SEGMENTATION AND FILTERING OF LASER SCANNER DIGITAL SURFACE MODELS

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ABSTRACT:

This paper discusses two aspects for filtering Digital Surface Models namely the derivation of parameters for filtering based on a segmentation of laser scanner data and the detection of breaklines. A problem associated with the successful filtering of laser data is the determination of appropriate thresholds used to classify the single height values. Heterogeneous areas, like areas including forest, buildings and undulated or rough terrain, need a specific setting of parameters to control the filtering mechanism. In order to do so, investigations on the use of segmentation approaches, like those being presently implemented within the Definiens eCognition software have been tested using data sets containing height information together with simple texture measures or additional intensity data of the reflected laser beam. The obtained results are presented and limitations are discussed.
Depending on the morphology of the terrain it sometimes would be very helpful, if break- or other form-lines of the terrain could be extracted from the existing data. This aspect is addressed within the second part of this paper showing some preliminary work for the detection of break-lines from laser altimetry data . The investigations have been performed on data from a German north sea island, which has very specific topographic properties with regard to surface roughness and absolute heights. For the extraction of break-lines from this laser altimetry data some edge detection filters like the Deriche- and the LOG filter have been tested. Although there are many ways of optimising and automating the approaches for break-. and form-line detection, a wast amount of manual work remains to first define the suitable thresholds and then to clean-up the results i.e. to remove small detected edges (noise).

1. INTRODUCTION

Techniques for generating Digital Surface Models (DSM) like image matching and laser scanning have the disadvantage of not representing the wanted bare terrain, but the visible surface including vegetation and buildings. A number of techniques have been developed to remove these “artefacts” in order to obtain the true Digital Elevation Model (DEM). Among these procedures are:

- spline approximations
- shift invariant filters
- linear prediction and
- morphological filters

At the University of Hannover mainly the last two methods have been used and their results are quite promising (Lohmann et al., 2000). However the quality of both morphological filters and the linear least square interpolation (linear prediction) depends on a proper setting of thresholds and control values (Jacobsen et al., 2002 , Kraus, 1997, Voelz, 2001). As a result different parameters have to be selected for different structured regions within a DSM. This requires a segmentation of a DSM into areas of similar properties to optimize the performance of the filter.
In addition it would be helpful to have knowledge about natural discontinuities (breaklines) in order to avoid a filtering across such structures yielding an unwanted strong smoothing of the terrain. Procedures for the detection of breaklines have been proposed (Wild, 1996, Brügelmann, 2000) but they are mainly used on already filtered data and not on the original DSM, because the above mentioned “artefacts” would give a too strong response and hence a lot of noise (i.e. each building would be detected as a set of breaklines). Nevertheless the results of automatic breakline detection especially in open areas (see section 3) are quite satisfactory.

2. SEGMENTATION OF A DSM

The segmentation of a DSM originating either from matching or laser scanner data should use classes which are most general in their definition and therefore transferable from one scene to another. It has been shown (Murphy, 2001) that the following list of classes is represented in some DSM:

- Forest
- Settlements
- Large buildings
- Alignments (i.e. highways, railways,…)
- Ramps
- Fields / Pasture
- Water
- Low vegetation

In most cases these classes can be easily interpreted by a skilled human interpreter using optical imagery. For many of the existing DSM however only height data is available. Modern laser scanning systems are capable of recording in parallel an additional reflectance image of the terrain.
It has been shown (Baatz et al.,2002) that recent software tools like Definiens eCognition are able to produce satisfactory segmentations on high resolution remote sensing imagery using a hierarchical network of image objects together with a set of definable rules based on a weighting not only of pixel values but also features like shape and

topology. This software has been tested to derive the above listed classes.

