# THE USE OF ANISOTROPIC HEIGHT TEXTURE MEASURES FOR THE SEGMENTATION OF AIRBORNE LASER SCANNER DATA

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## ABSTRACT

Airborne laser scanning data has proven to be a very suitable technique for the determination of digital surface models and is more and more being used for mapping and GIS data acquisition purposes, including the detection and modeling of man-made objects or vegetation. The aim of the work presented here is to segment raw laser scanner data in an unsupervised classification using anisotropic height texture measures. Anisotropic operations have the potential to discriminate between orientated and non-orientated objects. The techniques have been applied to data sets from different laser scanning systems and from different regions, mainly focussing on high-density laser scanner data. The results achieved in these pilot studies show the large potential of airborne laser scanning in the field of 3-D GIS data acquisition.

## 1 INTRODUCTION

In the last few years laser altimetry has become a very attractive and reliable technique for the acquisition of 3D information. Beyond pure elevation model oriented applications, users began to examin the suitability of laser scanner data for the generation of 3-D city or landscape models. A crucial pre-requisite for the generation of object models from laser scanner data is the segmentation of data sets. The segmentation of laser scanning data has often been performed using an external data source like available 2-D GIS data or multispectral image data, acquired independently from the laser scanner data. Haala et al. (1998) describes the use of ground plan information to improve the reconstruction of buildings. Lemmens et al. (1997) shows the fusion of laser-altimeter data with a topographical database to derive heights for roof-less cube type building primitives. However, in some cases suitable external data will not be available, so that the segmentation has to be performed based purely on the laser scanner data itself without any additional source of information. Maas and Vosselman (1999) show two approaches for the automatic derivation of building models from raw laser altimetry data, based on the analysis of invariant moments of point clouds and the other approach based on the intersection of planar faces in triangulated points.

The aim of the work presented in the following is to segment raw laser scanner data in a classification using anisotropic height texture measures. Texture is qualitatively and quantitatively defined by height, variation of height in local windows and measures such as homogeneity and contrast. Some of the measures are obtained by anisotropic operations to avoid false segmentations along object borders. Objects to be segmented are buildings, trees, infrastructural objects and several sorts of agriculture ground use. While the digital surface model given by first pulse laser scanner data will for example show large local height variations in regions with vegetation, it will show much lower variations and systematic behaviour on man-made objects such as roads or roofs of buildings. An important aspect of the work is the analysis of the benefit of reflectance measurements and simultaneous first and last pulse registration data. The reflectance measurements will be a crucial band to discriminate between several sorts of agricultural fields and also between roads and agricultural fields. If first and last pulse registration is available, the completeness of the classification will increase, especially the discrimination between buildings and trees.

The techniques have been applied to data sets from different high-density laser scanning systems. In this paper two kinds of data will be described. Figure 1 shows a part of a data set acquired with the FLI-MAP system over an urban area in the Netherlands. The FLI-MAP system was installed in a helicopter; the average point density within the laser scanner strips is in the order of 5 points / m$^2$. Figure 2 shows a part of a data set acquired with an Optech ALTM 1210

**Fig. 1: Part of FLI-MAP data set;**
**left: height image 0.5 meter grid resolution; center: reflectance image; right: video shot (not georeferenced).**

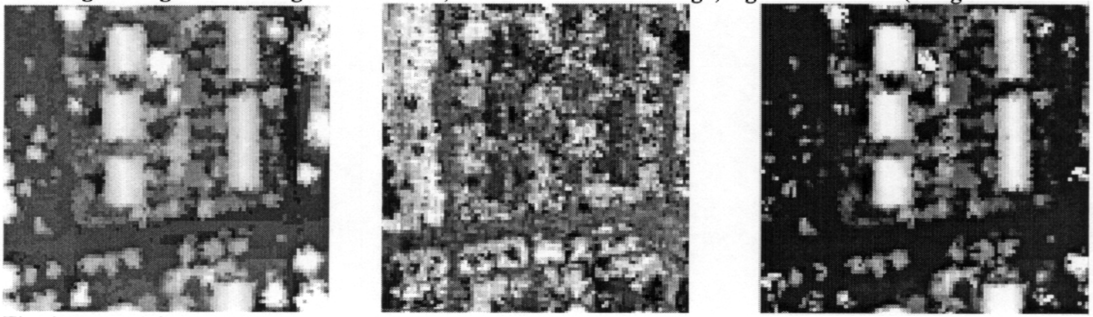


**Fig. 2: Part of Optech data set;**
**left: first pulse height image 1 meter grid resolution; center: reflectance image; right: last pulse height image.**

system over an other urban area. This system has been mounted in an airplane, the average point density within the overlapping part of two laser scanner strips is in the order of 0.7 points / $m^2$. The system has got the advantage that it registers the first and the last part of a laser pulse simultaneously.

