THE POTENTIAL OF HEIGHT TEXTURE MEASURES FOR THE SEGMENTATION OF AIRBORNE LASERSCANNER DATA*

Hans-Gerd Maas
Faculty of Civil Engineering and Geosciences
Section of Photogrammetry and Remote Sensing
Delft University of Technology
Thijsseweg 11, 2629 JA Delft, The Netherlands
e-mail h.-g.maas@geo.tudelft.nl

ABSTRACT

Airborne laserscanning is being used for an increasing number of mapping and GIS data acquisition tasks. Besides the original purpose of digital terrain model generation, new applications arise in the automatic detection and modeling of objects such as buildings or vegetation for the generation of 3-D city models.

A crucial prerequisite for the automatic extraction of objects on the Earth's surface from laserscanner height data is the segmentation of datasets. Besides the height itself, height texture defined by local variations of the height is a significant feature of objects to be recognized. The paper shows the potential of the analysis of height texture for the automatic segmentation of dense laserscanner datasets and the detection of objects in the segmented data. Based on the definition and computation of a number of texture measures used as bands in a classification approach, objects like buildings, single trees, ground vegetation and roads can be recognized. The technique was applied to a FLI-MAP laserscanner dataset with an average point density of more than five points per squaremeter, acquired over a village in The Netherlands. In a maximum likelihood classification based on the absolute height and several texture measures derived from it, a classification accuracy of 98% could be achieved. Based on the result of the segmentation, all buildings of the scene and most single trees could be automatically detected.

1. INTRODUCTION

Airborne laserscanning data has proven to be a very suitable technique for the determination of digital surface models and digital terrain models. Beyond this, laserscanning is also being used for an increasing number of mapping and GIS data acquisition purposes, including the detection and modeling of man-made objects. Delivering dense 3-D point clouds without the requirement of sufficient surface texture and without the necessity of time-consuming and potentially erroneous image matching techniques,

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airborne laserscanning forms a perfect supplementation to conventional image-based photogrammetry and may even replace it in a number of applications.

The aim of the research work presented here is the acquisition of data for the generation of 3-D city models to be used in GIS or virtual reality applications. First focus is the generation of 3-D building models, but tasks may also include modeling of other objects such as urban vegetation. A first step in the processing of laserscanner data with the aim of modeling objects is a pre-processing procedure for the detection of objects and the segmentation of data. Furthermore, a segmentation procedure detecting vegetation and man-made objects may also be used in digital terrain model generation tasks, where natural or man-made objects above the terrain surface have to be removed.

A number of different techniques have been suggested and applied to segment airborne laserscanner data with the aim of modeling buildings. In the ideal case, laserscanner surface data can be segmented by simple thresholding, with a threshold determined by histogram analysis. In regions with steep terrain, high vegetation and vegetation close to buildings, however, this approach will not perform well. An obvious option for a safe segmentation is the use of available 2-D GIS data, as shown e.g. in (Haala/Brenner, 1997) and (Lemmens et al., 1997). This will, however, limit types and actuality of objects that can be modeled to those available in an existing GIS. (Hug/Wehr, 1997) apply local histogram analysis techniques and use the reflectance value delivered by their phase measurement based sensor as an additional source of information in the segmentation process, making use of the high reflectivity of healthy vegetation in the near infrared. This option is of limited value for most of today's laserscanning systems, which use time-of-flight modes and deliver rather poor reflectance image quality. A sequence of thresholding, binning, morphological filtering and connected component labelling operations has been applied for the segmention of buildings in (Maas/Vosselman, 1999), but did pose some problems in detecting vegetation close to buildings. In the near future, some systems will come with a multispectral scanner integrated on an airborne laser scanner platform, thus allowing the use of classification techniques applied to image data co-registered with 3-D point coordinates. Studies using multispectral data acquired independently from the laserscanner data to be segmented were presented by (Haala et al., 1998) and (Andriesse, 1999).

