced lidar points is introduced. The next section gives a short overview about our previous classification algorithm emphasising its restrictions. Finally, in section 4.4 a new method for the estimation of the height offset in the lidar data caused by the vegetation is described.

4.1 Vegetation attributes and features

The interaction of the laser beam with complex objects, such as vegetation of different height and density, is difficult to model. In the corresponding literature this aspect is mathematically described as a convolution of the emitted signal with the cross section of the extended object. Every layer of the vegetation contributes to the signal received by the sensor. Low vegetation within the range resolution of the scanner system often generates a mixed echo with reflection from the ground. Therefore, the centre of gravity of this echo is situated above the terrain and an upwards shift is observed in the lidar data. In higher vegetation several distinctive echoes per laser pulse can occur. For the derivation of the DTM usually the last echo is used. However, also the last echo can be caused by a mixed reflection or within very dense plant population entirely created by vegetation layers. Thus, at locations of higher vegetation the last pulse data may also be biased upwards.

In order to assess the influence of vegetation attributes on the quality of the lidar height information, ground truth measurements were used in previous studies. For the purpose of comparison a DTM of the lidar data was generated and the heights were interpolated using the x- and y-coordinates of the terrestrial control points. In addition to the effect of the vegetation type on the lidar accuracy, the correlation between the height differences at the reference points and vegetation height and density were investigated. The vegetation density

was quantified by the analysis of the coverage rate of the plants in fish eye photos taken from the ground to the zenith.

In the next step the evaluated dependencies between the height shift and the vegetation attributes had to be related to the observables of the available remote sensing data. The significance of attributes as well as features depends strongly on the vegetation type. Therefore, without any context information a classification of vegetation types has to be performed in addition. In order to keep all features in the current remote sensing data exclusively for the distinction of accuracy levels with regard to the vegetation height and density, the separation of the vegetation types was realised using a biotope mapping.

The intensity value given with the data might be derived from the measurements in different manners by the providers. However, in any case it is a function of the signal amplitude, which is responsible for the main part of the spatial variation of the cross section (see Wagner et al., 2006). Reflectivity, directivity, and the effective area of the reflecting surface of an object are combined in the concept of the so-called cross section σ . Therefore, the amplitude of the echoes as well as the intensity values of the lidar points are related to the characteristics of the object, such as plant structure, and consequently to the vegetation density. In the basic case of normal incidence with uniform intensity, flat bare ground yields to a homogeneous cross section (coinciding with the circular beam footprint) as well as a narrow pulse width and high amplitude, while a mixed target consisting of terrain and low vegetation expands the pulse width and attenuates the amplitude. Considering coastal shrubberies in the leaf-off period, the higher the echo in the vegetation the thinner are the branches, which contribute to the cross section. Therefore, the amplitude as well as the intensity values decreases theoretically for elevated lidar points.

Due to in general higher reflectivity, bare ground in the investigation area appears brighter than shrubberies during the leaf-off time in the channels of multispectral data. Hence, the darker the pixel, the larger the proportion of vegetation and therefore the plant density is. Additionally, for evergreen plant population or measurement campaigns during the leaf-on period vegetation indices (e.g., the Normalized Difference Vegetation Index (NDVI)) are means to quantify the vegetation density, because a strong correlation between the leaf area index (LAI), describing the vegetation structure, and the NDVI exists (Pandya, 2004).

Higher vegetation areas cause larger variations in the height of the lidar points. Thus, the standard deviations as well as the contrast in the height data are correlated with vegetation height. Multiple echoes per laser beam can be separated by the system if the vegetation height is larger than the range resolution of the scanner. For pulsed scanner the range resolution corresponds to the half pulse length (e.g., LMS Q560 - $4ns \approx 0,6m$). Another premise for several echoes is a certain minimum vegetation density in the related height, which can generate a reflection strong enough to be detected by the photo diodes and the implemented signal processing software. In general, the occurrence of multiple echoes indicates larger vegetation height and density.