2.1 Segmentation of a laser scanner dataset

The data set was provided by the company TOPSCAN who carried out the laser survey on behalf of the Emscher cooperative in an area “Ickern/Waltrop” close to Castrop-Rauxel in North Rhine Westphalia, Germany. It was generated using the OPTECH ALTM 1225 laser scanner operated in first/last pulse mode and using the possibility to record an intensity image of the laser. The left side of figure 2 shows the gray coded last pulse heights while the intensity image is shown on the right side. The measurement density is approx. 0.6 points per m^2. This data set has been investigated for segmentation of the 8 general classes using 3 variants

(1) Only the height image
(2) The height image together with a derived texture image (Sobel)
(3) The height image together with the intensity image

The hierarchical net within eCognition was formed by 3 levels and the selectable segmentation parameters set iteratively to give the best visual result. As an example these values are shown in table 1 for variant (3)

Level	Weight		Scale	Homogenity Criteria			
	Height	Intensity		Color	Shape	Smooth-ness	Compact-ness
1	1	0	500	0,9	0,1	0,9	0,1
2	1	16	150	0,2	0,8	0,7	0,3
3	Segmentation with class based fusion						

Table 1: Parameters for segmentation (case 3)

The levels have been generated in accordance to human interpretation attempts. As an example within level 1 the segment borders should coincide with the building outlines to allow for the classification of buildings. Therefore the building is the essential element to define the segmentation parameters of level 1. Buildings are visually best discriminated by a brighter color (height) as compared to their surroundings. Therefore the parameter color dominates over the parameter shape in this level. By similar reflections the other segmentation parameters are found.
Basic class/feature descriptions as shown in figure 1 and table 2 are used to define objects at each level and to aggregate them on the next higher level up to the desired output class. As for the class of settlement (level 3) it starts with buildings at level 1, aggregated to housing areas, block of flats, or roads and backyards and row houses in level 2.

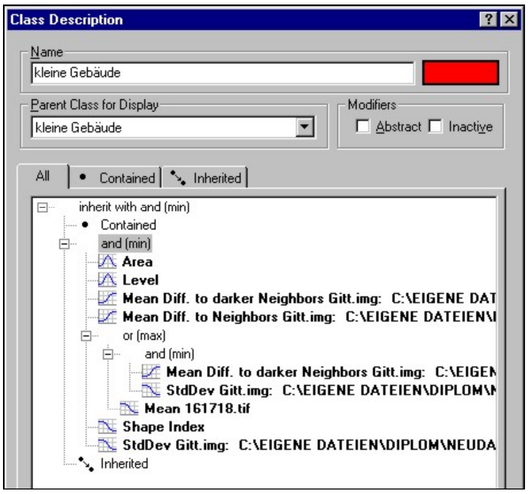

Figure 1: Class description within eCognition

<table>
<tr><td colspan="3" rowspan="2">SMALL BUILDINGS</td><td>→ Base to define class settlement (buildings, housings with backyards, small blocs of houses).</td></tr>
<tr><td>Feature Description</td></tr>
<tr><td colspan="3">Area</td><td>Segments between 80 Pixel (m²) and 2000 Pixel → defines max. size of a small building.</td></tr>
<tr><td colspan="3">Mean Difference to darker Neighbours (Height)</td><td>Terrain surrounding a building is lower → darker</td></tr>
<tr><td colspan="3">Mean Difference to Neighbours (Height)</td><td>The majority of neighbouring segments should be lower.</td></tr>
<tr><td rowspan="3">Or (max)</td><td rowspan="2">and (min)</td><td>Mean Diff. to darker Neighbours (Height)</td><td rowspan="3">If the mean value of the intensity channel is high (typical for vegetated areas), the feature Std. Dev prohibits confusion with forest.</td></tr>
<tr><td>Std Dev (Height)</td></tr>
<tr><td colspan="2">Mean (mean value intensity)</td></tr>
<tr><td colspan="3">Shape Index</td><td>The smooth geometry of buildings is used (length of border divided by area of building → < 2.6).</td></tr>
<tr><td colspan="3">Std. Dev. (Standard Deviation of Height)</td><td>Texture (First order statistics) within a segment. Relatively small compared to class forest)</td></tr>
</table>

Table 2: Object description table (level 1 – small buildgs.)

The accuracy of the results obtained for the three different variants have been checked against a manual interpretation of the area and are summarized in figure 3 and 4. It could be observed, that the accuracy of the classification/segmentation does not significantly improve by adding an extra channel like in variants 2 and 3, but the reliability of the class being produced raises as variant 2 and especially 3 is used. However even the single use of the height data produces a surprising good accuracy and reliability.