An inherent source of information for the segmentation of laserscanner point data is the analysis of height texture defined by local variations of height. Depending on the type of sensor used, objects to be segmented may show rather different behaviour in texture measures derived from these variations. Time-of-flight based laserscanning systems offer the option of measuring the rising or the decreasing edge of the returning laser pulse signal ('first- and last-pulse analysis'). Currently, there is one system, which is capable of measuring up to four returning echoes from one laser pulse, if the echoes have a separation of more than two meters. In the near future, there will be more systems allowing for simultaneous first- and last-pulse recording. As an alternative, two consecutive flights can be performed, one with first-pulse and one with last-pulse registration. A digital surface model given by unfiltered first-pulse laserscanner data will show large local height variations in regions with trees, while it will show much lower variations and a systematic behaviour on man-made objects such as roads or roofs of buildings. Similar characteristics apply to last-pulse data where many but

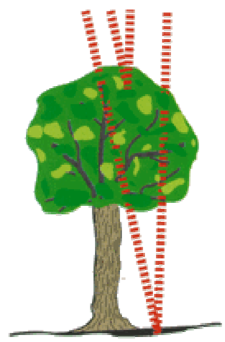


Figure 1: First- and last-pulse from a tree

not all laser pulses penetrate through vegetation and are reflected from the ground, thereby also delivering larger local variation over vegetation. In case of first- and last-pulse acquisition, the height difference between first- and last-pulse will be large over vegetation, while it will be close to zero over objects such as plain roofs.

The following considerations will be limited to the analysis of height texture in first-pulse data, but may also be applied to last-pulse or multi-pulse data with minor modifications. A number of texture measures will be defined and discussed. These texture measures are used as bands in a classification-like approach, performing a pixelwise segmentation of the dataset. In this first step, no further knowledge about the objects to be extracted is being used in order to show the potential of purely texture-based analysis.

2. TEXTURE MEASURES AND PROCESSING

The definition and analysis of texture measures has been used in many image processing and image understanding applications for a long time. While in 2-D imagery intensity patterns are being evaluated, the actual height of data points can be used instead when using $2^1/_2$-D laserscanner data. For reasons of compatibility with available software tools, these points can be interpolated into a grid structure, and the heights are favorably scaled to 8 or 16 bit data. Figure 2 shows a small part of an image generated by laserscanner data interpolated to a 0.5m grid.

In the following, a number of texture measures, which can be derived from laserscanner height data, are listed. In addition, some filters accentuating certain characteristics of the data are also included. All measures and filters are contained in standard remote sensing software packages. Texture measures and filter outputs are stored as new bands for further use in the segmentation procedure.

- Original height data: The original height data will allow for a segmentation between high objects such as buildings and trees on the one side and objects like streets or plain ground on the other. In data over hilly terrain, band- or highpass filtered height data might be used instead of the original height data.
- Data range: The difference between minimum and maximum height value in a window around a pixel will be zero on flat roofs or streets, small on tilted roofs and large within trees.
- Variance: The variance of height in a

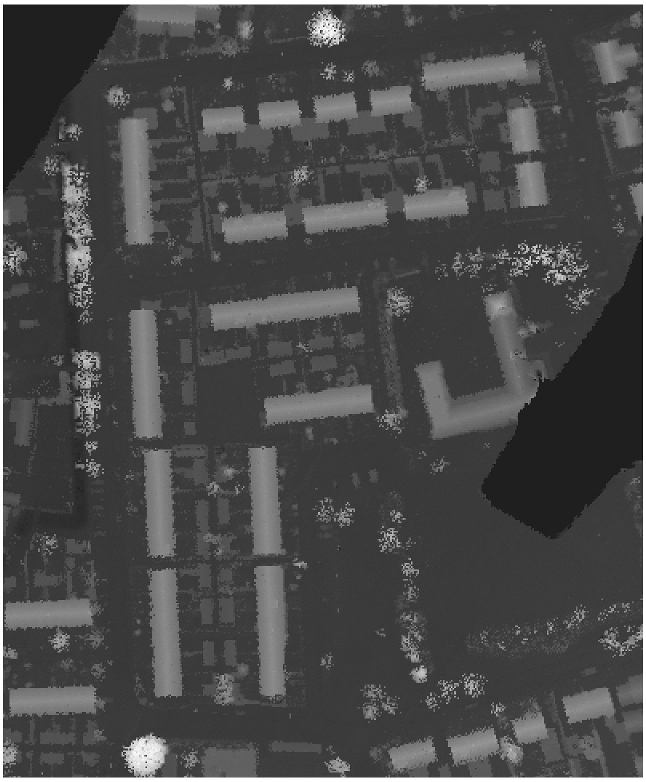


Figure 2: Part of laserscanner dataset (interpolated to 0.5m grid and grey-coded)