4.2 Feature extraction using raw data

The previous approach relied on transformation of the arbitrary distributed raw data to a regular spaced grid (3d to 2.5d mapping) in order to use conventional image segmentation and classification techniques. Disadvantages of the procedure are interpolation and smoothing artefacts reducing the significance

of the features related to the height offset in the lidar data. Additionally, the neighbourhood defined by the segments is not appropriate to the feature extraction especially for pixel near the borderline. Therefore, in this paper the features are determined using methods applied directly on 3D raw lidar data. A comparison is performed to evaluate the changes of the correlation between the different features, derived from grid and raw data, and the height shift caused by vegetation.

The raw data of the investigation area provided by the Milan Flug GmbH contains up to three echoes per laser pulse. The points were stored with x,y,z-coordinates together with intensity values in chronological order of their time stamps corresponding to the scan pattern. The different echoes are not assigned to a certain laser pulse, thus a separation into first, last and other pulses is performed based on geometric criteria. Afterwards, a file for the feature extraction is prepared, which only consists of last pulse data with the following attributes: coordinates, intensity values, number of associated returns and vertical differences between the last and related echoes. For the data of the first flight mission including only last echoes (Juist 2004) the separation step is omitted and the attributes related to multiple returns are not considered.

For feature extraction the n-nearest neighbours of each laser point are considered. The feature values for the intensity can be assigned directly from the examined point or the mean value in the neighbourhood is used alternatively, if a smoothing of noise effects is desired. Two additional features are calculated using the distribution of multiple echoes in the vicinity of the considered point: the ratio of laser pulses with several returns to all pulses and the average height difference between first and last echo in the defined neighbourhood. In order to analyse the variation of the height in the neighbourhood of the current laser point, the standard deviation and the contrast derived from a co-occurrence matrix are calculated. The influence of the terrain slope on the height variations is reduced by an adjusted plane fitted in the lidar points of the neighbourhood. The standard deviations of the point heights with respect to the plane are stored acting as features. The height values related to the plane are also used to determine the co-occurrence matrix. In Haralick (1979) the textural features were established based on grid data and Pfeifer et al. (2004) suggested their application to irregularly distributed points. The range of the height differences in the neighbourhood of the investigated point is divided into regularly spaced intervals. The number of these bins corresponds to the size of the square co-occurrence matrices. For each pair of points in the area of interest the horizontal distance is determined defining those pairs, which relate to a certain co-occurrence matrix. Afterwards, the height differences of the point pairs are calculated and assigned to the defined intervals. Like in (Pfeifer et al., 2004) all directions are considered, because in areas with natural vegetation, such as shrubberies, the direction dependency of the height variation should be marginal. The contrast is determined from the matrices using the following equation:

$$\text{Contrast} = \frac{\sum (i * (h_{diff})^2)}{N} \quad (1)$$

- i Number of counts in the matrix cell related to the height interval
- h_{diff} Related height interval
- N Number of all point pairs contributing to the values of a certain matrix depending on their horizontal distance

The features can be determined for lidar as well as for control points using the adjacent lidar points. For the purpose of comparison the features from the segments of the previous approach are assigned to the single points using their horizontal coordinates.

