ON THE USE OF AIRBORNE LASER SCANNING DATA TO VERIFY AND ENRICH ROAD NETWORK FEATURES

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KEY WORDS: LIDAR, Surface Parameter Extraction, Detection, DEM/DTM, Cartography, Database

ABSTRACT:

High-resolution digital terrain models (DTM) provide accurate descriptions of our surrounding with respect to its 2.5D shape. Besides that existing cartographic databases provide detailed 2D representations of topographic objects. Integrated products, which combine both planimetric and height information are rare. This paper proposes an algorithm to elaborate the outline of a road. It is founded on a well-known line simplification algorithm. Prior information is used to guide the interpretation process. Hypothesize and test methods based on support functions are used for decision-making. Robust estimation techniques are used to derive the outline of roads. Results and a discussion, which covers qualitative aspects, are given for different types of roads. The paper ends with a conclusion and a glimpse on future work.

1. INTRODUCTION

Digital terrain models (DTM) like those derived from airborne laser scanning provide detailed descriptions of our surrounding with respect to its 2.5D shape. Due to the high level of automation during the stages of data collection and post processing, laser scanning has become an efficient alternative to airborne photogrammetry for the production of DTM. Besides that existing cartographic databases provide detailed 2D representations of topographic objects. However, production of both DTM and cartographic databases usually share similar capturing and processing techniques. Whereas DTM data usually is distributed by means of regular grids, features represented by cartographic data sets are modelled as points, lines and areas. It is up to the user to establish a link between these two different data sets. This work proposes a technique for the enrichment of cartographic data by features derived from the DTM with a strong focus on road networks.

The paper is organized as follows. The next chapter will motivate for applications that could benefit from this approach. Afterwards we will discuss the data sets and additional information, which has been used throughout this work. Then we will describe the approach used for the identification of roads within the DTM. A section on results and discussion follows. The paper concludes with future work and an outlook.

2. MOTIVATION

Laser scanner data based digital terrain models (DTM) can provide dense height information by their nature. The integration of two-dimensional information taken from existing cartographic data sets and height information derived from a DTM enables for development of new applications. A broad variety of business segments, e.g. planning and administration, environmental protection, car navigation, tourist information or game development could benefit from this.

Having in mind traffic information and road network related belongings, the third dimension can be applied to facilities, which are related to transportation. Spatial features enriched by 2.5D can help to improve the process of planning, construction, operation and use of roadway networks. Besides height, longitudinal and transversal slope make up new attributes enabling for more precise description of the roadway network. Further attributes like the exposition or curvature of objects can be derived as well. Further advances could lie in the more precise prediction of emissions rates of harmful substances and noise, depending on varying road gradients. Car navigation systems can use three-dimensional data for optimized routes computations. Driver assistance and warning systems can use it for automatic speed warnings ahead of sharp curves and hills, computation of visibility ranges and automatic adjustment of the car's headlights. Safety functions could actively slow down the car in front of anticipated dangers, especially for such vehicles carrying heavy or dangerous loads. The exposition of lanes might be an indicator for glazed frost sections during cold seasons. Functions increasing driver's comfort include applications like drive train management or 3D navigation systems. All of those applications are currently actively researched in the automotive industry.

Due to the high density of the data, not only height information can be derived from the 3D-surface, but also the detailed shape of objects. This allows to automatically extracting the exact the road geometry, as long as it is bordered by typical height changes. In the context of car navigation, this enables for lane-precise vehicle positioning and more precise route guidance.

Additionally, this approach allows for validation, change detection or enrichment one of map data. Thus it enables 2D map producers either to perform validation or change detection against digital terrain models. When using high resolution DTM data topographic objects usually exhibit more details than currently present within the map database.