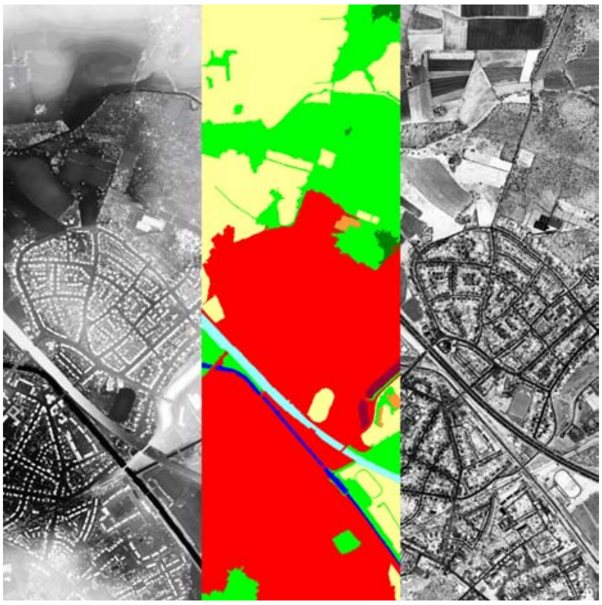

Figure 2: Segmentation result for variant (3) (left gray coded height, middle segmentation result, right intensity image of laser scanner data)

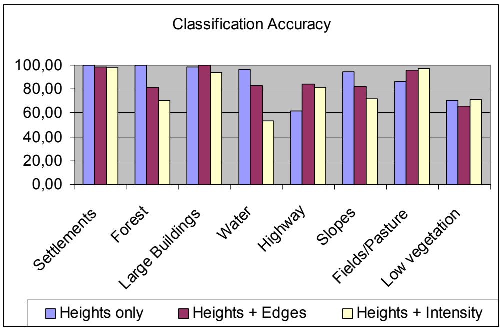

Figure 3: Accuracy of classification/segmentation

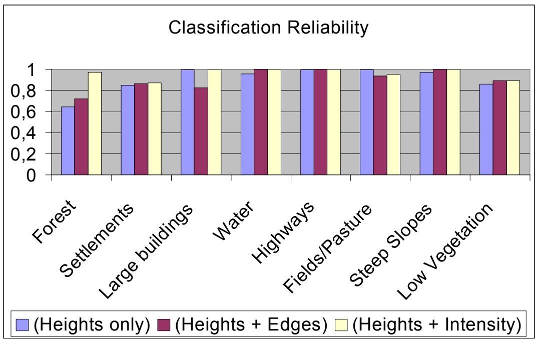

Figure 4: Classification/Segmentation reliability

3. BREAKLINE DETECTION

The second topic addressed within this paper is the detection of breaklines from DSM. Both segmentation into regions of the same structure and the knowledge of breaklines would be of major help for a precise DSM filtering. The work presented here is based on a diploma thesis (Weitkamp, 2001).

For the extraction of breaklines from laser altimetry data some HALCON [MVTEC,2000] edge detection filters like the Deriche- and the Laplace-of-Gaussian filter have been tested

The investigations have been performed on a different data set being acquired with the Optech ALTM 1020 equipment over the German north sea island Juist in course of a survey for the establishment of the Digital Height Model 1:5.000 of the federal state surveying authority in Lower Saxony. The data set has a mean point distance of about 1.5 m. Figure 5 shows the test area. Of special interest were the breaklines of the dikes and of the tidal channels which have a high risk of change at the yearly winter storms. The height variations within the tidal river structure is about 0.2 to 2.5 m and 0.5 to 15 m for the dikes.