4.3 Previous classification approach

In the previous approach a supervised classification is performed based on different data sources (multispectral image, lidar data, biotope mapping), in order to divide the lidar data into different levels of accuracy depending on the predominant vegetation. For the classification a segment based algorithm was chosen in order to consider the local neighbourhood of the laser pulse and to calculate mean values and standard deviation as well as other texture parameters. Initially, the height and intensity values of the unfiltered lidar data are transformed to regular grids for a combined image classification with multispectral data. Unfiltered data are used, in order to preserve texture information stemming from the vegetation. The segmentation for the tests in this paper is performed using a watershed transformation applied to the low pass filtered lidar intensity image. Starting from the local grey value minima as seed points (corresponds to areas of low lidar accuracy), a flooding of the surface depending on the grey values is simulated. This procedure continues as long as water of different sources is only separated by the watershed lines. Afterwards, these lines are assigned to an adjacent segment using the minimum grey value difference between the segment and the line pixel. The significance of the features for the different accuracy intervals depends mainly on the vegetation type. Thus, the extension of the segments and, consequently, the area of the following classification are limited to one predominant vegetation type using the borderlines of the biotope mapping. Training areas are generated by slicing the height offset of the control points. For that purpose a difference model is calculated and transformed into an image, so that the grey values correspond to the height discrepancies. This image is segmented into different accuracy levels. These segments are used as training areas for supervised classification.

In the last step the feature vectors derived for the training areas and the segmentation are used to classify the lidar height data into different accuracy levels. In this paper a Minimum Distance Classifier (Euclidian distance) is applied to assign the current segment. For this method the features are normalised to the same overall value considering the distribution of the feature values, in order to weight the features equally.

4.4 New prediction algorithm

Studies indicated that the regular spaced accuracy intervals related to the classes do not correspond to separable clusters in the feature space. Considering one vegetation type the height offset and the related features show a rather continuous characteristic. Theoretically, lidar echoes can stem from reflection at any level of vegetation and hence every value in the range of the height offset for the current vegetation type is possible. Therefore, a standard classification is not the most suitable method to estimate the shift in the lidar data caused by vegetation. Hence, in the new approach the connection between the features and the height offset is realised by continuous functions. Initially, the parameters of the functions have to be determined using the reference data. For the unfiltered lidar data a DSM is calculated and the heights at the control points are interpolated. The height offset is determined based on comparison of the lidar and the reference height for every point.

Afterwards, the features for the control points are calculated depending on the adjacent lidar points (section 4.2). In order to eliminate outliers and attenuate the noise of the features a median filtering is performed. Subsequently, the parameters of the functions, which connect every chosen feature to the height offset, are estimated by least square adjustment. Polynomial functions of different order and exponential functions are implemented. For instance, if the lidar intensity values increase, the height offsets decrease implying the use of monotonic functions. Additionally, for high intensity values the height offset converges to zero. Therefore, in this case exponential functions are suitable to represent such dependency, while polynomials of higher order tend to oscillate between the interpolation points. For every single lidar point the height shift can be calculated based on its features and the estimated functions. Every feature and the related function generate an estimate of the shift. The final height shift of the current lidar point is computed by a weighted average of these single shifts. The weights are derived from the standard deviation of the points with respect to the fitted function for each feature (Equation 2) or from the correlation of the feature and the height shift (Equation 3).

$$\Delta H_f = \frac{\frac{\Delta H_1}{\sigma_1} + \frac{\Delta H_2}{\sigma_2} + \dots + \frac{\Delta H_n}{\sigma_n}}{\sigma_1^{-1} + \sigma_2^{-1} + \dots + \sigma_n^{-1}} \tag{2}$$

$$\Delta H_f = \frac{c_1 * \Delta H_1 + c_2 * \Delta H_2 + \dots + c_n * \Delta H_n}{c_1 + c_2 + \dots + c_n} \tag{3}$$

- ΔH_f Final height shift derived from all features
- $\Delta H_1 \dots \Delta H_n$ Height shift derived from single features
- $\sigma_1 \dots \sigma_n$ Standard deviation of the points regarding to the fitted function for single features
- $c_1 \dots c_n$ Correlation of the features and the height shift

The features correspond to the height offsets only for the vegetation type in the reference area, which is used to calculate the function's parameters. Therefore, the estimation of the height shift is conducted for the lidar points situated within the same kind of vegetation, which is realised using a biotope map.