The amount of significant classes to be extracted depends mainly on the point density, the range accuracy and the quality of the reflectance image. In both the FLI-MAP and the Optech data sets one can recognize objects like buildings, sheds and trees in the height image, and roads, grass-lands and agriculture fields in the reflectance image. In the very dense FLI-MAP data set even small objects like cars, cows and lampposts are visible in the height image.

## 2 NORMALISED DSM

Airborne laser scanners provide a Digital Surface Model (DSM) that not only represents the terrain surface like Digital Terrain Models (DTM), but also contains buildings and other objects like trees, which are higher than their surroundings. To enable the use of thresholding techniques in the extraction of objects above the terrain surface, a

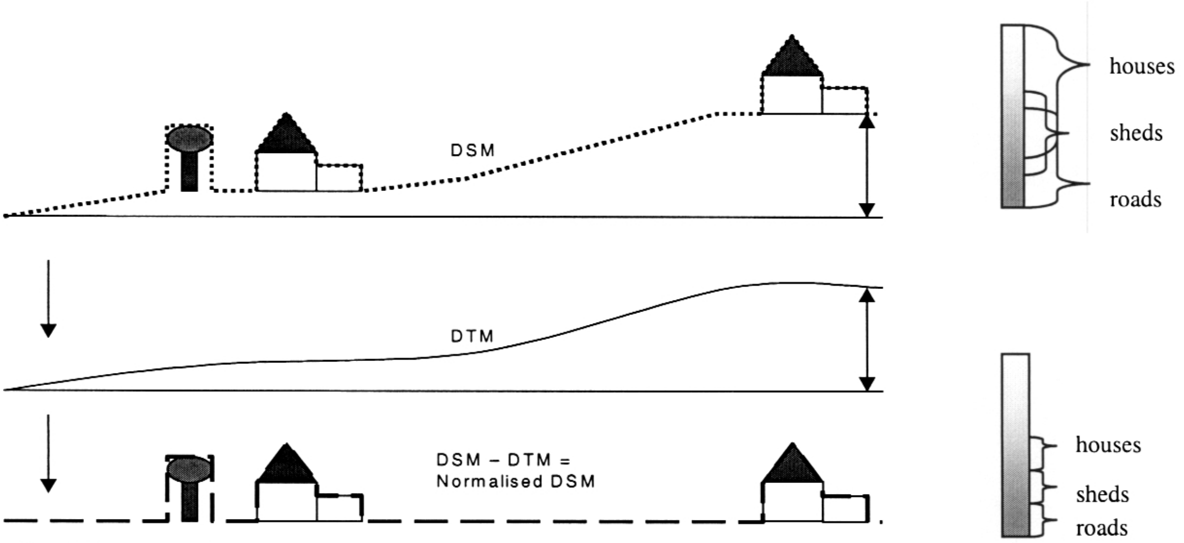


**Fig. 3: Determination of the normalised DSM.**

normalised DSM, i.e. the difference between DSM and DTM is often calculated as a first step (Haala, 1999). The required DTM can be derived from the DSM by mathematical gray scale morphology like it is suggested by Weidner and Förstner (1995). In their approach the DSM is processed by a morphological opening of the DSM surface, eliminating all local maxima in height of a predefined size. In the normalised DSM buildings and trees rising from the terrain approximately put on a plane, see figure 3. This is an important step to narrow the gray value cluster of buildings and trees, and to make a proper discrimination between high and low objects.

## 3 TEXTURE IN LASER SCANNER DATA

Texture is an important characteristic for the segmentation of an image. In a laser scanner image texture is given by local variation of height and height derivatives.
Here the aim of the use of texture measures is to discriminate between man-made and natural objects. In order to classify buildings and trees in laser scanner data one can their difference in height texture. In general, buildings will show a regular, smooth pattern with small variations in height, while trees show an irregular pattern with high height variations. When a small-area patch has wide variation of gray level primitives, the dominant property is texture (Haralick and Shapiro, 1992). In this research texture features derived from co-occurrence matrices have been used to detect trees in laser scanner data and afterwards make a proper discrimination between trees and buildings.