3. DATA SOURCES

3.1 Laser scanning data

The data sets used in this paper are acquired by airborne laser scanners. The data is collected by sending out laser beams to the ground using pulsed or continuous wave techniques. Therefore the distance is derived by measuring travel time or phase shift of the emitted signal. To improve coverage of the sampled area system manufacturers use varying techniques to deflect the laser beam during flight time. The result is called a digital surface model (DSM) because it contains both points from the ground surface and points from objects on top of the surface, like buildings and trees. Often a distinction is made between last and first pulse DSM. The first one primarily contains ground points. The latter is dominated by top points of vegetation if present

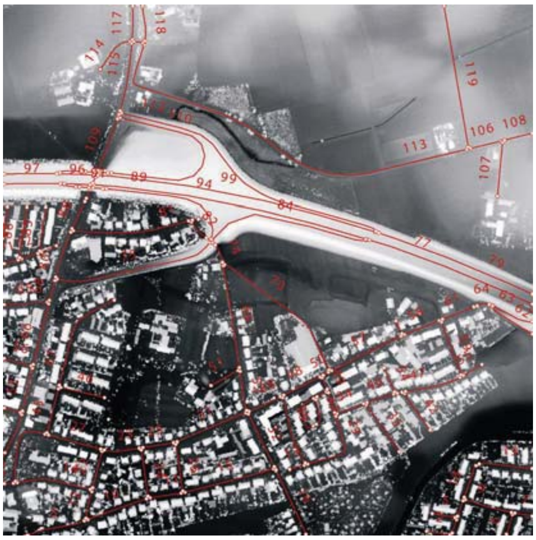


Figure 1. Test area used within this work

within the data. Several methods have been developed to derive DTM from the DSM. Many of these approaches use filtering techniques. Both DSM and DTM data sets are available by commercial companies. For a more detailed description e.g. refer to (*Baltsavias 1999a)*. The planimetric accuracy of the laser points is approximately 0.5 m *(Baltsavias 1999b, Lohr 1999)* where the point density is up to four points per square meter. The accuracy in height is 0.01 up to 0.15 m *(Briese 2001, Wever 1999)*.

The test region used in this paper covers a small part of Castrop-Rauxel in the western part of Northrine Westphalia, Germany. Its spatial extent is about 1 x 1 kilometres. The data has been interpolated on a regular grid, the ground resolution is four points per square meter. Figure *1* gives an overview of the test region. It shows the last echo DSM overlaid with labelled 2D lines derived from a cartographic database. Red colour lines denote road centrelines as present in the database. Darker colour values denote lower terrain. The test region is dominated by rural areas. It contains arterial roads as well as local access roads. From east to west a super highway crosses the test region. Field tracks can be seen in the northern part of the rest region.

3.2 Topographic datasets

The Authoritative Topographic Cartographic Information System (ATKIS) is one of the German authoritative spatial data sources. It describes topographic features of the landscape *(AdV 1998)*. ATKIS data is nationwide available. The Digital Landscape Model (DLM) is part of ATKIS. It provides primarily two dimensional information on the landscape. ATKIS DLM geometry is expressed by points, line and areas. In this paper data from the Base-DLM has been used. Transportation related feature attributes provide information about lane or road width, number of driving lanes and functional road class. However, depending on the features type (road, way) not all of the attributes are present with each feature. Planimetric accuracy is aimed to be better than three meters. Depending on the underlying data source, however, errors of up to 10 meters can be observed.

3.3 Road profiles

The process of design and construction of road networks usually is guided by rules and regulations. Such normative resources can help to keep the quality of a road network with respect to safety and capacity on a common level throughout the whole country. Some of the rules concerning this research are laid out in detail in normative references like *(RAS-Q 1996)* and *(RAS-L 1995)*. These rules describe both the longitudinal and transversal shape of a road with respect to its intended purpose.

Three different geometric entities can be used to design the longitudinal shapes of a road: straight lines, circular arcs and clothoids. Usually a road is designed by a sequenced couple of instances of such entities. However, to ensure a proper run of a road one has to make sure that there occur only small or even no discontinuities while switching from one instance to another. Parameters like inclination and curvature of a road not only depend on the underlying terrain but also on the projected average traveling speed. In order to ensure high levels of safety and driving comfort, these values are limited by rules, e.g. the inclination of highways is limited to a maximum of nine percent.

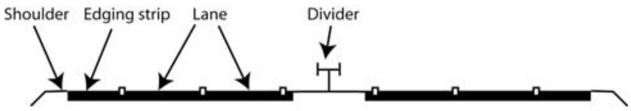


Figure 2. Cross section sketch

Besides from that rules which specify longitudinal shape of a road further recommendations are given using several standardized cross section prototypes. They are characterized by the number of driving lanes per driving direction and by width of edging strip, road dividers and embankment. It depends on the estimated traffic volume which profile is applicable for a certain type of a road. In addition the inclination of a cross section is limited to a range of 2.5 up to 8 percent in order to ensure proper drainage and a high level of drivers safety. In cases of strong longitudinal curvature each carriageway is to be tilted around its centre to allow for smooth compensation of centripetal forces.