5. RESULTS

5.1 Vegetation attributes and features

For all studied vegetation types in the coastal zone we observed a general upwards shift of the lidar DTM ranging from 10cm to 23cm for several control areas. The largest height shift was detected for beach grass (+19cm), sand couch grass (+20cm) and the mixed area sea buckthorn/willow (+23cm). Without considering the biotope type vegetation height and density did not show strong dependencies with respect to the height offset.

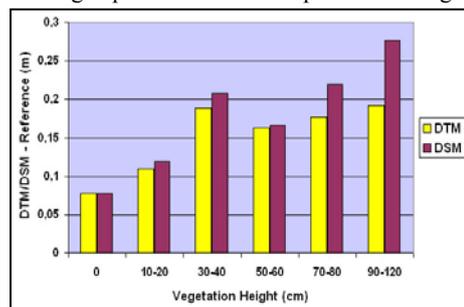


Figure 2. Average height shift plotted over vegetation heights for creeping willow (Langeoog, Riegl scanner)

However, a high correlation for height as well as density was determined observing exclusively one kind of vegetation. Hence, the knowledge of the vegetation type is crucial for the applicability of the other attributes. An example for the dependencies of the height shift and vegetation heights within an area of creeping willow is given in Figure 2.

The vegetation attributes are connected to features extracted from the remote sensing data (lidar and multispectral data), which are used to estimate the height shift of the lidar data in vegetated areas. For example, Figure 3 visualises the relations between the intensity of the lidar echoes and the height shift for an area covered with Japanese rose and creeping willow mapped by the ALTM 2050 scanner. A strong dependency and a continuous characteristic of the feature and the related offset are obvious. Maximal two clusters could be separated in the diagram. Intensity values lower than 60 indicate elevated targets, while for higher values mixed or ground echoes are expected.

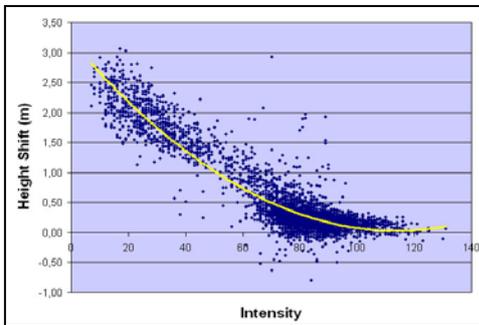


Figure 3. Dependencies between the height shift and the lidar intensity values (Juist 2004 TopScan)

5.2 Feature extraction using raw data

In order to increase the significance of the features the extraction is conducted using raw lidar data. Figure 4 depicts on the left side a part of a RGB-Image of the island Langeoog and on the right side the related density of multiple echoes extracted from the point cloud.

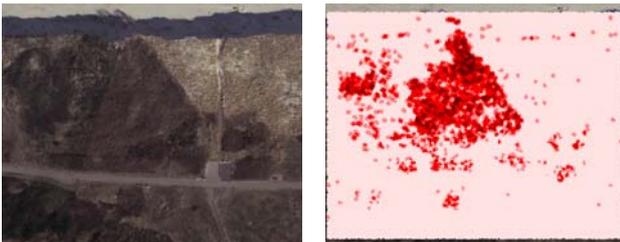


Figure 4. Left: RGB-photo of an area of the island Langeoog; Right: Density of multiple echoes (higher density is visualised with darker colour)

Reference area (flight mission)	Correlation between Height Contrast and Height Shift	
	Segments	Raw Data
Rose +Willow (2004)	0.45	0.51
Rose + Sea Buckthorn (2005)	0.36	0.55
Rose1 (2005)	0.38	0.48
Willow1 (2005)	0.46	0.72
Willow2 (2005)	0.65	0.69

Table 1. Correlation between the height shift and the height contrast extracted from the segments and raw data

In Table 1 the correlation of the offset to the height contrast extracted from raw and grid data (values for segments) is

compared. Obviously, the dependency of this feature to the height offset increases for all investigated reference areas using the raw data.