### 3.1 Co-occurrence matrix

Texture is characterized by its gray level primitive properties as well as the spatial relationships between them. The gray level co-occurrence can be specified in a matrix of relative frequencies f(i,j) with which two neighboring pixels separated by a distance *d* occur on the image, one with gray level *i* and the other with gray level *j* (Haralick and Shapiro, 1992), see figure 4.

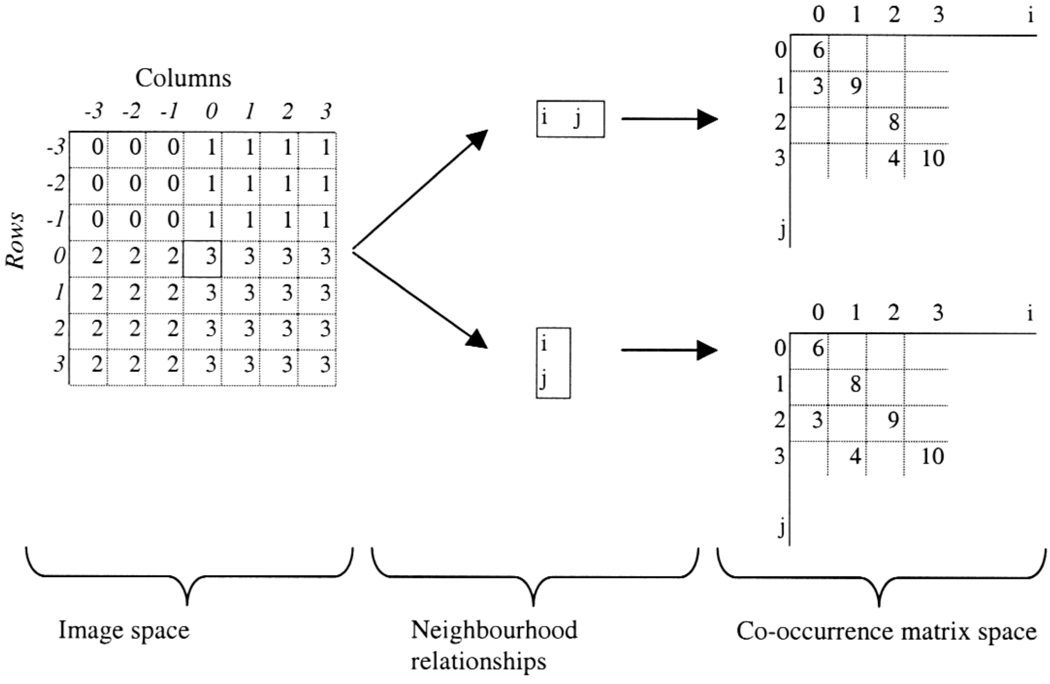


**Fig. 4: Transformation of the gray value relationships within a 7 x 7 window into the co-occurrence matrix space with horizontal and vertical directions (interpixel distance = 1) (modified after Zhang, 1999).**

On the hand of the co-occurrence matrix several measures like correlation, entropy, contrast and angular second moment can be calculated to discriminate between several textural objects.

### 3.2 Contrast texture measure in a laser scanner image

The main property of trees in an laser scanner image is the high local height variations, which are very well described by the co-occurrence contrast texture measure as e.q. implemented in ENVI. Typical values of the parameters kappa and lambda vary between 1 and 3.

$$CONTRAST = \sum_{i=0}^{N-1}\sum_{j=0}^{N-1}(i-j)^{\kappa} f(i,j)^{\lambda}$$

The knowledge that the orientation and shape of man-made objects result in orientated height derivatives allows for the use of the contrast texture measure to separate buildings and trees. Trees are supposed to have contrast in horizontal, diagonal, as well in vertical directions. Buildings will show contrast at the edges in only one direction. Therefore, one can use an anisotropic operation to discriminate between orientated and non-orientated features. The minimum of the contrast measures for all directions will have an high value at trees and will show low values at buildings, except for corner pixels (figure 5). In the figure only the horizontal and vertical directions of the contrast measure have been showed. These corner pixels of buildings can be removed by a 2x2 morphological gray value opening. Once the trees are detected and removed from the height model, buildings will be leftover together with small objects like cars and bushes (Oude Elberink, 2000).