4. RELATED WORK

Basically, only a few approaches exist which rely primarily on height information in order to identify roads within digital terrain or surface models. Related efforts exist that cope with the extraction of breaklines from laser scanner data. Breaklines are hereby described as linear structures that show discontinuities perpendicular to their shape. This can also be defined in terms of continuous areas to the left and right of the structure. The approach proposed by Brügelmann *(2000)* is based on second derivatives and hypothesis testing. It is used for breakline extraction on dikes. Briese *(2003)* uses advance information derived from a topographic database to identify breakline candidates. Plane intersection and iterative refinement of the intersecting planes are used to derive the breaklines. Wild et. al. *(1996)* propose an adaptive edge preserving filter to derive breaklines. It is based on bilinear finite element interpolation. Local maximum curvature values and variance component estimation are used to preserve breaklines while filtering the DTM data. Akel et. al. *(2004)* extract roads from a LIDAR data in order to derive a DTM. Geometrical constraints like deviation in height or deflection from surface normals are used to identify roads within the DSM. Clode et. al. *(2004)* propose a method based on hierarchical classification in order to extract roads from DTM data. A roads surface is defined by means of a homogeneity measure. This is in turn defined by claiming some point density still to be present after applying constraints – like those used in Akel et. al. *(2004)* – to the input data.

5. INTERPRETING DSM'S BY USE OF PRIOR INFORMATION

Interpretation usually consists of several steps, a set of model features is set up which comprises prior information. Output from segmentation is transformed into data features. Some kind of mapping function from data to model features or vice versa is established in order to be able to decide which of the data features comply to the model *(Grimson 1990)*

As already pointed out above, valuable prior information can be derived from both cartographic databases and road construction guidelines. This approach relies on a road position that has been derived from a cartographic database. In addition to this, its functional road class is used to select an appropriate cross section model proposed by road construction guidelines. The cross section model contributes further parameters like feature width and/or number of lanes. All these data helps to improve interpretation results. In the following, an approach will be introduced that is specially targeted for the interpretation of roads.

5.1 Processing along linear feature axis

In this approach, the process of identifying of a road within the DSM is guided by the middle axis imported from a cartographic database. The reason for this is twofold. First we want to reduce the search space. Second, it allows of a natural description of the underlying model.

Along the roads axis each feature is split into n perpendicular sections where n depends on the resolution of the underlying DSM, here we set n to 0.5 m. The width of the sections depends on both positional accuracy and assumed cross section length. This is obvious as different types of roads are based on different types of cross section prototypes. Thus, roads like super highways will show up greater cross section width than a local access street. Practically, actual values range from 15 up to 100 m. A set of parametric model features is defined. It describes a road cross section in terms of two dimensional consecutive segments s_i. Mapping our DSM data to model features while considering some geometrical constraints can be done by robust image segmentation techniques as k-means clustering, Hough transformation or RANSAC based methods (*Forsyth and Ponce 2003, Hatger and Brenner 2003)*.

5.2 Segmentation by iterative end-points fit

By its nature each section which hits the DSM and perpendicular crosses a road is represented by a list of vertices which are of monotone increasing order. The initial number of vertices depends on resolution and size of a section. It is now to figure out which set of vertices belongs to which part of a cross section prototype. One solution to this problem is given by applying a line simplification algorithm to each set of vertices. Thus, the idea is to reduce the number of vertices contained within a section as long as a meaningful mapping of data to model features can be established. A well known line simplification algorithm is given by an iterative end-points fit technique used in image processing *(Duda et. al. 1973)*. It was independently discovered by Douglas and Peucker *(Douglas et. al. 1973)* and by Ramer *(Ramer 1972)*. We will refer to this as the Douglas-Peucker algorithm. Computation can be done in $O(n \log n)$ time if the polygon is planar where n denotes the number of vertices (*Hershberger et. al. 1992)*. The algorithm ends up with a list of contiguous segments that are smooth with respect to a threshold ε denoting the smoothness. In this paper ε is set to the noise of the DSM data.