window around a pixel will show similar characteristics as the data range, with somewhat different behaviour concerning single outliers.

- Laplace filter: Will react only on edges or noise and thus deliver large values in vegetation, while tilted plane roof faces will, unlike with the analysis of variance, obtain zero values.
- Sobel operator: Edge filter with behaviour similar to Laplace-filtering.
- Slope: The maximum slope around each pixel is determined from the local slopes in X and Y. The use of this slope image will be valuable for distinguishing tilted roofs from flat roofs or street as well as from trees, where the slope will reach very large values.
- Fractal dimension: As a plane becomes more and more convoluted, it will progressively fill space. Thus the fractal dimension of patches can serve as a useful measure of texture. Operators determining fractal dimensions are contained in several software packages.
- Directional edge enhancement: Eight bands are generated by using compass gradient filters with 3 x 3 kernels under eight different rotations and two new bands are defined from the maximum and minimum of these bands for every pixel. The maximum absolute gradient will show a behaviour similar to that of the slope, while the minimum gradient will deliver values close to zero on tilted roof planes.

The results of applying these filters to the height image are temporarily stored as new bands. Note that some of these measures will show a large correlation with others and that a segmentation process can be based on a subset of them. The user may choose suitable measures depending on their availability in his image processing packages. To reduce noise caused by small objects such as antennae or chimneys, the obtained bands should be median-filtered. As the objects to be detected in this data do not show predictable spatial patterns, co-occurrence measures showing relative frequencies with which heights occur in shifted processing windows were not further analyzed.

A selection of the thus generated new bands is used as input to a maximum likelihood supervised classification, which is initialized by sparse training regions. Alternatively, the user may of course also edit the class signatures and covariances directly, if suitable a-priori knowledge on building heights, roof slopes, tree heights etc. is available. Without post-classification processing applied to the results of the classification the result will show two major deficits:

- The result will show some noise in the way that single pixels within an object to be segmented are misclassified.
- As a general tendency the edges of buildings will be misclassified, mostly as vegetation, as a consequence of large gradients.

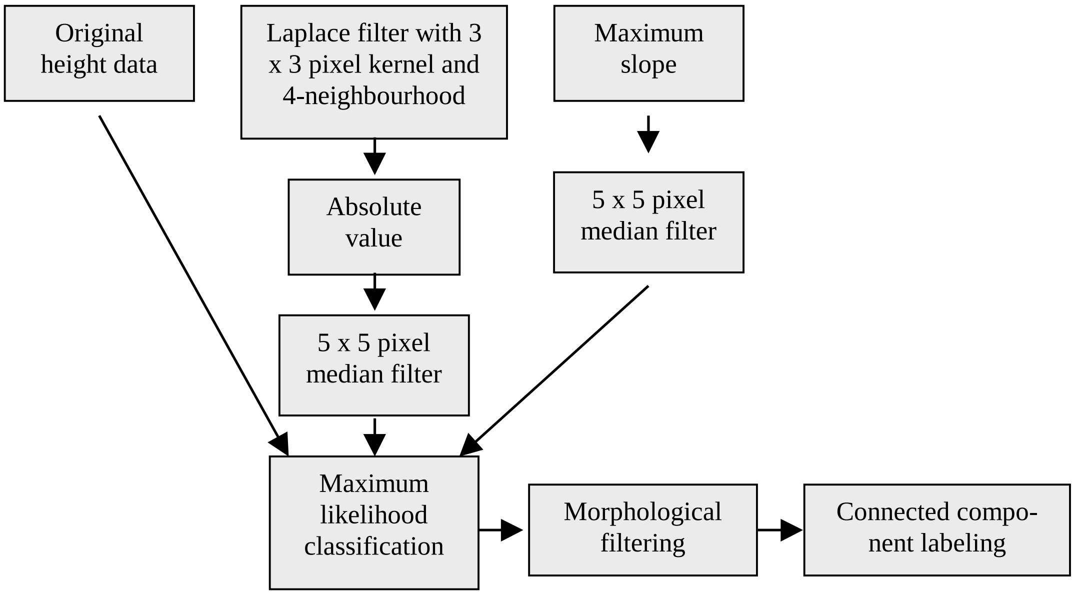
These deficits can be removed by splitting the result of the classification into individual bands for each class of objects to be detected and postprocessing those bands by morphological filtering. Concerning the houses, which are of primary interest here, a significant improvement can be achieved by a closing step followed by a dilation. As a final processing step, connected components labeling will deliver the basis for filtering individual point clouds for each house.