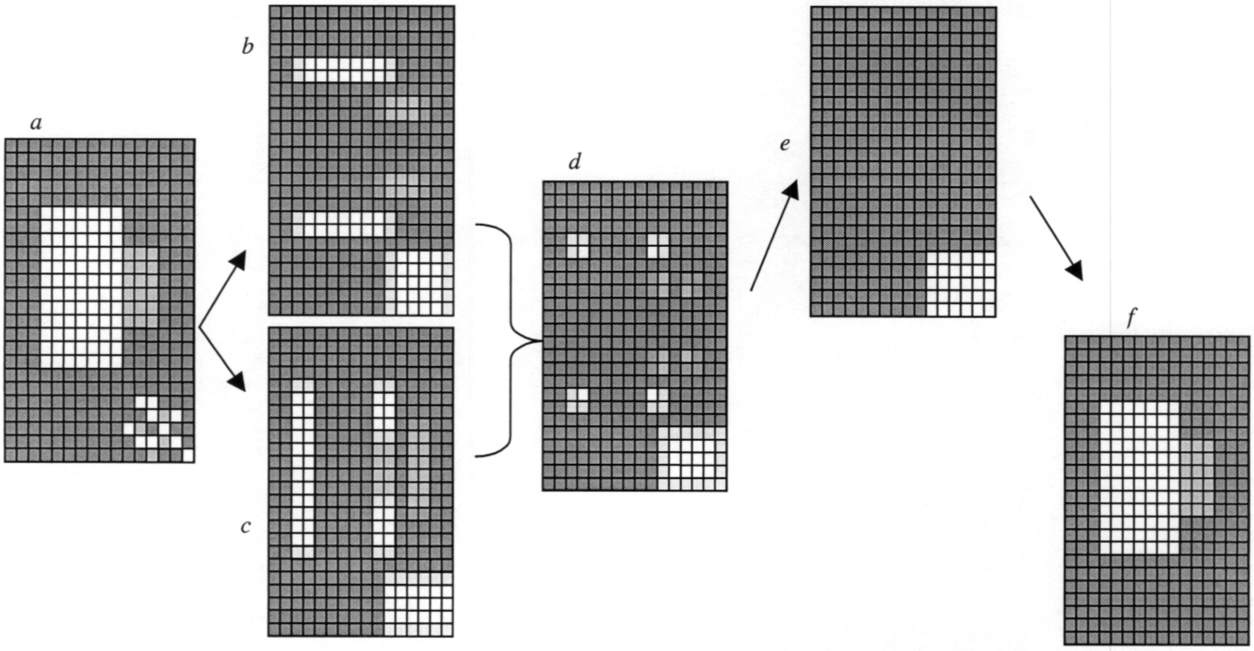


**Fig. 5: Flow chart of the anisotropic contrast measure; a) building and tree in height model; b) co-occurrence contrast measure in vertical direction; c) co-occurrence contrast measure in horizontal direction; d) minimum of two contrast measures; e) trees extraction, result after morphological 2x2 opening; f) building extraction.**

Further options of isotropic texture measures would be the first and second derivatives of height data. On gable roofs for example, the first derivative should be constant and close to one, while the second derivative should be zero (Maas, 1999). A general disadvantage of these measures, however, is their noise sensitivity (especially in very dense data sets) and the fact that they take very high values at building edges.

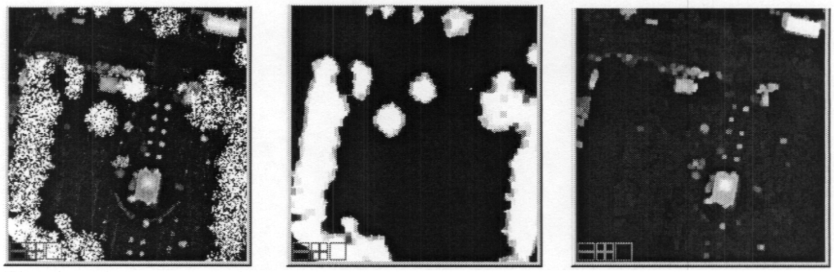


**Fig. 6: Left: original DSM; center: trees extraction as a result of the anisotropic contrast measure; right: building extraction.**