5.3 Interpretation by support measures

Recalling that we want to identify roads within a DSM an interpretation step that maps our segmentation result to some kind of model is necessary. This leads to a comparison of each segment $s = \langle p_1, p_2 \rangle = \langle (x_h,y_h), (x_t,y_t) \rangle$ to model features and check whether it satisfies certain criteria. In this case our model heavily relies on prior information, which has been derived from cartographic data bases and road construction guidelines. To be more precise, these are position of the road middle axis, admissible slopes and section type and width.

In order to decide whether a set of segments fits our model we define support functions. These functions can be interpreted as a measure of similarity between data and model features. By measuring total support for each possible solution of segments mapped onto the model, one can decide which solution is acceptable or to be discarded. Appropriate thresholds limiting for a minimum of support help to narrow down the search tree.

Consider the monotone set $S = \{s_1,\dots,s_n\}$ of segments obtained from segmentation. Let set M out of S fulfill some slope constraint. Then set S can be partitioned into two different subsets $M \subseteq S$ and $N \subseteq S \wedge N \cap M = \varnothing$. As already pointed out slope values of section parts are limited to a certain range. Practically, those values range between ± 0.08 rad denoting the tangent of a segment. This criterion can also be expressed as a binary valued support function H_1:

$$H_1(s_i) = \begin{cases} 1 & \forall\ s_i \in M \\ 0 & otherwise \end{cases} \quad i = 1,\dots,n \tag{1}$$

Further on, consider the function H_2 denoting a measure of support for the minimal gap between road centreline l and segments s_i. Computing support for the overlap of road centreline and segment centre makes no sense, since there may be solutions which are not be well bordered by discontinuities. As a consequence this would lead to ill conditioned support values. Thus, we compute support by reverting to the minimum gap between a segments head x_h or tail x_t and the position x_0 of the road centreline. Computing support h_i for each segment is limited to elements of subset M. However, H_2 should be based on stochastic information derived from the data itself. In this case we compute values by relying on a triangle function that has its maximum at the centre of the cross section which coincides with the road centreline position x_0.

$$\Lambda = \begin{cases} 0 & |x| \geq 1 \\ 1 - |x| & |x| < 1 \end{cases}, \quad x = x_{h,t} - x_0 \tag{2}$$

Let Δ_{max} denote the maximum admissible offset of segment s_i outline from road centreline r. In this case Δ_{max} is determined by section width and data noise.

$$H_2(s_i) = \begin{cases} \Lambda(x) & |x| < \Delta_{\max} \\ 0 & |x| \geq \Delta_{\max} \end{cases} \tag{3}$$

Last but not least let H_3 denote a function measuring support of data to model feature length. Reasonable reference values for length l of data features are derived from the designated cross section prototype. In such cases where a segment s_i exceeds a model feature in length by a multiple. Probably there exists no discontinuity between a road surface and adjacent features. So we assume two different features to be present. One of them called *nil* feature not being modelled, the other one we are searching for. A reasonable design of H_3 therefore computes support only by measuring Δ, which are of equal or shorter length than that proposed by model features. This goes well with H_2 where we decided either to bind support on head or tail of a segment. As a consequence, H_3 is built upon a normalized ramp function.

$$H_3(s_i) = \begin{cases} 1 & x \geq l \\ x & 0 \leq x < l \end{cases} \quad , \quad x = \frac{x_t - x_h}{l} \tag{4}$$

So far, we are able to rank the output of an iterative endpoints fit with regard to the support functions defined above. Data features next to the road centreline are favoured over those being too much off. Erroneous data and not modelled phenomena (cars, etc.) will probably lead to shorter segments than expected. Thus, features corresponding with proposed road width are to be more privileged than those being shorter. Finally, we select the best-rated data feature from our ranking and submit it to further processing.