5.3 Previous classification approach

The previous and the new method are applied to a data set from the ALTM 2050 scanner covering the East Frisian island Juist in 2004. Figure 5 shows the terrestrial measured control points of the reference area, which is situated within a mixed habitat of rose and willow in the dunes. From the southern part of the points (green) the training areas are generated, which are used to learn the features for the classification. According to intensity values and height contrast the segments, created by the watershed transformation, are classified to five accuracy intervals using the minimum Euclidian distance.

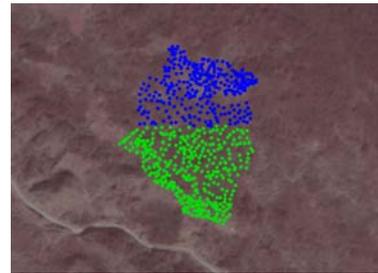


Figure 5. Control points of the test area on the island Juist (background: CIR-Orthophoto)

With the northern part of the reference points (blue) the classification result is checked. Table 2 visualises the related accuracy. The correctness for the different classes varies in the range of 54 – 75%. However, the proportion of the adjacent classes is quite high. These errors are caused by the arbitrarily chosen borders of the accuracy intervals. As shown before, the features and the related height offset have a rather continuous characteristic, which is not suitable to be modelled in clusters. Another reason for the errors is that the borderlines of the control areas and of the segments, which are classified in the aggregate, do not match.

Proportion of class with respect to the training area	Class 1 <20cm	Class 2 <50cm	Class 3 <100cm	Class 4 <150cm	Class 5 >150cm
Train Area 1	65,3	27,0	1,4	-	-
Train Area 2	32,7	56,9	18,7	2,01	0,3
Train Area 3	2,0	11,7	54,3	22,1	0,2
Train Area 4	-	4,0	22,0	54,0	24,5
Train Area 5	-	0,3	3,5	20,6	75,0

Table 2. Classification result

5.4 New prediction algorithm

In the new approach the control points are used to connect the height offset to the extracted features with continuous functions. In this test a second order polynomial is chosen both for the intensity and the height contrast. These features are weighted by their standard deviation with respect to the fitted functions. For the parameter estimation again the southern part of the control points is used as training area and the height offset of the northern points is calculated based on the features from the adjacent lidar data. The diagram in Figure 6 visualises a high correlation between the estimated height shift and the offset determined by the comparison of lidar and reference heights. This method shows potential for the estimation of the height offset in different coastal vegetation, because the continuous

characteristic of the accuracy in these vegetated areas is taken into account. But the algorithm depends strongly on the significance of the features.

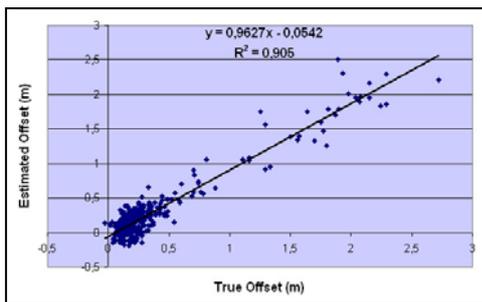


Figure 6. True height offset vs. estimated height offset

However, first tests using the lidar data acquired by the LMS Q560 system indicate that the correlation of the features and the height shift is not strong enough for some vegetation types, in order to fit robust functions. Therefore, the applicability of the features for the method has to be checked before.

6. CONCLUSION AND OUTLOOK

Starting from theoretical considerations about the interaction of the laser beam with different layers of vegetation, this paper compares two methods for the estimation of the height shift in the lidar data caused by coastal vegetation. Features, such as lidar intensity and height contrast, are connected to vegetation attributes, which influence the accuracy of lidar measurement. In a previous approach these features are used to classify the lidar data into different accuracy intervals. However, the characteristic of the accuracy of lidar data belonging to one vegetation type does not correspond to distinct and easily separable clusters in the feature space. Therefore, a new method is developed, which connects the feature to the height shift with continuous functions. The shift of a single lidar point can be easily calculated using its features and the parameters of the functions. However, this approach depends strongly on the significance of the extracted features, which is basically influenced by the scanner type and the echo detection algorithm. For future work upcoming scanning devices, which are able to record the full waveform, can provide new meaningful features. For instance, the pulse width can be a quality criterion by itself. It describes the uncertainty of the target surface and the range measurement for the related echo. Another idea combines the extracted feature with geometric criteria of filtering methods, in order to eliminate vegetation points and to generate a DTM for the vegetated coastal zone.