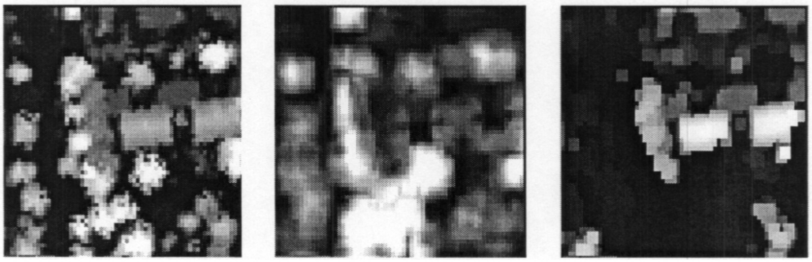


**Fig 7: Left: first pulse DSM; center trees extraction as a result of the anisotropic contrast measure; right: building extraction.**

## 3.3 Practical results of the anisotropic height texture measures

The following examples show the practical results of the minimum of contrast measures in four directions. The density of the laser scanner data has a great influence on the success of the contrast measure. In cases of 0.5 meter grid resolution the contrast measure will give a sufficient extraction of trees in the laser scanner image, as one can see in the FLI-MAP data set in figure 6. Figure 7 and 8 show the 1-meter resolution Optech data set. One can see the extraction of buildings and trees extraction on the hand of texture measures in figure 7 or the (more satisfying) extraction using simultaneous first and last pulse in figure 8. In data sets with greater than 1.5 meter grid resolution the result of the contrast texture measure does not lead to a satisfactory distinction between buildings and trees anymore.

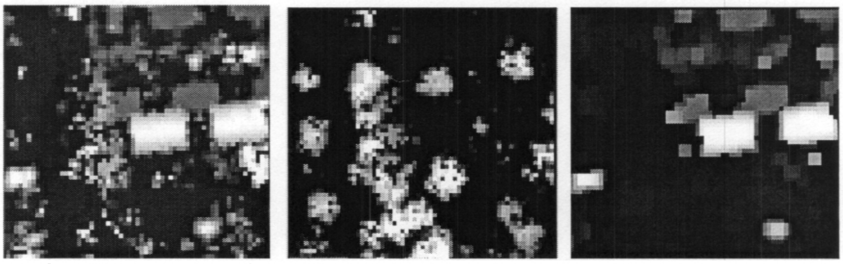


**Fig 8: Left: last pulse DSM; center: trees extraction by first minus last pulse; right: building extraction by morphological filtering of last pulse DSM at non-tree pixels.**