3. PRACTICAL RESULTS

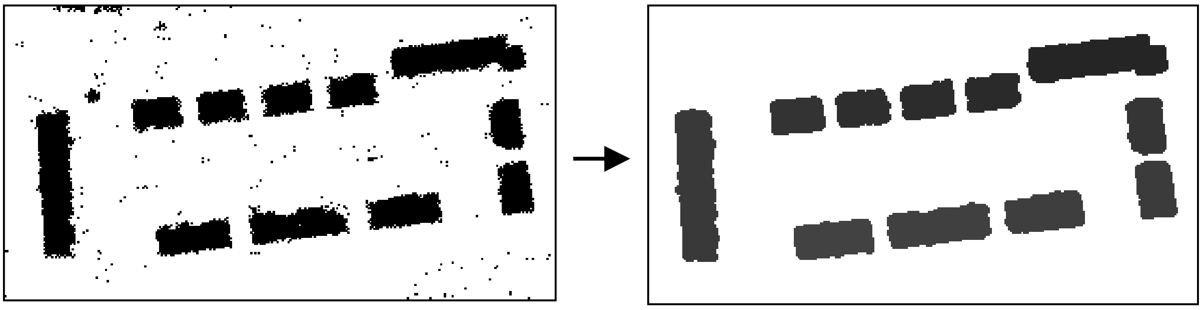
The techniques shown above were applied to a FLI-MAP laserscanner dataset of a part of a village in the Netherlands. FLI-MAP (Fugro N.V., see e.g. Pottle, 1998) is a helicopter-based laser scanning system with 8000Hz sampling rate. It acquires 40 profiles per second with 200 points per profile. Range measurement is limited to first-pulse measurement at 20-200 meter distance, thus providing a maximum strip width of 200m at a scan width of 60°. Due to these system parameters, the point density is rather large (usually more than one point per squaremeter). In addition to the laser range measurements, the FLI-MAP system is capable of delivering intensity data.

The area used for testing the technique covers approximately 12 hectares. Figure 2 shows a part of this test region, which is mainly composed by saddle roof buildings, sheds and a number of trees. The average point density within the laser scanner strips is in the order of five points per squaremeter. The data was interpolated to a 0.5m grid.

An analysis of the results obtained from the classification using different combinations of the texture measures discussed in chapter 2 showed that good results are obtained when using the following three bands, which were further processed to highlight the desired characteristics of data on objects to be segmented:



Both unsupervised classification and supervised classification techniques were applied to these three bands. While unsupervised classification did not lead to a satisfactory segmentation, good results were obtained with maximum likelihood classification. Figure 3 shows the result of the classification for a small part of the test region, the result of postprocessing and a visualisation of parametric house models obtained from the segmented individual point clouds by a technique based on the analysis of invariant moments (Maas/Vosselman, 1999). The confusion matrix obtained from a comparison of the result of the maximum likelihood classification for the test region with the result of an interpretation of a part of the scene performed by an experienced user is given in Table 1.