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REFERENCES

Axelsson, P. (2000). DEM Generation from Laser Scanner Data using adaptive TIN-Models. *The Int. Arch. of Photogrammetry and Remote Sensing*, Amsterdam, Netherlands, Vol. XXXIII, Part B4/1, pp. 110-117.

Göpfert, J., Heipke, C. (2006). Assessment of Lidar DTM Accuracy in Coastal Vegetated Areas: *The Int. Arch. of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVI, Part 3, pp. 79-85.

Gorte, B., Pfeifer, N., Oude Elberink, S. (2005). Height texture of low vegetation in airborne laser scanner data and its potential for DTM correction. *The Int. Arch. of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVI, Part 3/W19, pp. 150-155.

Haralick, R. M. (1979). Statistical and structural approaches to texture. *Proceedings of the IEEE*, 67(5), 786-804.

Hopkinson, C., Lim, K., Chasmer, L.E., Treitz, P., Creed, I.F., Gynan, C. (2004). Wetland grass to plantation forest – estimating vegetation height from the standard deviation of lidar frequency distributions. *The Int. Arch. of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVI, Part 8/W2, pp. 288-294.

Jelalian, A.V. (1992). *Laser Radar Systems*. Artech House, Boston and London.

Moffiet, T., Mengerson, K., Witte, C., King, R., Denham, R. (2005). Airborne laser scanning: Exploratory data analysis indicates variables for classification of individual trees or forest stands according to species. *ISPRS Journal of Photogrammetry & Remote Sensing* 59 (2005), pp. 289-309.

Mundt, J. T., Streutker D. R., Glenn N.F. (2006). Mapping Sagebrush Distribution Using Fusion of Hyperspectral and Lidar Classifications. In *Photogrammetric Engineering & Remote Sensing*, Vol. 72, No.1, January 2006, pp. 47-54.

Oude Elberink, S. and M. Crombaghs (2004). *Laseraltimetrie voor de hoogtemetingen van de kwelders Waddenzee*. Technical Report AGI-GAP-2003-50 (in Dutch), AGI, RWS.

Pandya, M.R. (2004). Leaf Area Index Retrieval Using Irs Liss-iii Sensor Data and validation of Modis Lai Product Over India. *The Int. Arch. of Photogrammetry and Remote Sensing*, Vol. XXXV, Part B7, pp. 144-149.

Pfeifer, N., Gorte, B., Oude Elberink, S. (2004). Influences of Vegetation on Laser Altimetry – Analysis and Correction Approaches. *The Int. Arch. of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVII, Part 8/W2, pp. 283-287.

Sithole, G., Vosselman, G. (2005). Filtering of Airborne Laser Scanner Data based on Segmented Point Clouds. *The Int. Arch. of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol. XXXVI, Part 3/W19, pp. 66-71.

Tóvári, D., Vögtle, T. (2004). Object Classification in Laser-Scanning Data. *The Int. Arch. of Photogrammetry and Remote Sensing*, Vol. XXXVI, Part 8/W2, pp. 45-49.

Wagner, W., Ullrich, A., Ducic, V., Melzer, T., Studnicka, N. (2006). Gaussian decomposition and calibration of a novel small-footprint full-waveform digitising airborne laser scanner. *ISPRS Journal of Photogrammetry & Remote Sensing* 60 (2006), pp. 100-112.