## 3.4 Flowchart

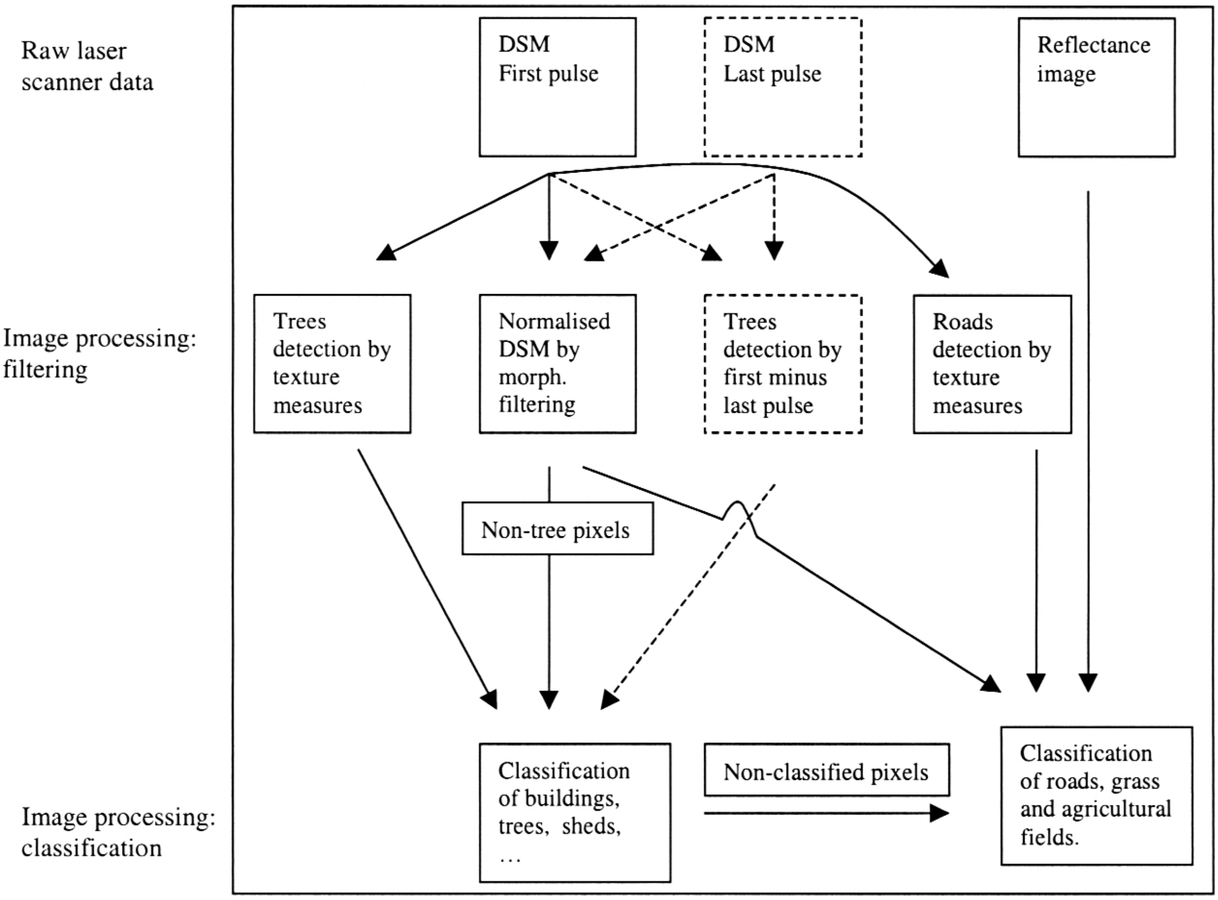


**Fig. 9: Flowchart from data to classification.**

Figure 9 shows the flowchart of the raw laser scanner data towards the classification result. Because the registration of last pulse data is not necessary, but desirable, and the fact that only a few systems are able to register first and last pulse simultaneously, the flowchart of the last pulse data is shown by a dotted line. The reflectance value, while it is not recorded by all systems, is a crucial pre-requisite for the classification of roads, grassland and agricultural land.

## 4 CLASSIFICATION

### 4.1 Results

The classification has been done by performing an unsupervised, K-means classification. In the first step, houses, sheds and trees will be classified using the contrast texture measure and the normalised DSM at non-tree pixels. The profiles of these two bands are shown in figure 10b. Thereafter the reflectance image has been used to classify pixels at ground level. Figure 11 a-d show the two step classification of a small part of the Optech data set, where figure 11 e-f show the classification of the FLI-MAP data set.