5.4 Deriving a roads outline

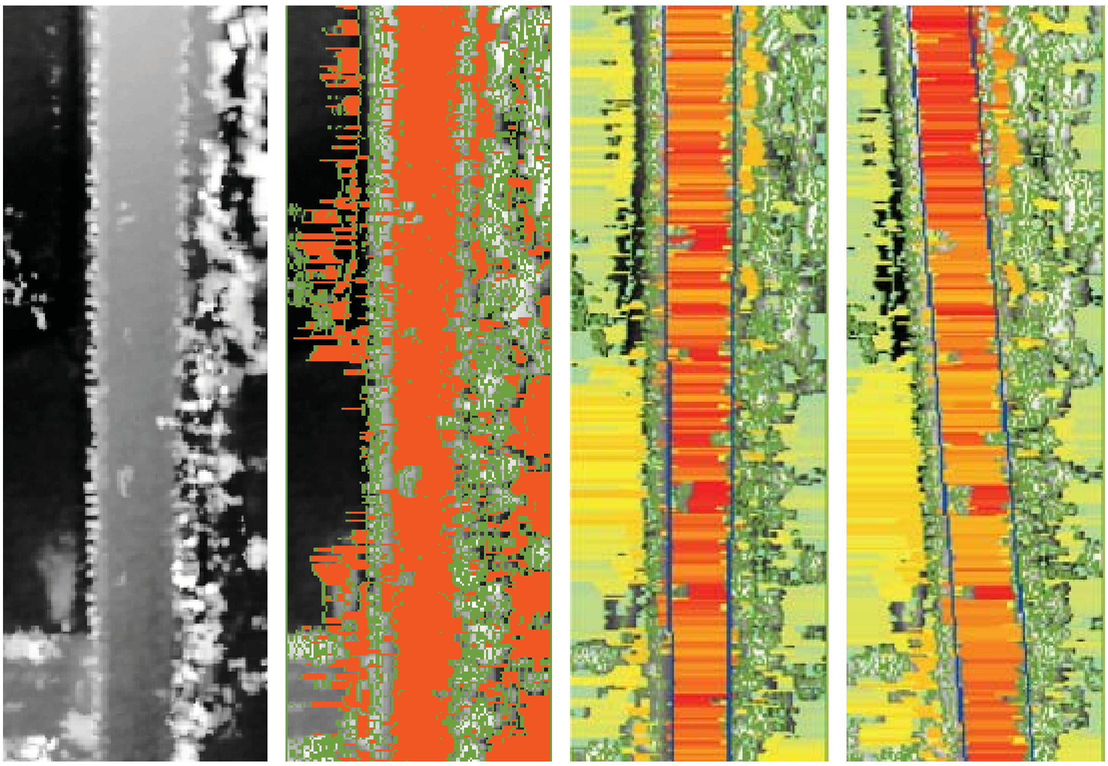
It seems natural to merge several best solutions in order to derive the outline of the road. Unfortunately this does not lead to an acceptable solution immediately because of heavily jagged left and right borders, caused by missing discontinuities.
Assuming there is no error while the centreline was being captured we can describe road borders by two straight lines and search for the best fit of a set of segments against this model. We choose a robust estimation technique based on the random sample consensus principle that first was described by Fischler et. al. *(1981)* in order to derive the borders. For all results that were obtained in section 5.3 at least two samples are drawn which uniquely define two straight lines, one for the left and one for the right border of a road. The consensus is obtained by the set of segments for which

$$|ax + by + c| < \varepsilon \tag{5}$$

holds. Threshold ε denotes an arbitrarily chosen value controlling the maximum allowable offset from the line defined by its parameters *a, b, c*. Iteratively, we now draw samples from the set of segments. If the sample set is chosen large enough, this will lead to the probably best solution for straight-line parameters. Thus, maximum consensus is given by the maximum number of segments for which equation (5) holds.