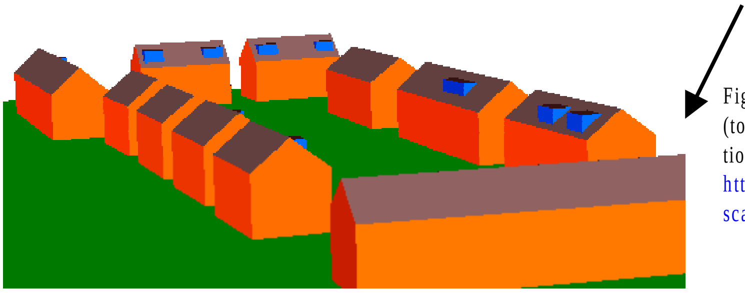


Figure 2: Pixels classified as 'house with tilted roof' (top left), result of postprocessing (top), visualization of parametric house models (left, see also http://www.geo.tudelft.nl/frs/ laser-scan/texture_measures.html for a VRML model)

	tilted roof	flat roof	trees	flat terrain or street	no data	sum	error of commission
tilted roof	4256	4	5	0	0	4265	0.0021
flat roof	4	986	0	0	0	990	0.0040
trees	118	56	2566	73	0	2813	0.0878
flat terrain / street	0	1	11	2638	0	2650	0.0045
no data	0	0	0	0	9977	9977	0.0000
sum	4378	1047	2582	2711	9977	20695	
error of omission	0.0279	0.0062	0.0583	0.0269	0.0000		0.0131

Table 1: Confusion matrix for 12 hectare test region

As can be seen from the confusion matrix, the error of commission for the class 'building with tilted roof' (a part of which is shown in figure 3) is 0.2%, while the error of omission for this class is 2.8%. That means that 0.2% of the pixels which were classified as belonging to this class, belong to other classes according to the interactive interpretation, while 2.8% of the pixels which were interpreted as belonging to this class, were classified as belonging to an other class (mostly 'tree'). This result is obtained from texture measures computed for individual pixels and can be improved further by the application of morphological filtering, as visible in figure 3. The segmentation accuracy in this region after morphological filtering is more than 99%. These figures were achieved solely by applying low level image processing techniques. The subsequent step of parametric building model generation (Maas/Vosselman,

1999) contains a model fit analysis step, which removes outliers and leads to a additional reduction in classification errors.

Good results were also obtained for the classes 'flat roofs' (here sheds and garages) and 'flat terrain or street', while the errors for trees were significantly larger. This lower accuracy for trees is mainly caused by the fact that there is a gradual transition between trees and lower vegetation, as well as by pixels on roof edges being classified as 'tree'. The latter effect can be reduced by a logical combination of this class with the result of the of the class 'building', postprocessed by morphological filtering.

No significant improvement in the overall results could be achieved when using more than the three bands mentioned above. Also, the intensity values delivered by the FLI-MAP system turned out to be rather noisy and did not lead to an improvement in the results in the segmentation process.

The data processing chain as discussed above was optimized for the type of data at hand. For data from different types of sensors, other texture measures may perform better, and modifications in the postprocessing scheme may be necessary. Especially when data from laserscanning systems with multi-pulse recording is used, the analysis of the height range of single grid cells will be of great value.

4. CONCLUSION

The analysis of height texture in airborne laserscanner data with a density of more than one point per squaremeter has proven to be a valuable tool for the segmentation of laserscanner data with the aim of detecting and modeling buildings. A number of complementary texture measures can be derived from the height data and used for segmentation in a classification approach. The technique was applied to first-pulse FLI-MAP data interpolated to a 0.5m grid. In a comparison of the results of interactive interpretation with supervised classification based on a number of texture measures, an error of omission of 2.8% and an error of commission of 0.2% could be achieved for the classification of houses. These results could be further improved by postprocessing. Good or acceptable results were also obtained for the detection of other object classes such as sheds or trees. Additional benefit can be expected when using laserscanner systems that are capable of recording the first and the last pulse of the returning signal simultaneously.

The laserscanner 3-D point data was interpolated into a regular raster in this study. Future research should also concentrate on the definition of the same texture measures in a TIN structure of irregularly distributed original point clouds, thus avoiding effects caused by the interpolation.

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