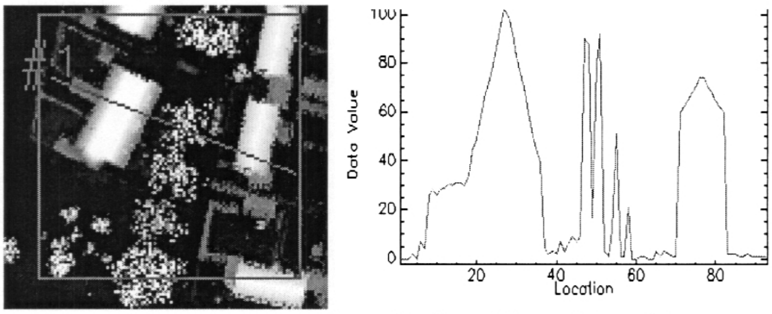


**Fig. 10a: Left: Height image, with profile #1; right: spatial profile.**

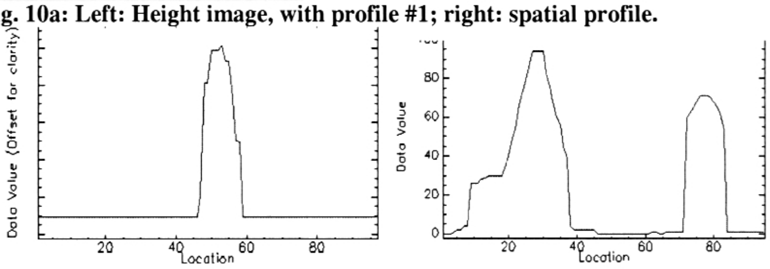
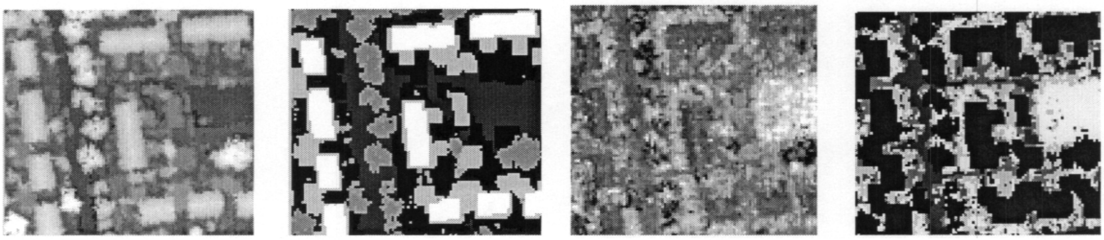


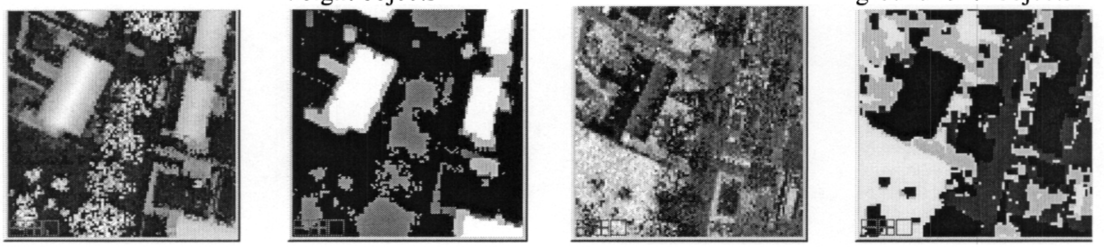
**Fig. 10b: Left: Profile in anisotropic contrast texture measure. Right: spatial profile in DSM at low contrast values.**

### 4.2 Accuracy assessment

Accuracy is determined empirically, by selecting a sample of pixels from the classification result and checking their labels against classes determined from test areas. Houses and sheds can be determined separately with an accuracy of about 90 %, but if those two classes are combined to a new class "buildings", an accuracy of 98 % is obtained. This is obvious because the distinction between houses and sheds only depends on their height; this distinction is not as clear as the distinction between the complete building and its surrounding. Trees can be detected with an accuracy of 97 % in the very dense laser scanner data with the contrast texture measure, and an accuracy of 98 % is obtained in the 1 meter resolution Optech data sets with simultaneous first and last pulse registration. The accuracy of the ground level objects directly depends on the quality of the reflectance image. In these two data sets ground level objects could be detected with an accuracy of no more than 70 %. Better results can be achieved by using additional data, like multispectral data or reliable GIS data.



a) Optech height image b) K-means result height objects c) Optech reflectance d) K-means result ground level objects



e) Fli-Map height image f) K-means result height objects g) Fli-Map reflectance h) K-means result ground level objects

**Fig. 11: Original data and classification results.**

### 4.3 Interpretation of the results

The determination of a normalised DSM is an important step to narrow the gray value cluster of buildings and trees, and to make a proper discrimination between high and low objects. These results show the reliability of the classification of trees on the hand of first and last pulse data, compared to first pulse only data with a higher resolution. After the classification of buildings, discrimination can be made in several sorts of buildings by using the first and second height derivative. The unsupervised classification proved to be superior to supervised classification techniques, because the selection of homogeneous training areas proved to be a very time consuming activity, while the supervised classification does not show improved results comparing to the unsupervised classification.

## 5 CONCLUSIONS

The achieved results show the potential of image processing techniques applied for the segmentation and classification of laser scanner data. In very dense laser scanner data the anisotropic height texture measure can be used for an accurate, automatic detection of trees. If a laser scanner system is able to register first and last pulse simultaneously, the detection of trees can be done by extracting the last pulse from the first pulse. At non-tree pixels one can easily detect buildings by its height in the normalised DSM. The poor quality of reflectance measurements results in poor classification results of roads, grasslands and agriculture fields.

Obviously, the low-level vision techniques described here can only depict a first step in the procedure of the segmentation of laser scanner data. Low- and high-level techniques using knowledge, e.g. on size and shape, on the objects to be extracted have to be used to improve the reliability of the results and get to products that can be used in GIS-related applications.

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