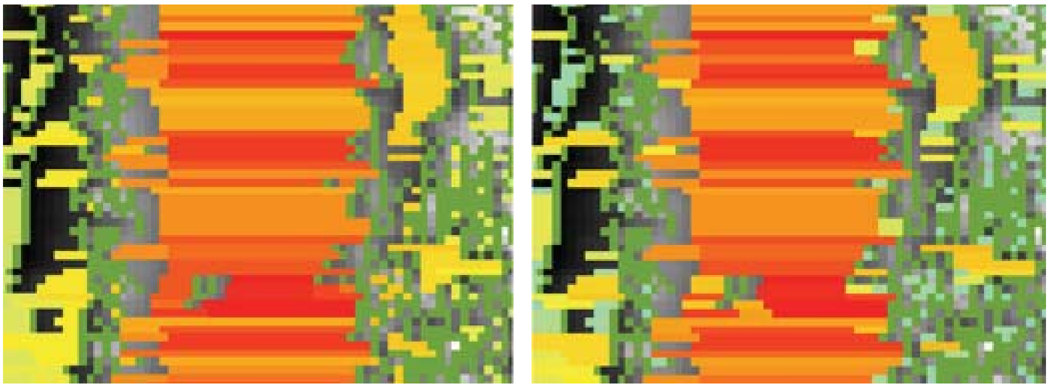
6. RESULTS AND DISCUSSION

Figures 3, 4 and *5* show resampled cutouts of Figure *1*. Resolution is set to 0.5 m. Cutout figure *3a* represents the DSM of a highway exit. The image has been resampled along the road centreline; darker colour values denote lower terrain. The total difference in elevation is about 20 m; size is 150 x 50 m. Figure *3b* shows the results of segmentation draped onto the DSM after applying the iterative endpoints fit to the data. Green pixel values denote vertices produced due to a smoothness threshold of 0.4 m. Segments that comply with a slope not steeper than 0.08 rad are shown in orange. So far, the roads surface has been surprisingly well identified through the application of smoothness and slope constraints. However, the result still has



(a) (b) (c) (d)

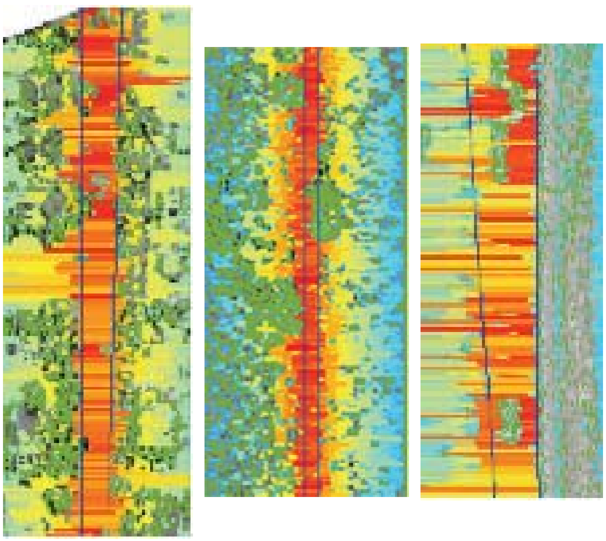
Figure 3. Resampled DSM (a), Intermediate results (b), results based on original (c) and erroneous data (d)



(a) (b)

Figure 4. Intermediate results after applying equations (3) (a) and (4) (b)

some flaws denoted by holes contained within the results achieved up to here. These arise from vehicles which have neither been filtered out from the DSM nor been taken into account by an appropriate model in order to deal with such events. Figure *3c* shows final results after considering those support values that have been introduced in one of the previous sections. Once again, results are overlaid onto the DSM. Green pixel values denote segment vertices. Segments ranked by support are coloured using a temperature scale. That are best ranked segments are shown in red, poorly evaluated ones appear in yellow or even worse green pixel values. Finally, applying the formerly mentioned RANSAC method to the full set of best segments so far detected derives left and right road borders. Results are shown by blue pixel values. Obviously, one would expect these two lines to be parallel as a road usually appears within the landscape as a symmetrically bordered phenomenon. As this is not the case a more sophisticated model would prescribe parallel borders and therefore produce more accurate results. In figure *3d* the centreline of the road has been displaced by hand. Centreline vertices have been shifted to the left and right border of the road in order to show the effect of a data capture error. Threshold values have not been modified with respect to fig. *3c*. By comparing results to figure *3c* the outline has been derived quite well once again. A comparison of the orientation of the road outline and the road centreline – which is implicitly defined through the image grid – enables for detection of data capture errors to some extent. However, one should keep in mind, that if such a displacement were too large this would not hold anymore. This is because the slope constraint is applied to segments, which are perpendicular to the centreline. If deflection by capture error becomes too large we would no longer be able to achieve meaningful results, especially when terrain shows steep slopes along the road track.