Figure 5 : Test area

The process starts calculating a 3 x 3 standard deviation image followed by a Laplace of Gaussian (LoG) filter. This filter uses the two-dimensional derivates of the Gauss-function together with a gaussian lowpass for noise suppression [Klette, 1995]. The "LoG" operator computes the laplacian $\Delta g(x,y)$ for an arbitrary smoothing of the gauss-function σ :

$$\Delta g(x,y) = \frac{\partial^2 g(x,y)}{\partial x^2} + \frac{\partial^2 g(x,y)}{\partial y^2}$$

The derivates within the LoG operator are approximated by derivates of the Gauss function

$$G_\sigma(x,y) = \frac{1}{2\pi\sigma^2} \exp\left[-\frac{x^2+y^2}{2\sigma^2}\right]$$

giving an expression for the kernel:

$$\Delta G_\sigma(x,y) = \frac{1}{2\pi\sigma^4}\left(\frac{x^2+y^2}{2\sigma^2}-1\right)\left[\exp\left(-\frac{x^2+y^2}{2\sigma^2}\right)\right]$$

The result of this detection of an ideal edge are both the maximum/minimum and a zero crossing. The advantages of this operator are its insensitivity for noise and the good detection of the edge position even with low edge gradients. The final breaklines are derived by thresholding and skeletonizing. This method, however, failed for the top edges of the dike because of difficulties in defining the appropriate thresholds.

Therefore the mean curvature H of the derivates of the Gauss-function (see above) was determined, which allows again after thresholding to determine the position of the top dike breaklines,

mean curvature H:

$$H = \frac{a - b + c}{d}$$

$$a = \left(1 + \frac{\partial g(x,y)^2}{\partial x}\right) \cdot \frac{\partial^2 g(x,y)}{\partial y^2}$$

$$b = 2\frac{\partial g(x,y)}{\partial x} \cdot \frac{\partial g(x,y)}{\partial y} \cdot \frac{\partial^2 g(x,y)}{\partial y \partial x}$$

$$c = \left(1 + \frac{\partial g(x,y)^2}{\partial y}\right) \cdot \frac{\partial^2 g(x,y)}{\partial x^2}$$

$$d = \left(1 + \frac{\partial g(x,y)^2}{\partial x} + \frac{\partial g(x,y)^2}{\partial y}\right)^{3/2}$$

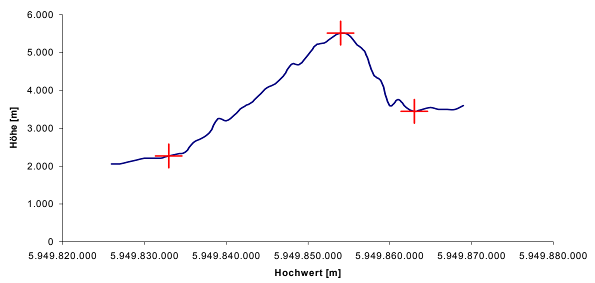

Figure 6a: Dike cross section

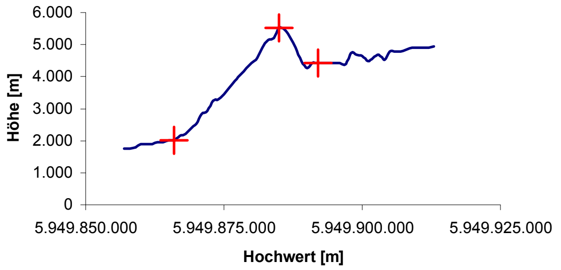

Figure 6b: Dike cross section

Fig. 6a and b show as a result the position of breaklines detected (red crosses). By visual inspection it can be seen that the positions found are all below 1m from their ideal position. However difficulties arise whenever there is bushy grass and / or footpaths crossing the "natural" dike structure, while "artificial" dikes, like those shown in the next image allows a very precise breakline detection.