(a) (b) (c)

Figure 5. Results for local access street (a), country lane (b) and highway (c)

Figure *4a* and *4b* show a zoom in of figure *3c*, left and right borders have been omitted. Pixel values show support values using a thermal scale colour coding, highest support values are shown in red, lower ones in orange, then yellow and finally the worst ones coloured cyan. Figure *4a* shows computed support values according to equation (3). Figure *4b* shows the results after equation (4) has been applied. It can clearly be seen that segments that are of shorter length than their competitors gain lower support. This makes the algorithm always selecting those segments for which the maximum evidence has been found within the DSM data. Another approach would be to merge disjoint segments by hypothesizing a disruption within the underlying data. However, this would afford a suitable model demanding additional thresholds that describe position and shape of such holes.

Figure *5* shows results for different types of roads. Figure *5a* shows a cutout of a local access street with about 125 m length. The road is bordered by trees, which have not been filtered out from the DSM. At least one vehicle is located on the roads surface. The left centre and right top of the image shows parcels access ways. It can clearly be seen, that if there are some discontinuities available the approach produces – to some extent – sensible results. Road width derived from bordering lines is about 10 m. This indicates that the true shape of the road has not been found, as it has been expected to be near 5 m. Thus, the question arouses whether the vertices that have been inserted by the Douglas-Peucker algorithm often do rely on steep slopes caused by vegetation and not terrain surface. Left and right border given in blue do not appear as parallel lines, thus demanding a "parallel" constraint. Image *5b* is a cutout of a tarred country lane with a total length of 750 m. The cutout shows a segment of about 125 m. The road is two side bordered by a small ditch. Road width has been estimated to 3.5 m, borderlines appear to be parallel. This corresponds quite well to that value derived from orthophoto (4 m). However, final results have been computed using the full image given by spatial extent of the road centreline. This is admissible since capturing rules of road centrelines prescribe the creation of different objects in case of significant changes within road width. Nevertheless it seems more natural to limit processing of border detection to a certain part of the image. Hence, we would be enabled for the detection of changes within the road width that have not been considered so far. Figure *5c* shows a 125 m long cutout of a super highway (German: Autobahn). The road is right bordered by a noise-barrier wall. The outer left of the image shows the lanes belonging to the opposite driving direction. At least four vehicles are located on the road. While the right border has been well derived, the left one is obviously erroneous. Further inspection of the image shows two major drawbacks of the proposed algorithm. First we should allow for disruptions within the data that have been caused by vehicles. Second, border detection can only produce reliable results if we meet the conditions imposed by the Nyquist sampling theorem. Thus outline estimation should be restricted to those segments, which are well bordered on both sides, head and tail.

7. CONCLUSION AND OUTLOOK

Segmenting a DSM perpendicularly along a road centreline by iterative end-points fit provides reasonable output. This is used by an interpretation technique, which relies on support measures. Knowledge derived from a cartographic database makes the method preferring well affirmed and next to the centreline positioned segments. The outline is derived by robust aggregation. This is achieved by searching for the maximum consensus of a set of segments heads and tails, which fit best onto two straight lines, denoting the left an right border of a road. However, if the spatial extent of a model feature is near to the spatial resolution of one of the used data sets, interpretation becomes impossible. This is also the case if there are no discontinuities available. The support functions chosen for matching data against model features seem to be robust against gross errors within the data. Nevertheless an appropriate model has to be developed that is capable of dealing with vehicles, which are located next to or on the roads surface. Left and right borders are required to be parallel in many cases. Thus, a method deriving the roads outline should take care of this. Additionally, if there are data capture errors expected to be present in the map data the deflection of the roads centreline has to be taken into account. Hence threshold values have to be updated accordingly. While estimating the outline of a road either consecutive centrelines or fractional parts should be considered. This procedure should at least depend on the varying section width along the centrelines. Of course, the road network connectivity must be exploited, which is currently not the case since road segments are considered individually. Last but not least, prior information and results of the line simplification algorithm suffer a common stochastic model. This could be used for a more sophisticated interpretation and eliminate the need for some of the thresholds. The spacing of cross sections could be varied along the feature axis order to reflect changes along the roads. A quantitative analysis of these results would give a more precise description of the algorithms performance.

ACKNOWLEDGEMENTS

The laser scanner data by courtesy of TopScan GmbH, Steinfurt, Germany and Emschergenossenschaft, Essen, Germany. ATKIS-DLM: (c) Geobasisdaten: Landesvermess-ungsamt NRW, Bonn, Germany, 1116/2002.

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