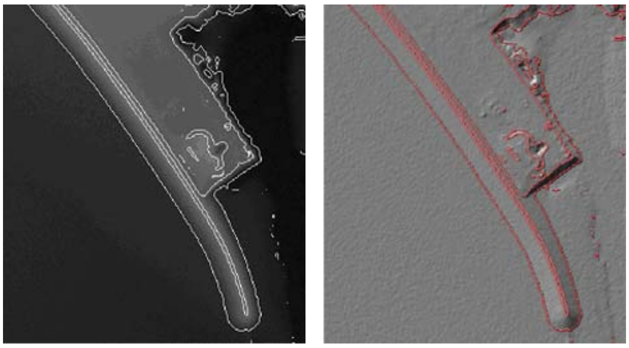

Figure 7: Breaklines at man made dikes

For the second class of objects, namely the tidal channels, one has to consider the special structure and outline of these objects. The height variations between the top and bottom channel edges are only in the range of 0.2 to 0.5 m and hence cover only a limited dynamic range of the data. Stretching the dynamic range therefore will also enhance possible noise which can be suppressed to certain extend again by using a gaussian smoothing. A DERICHE filter [Deriche, R:, 1992] was assumed to be appropriate for this task. This recursive filter reacts sensitively to real edges, i. e. the position and length of the edges are generally detected correctly. Additionally this filter is relatively insensitive with respect to noise. It's bandpass characteristic results from an combination of edge detection and smoothing, which can be controlled by an adjustable parameter. The smaller this parameter is, the stronger the smoothing is, resulting in wide blurred edges, which are relatively free of noise. In contrary small elongated edges require a large value and again the sensitivity for noise increases.

Figure 8 shows the result of applying this type of filter with different parameter settings in an area made up of of tidal channels together with a plot showing the locations of the detected edges (breaklines). It can be seen that the position of the edges within the data set remain relatively constant, besides some artefacts which show up along small ripples not belonging to the channel system. These artefacts could be removed by analyzing their length or any other appropriate way.

As already mentioned, the cross sections of the channels showed on an average a height difference between the top of the channel and the water level of about 0.2 to 0.5 m. By analyzing the positions within the profiles of the cross sections a positional error of about 1 to 2 m have been found, which is in the order of the point density. The parameter setting for the detection of the edges on this terrace like structures have been found to be very stable as long as there is no vegetation on, or near the ramps.

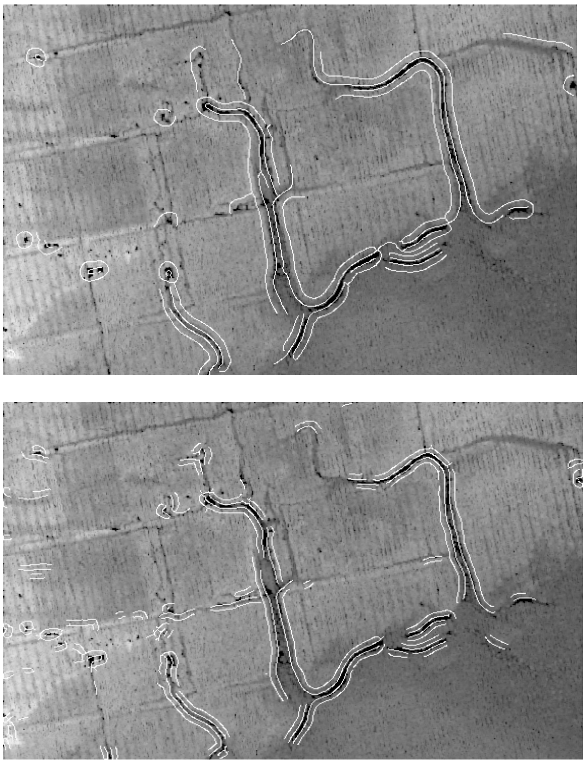

Figure 8a: Effect of parameter selection

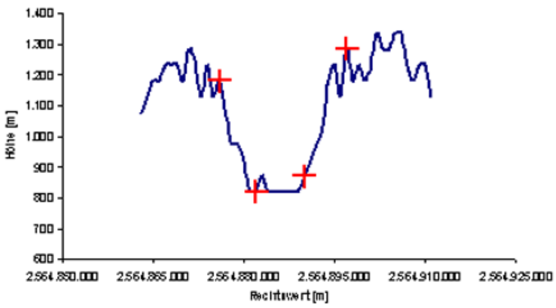

Figure 8b: Cross section and position of detected breakline

4. CONCLUSIONS

It has been shown that the segmentation of laser scanner data is feasible even if only the height data is available. The object/class description developed should be as general as possible in order to be transferable to other DSM, which still remains to be proved in future. Once a segmentation has been performed the filtering parameters can be set according to class specific values. In general it is also possible to directly detect breaklines from laser scanner data sets. The results are quite promising as far as open areas are concerned. In most cases however the areas under concern are a mixture of the 8 classes mentioned in section 2 and will produce wrong and noisy short lines not representing the terrain. Therefore the data has to be filtered beforehand in order to avoid long and costly manual editing.

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