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

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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.

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 high levels 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 modeled 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 an discussion follows. The paper concludes with future work and an outlook.

MOTIVATION

Laser scanner data based Digital Terrain Models (DTM) 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.

In mind of traffic information and road network related belongings, 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 drivers 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 the objects. This allows to automatically extract the exact the road geometry, as long as it is bordered by

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typical height changes. In the context of car navigation, this allows for a 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.

DATA SOURCES

Laser scanning Data

The data sets used in this paper were 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 containing ground points, the latter one dominated by top points of vegetation. Several methods have been developed to calculate the difference between DSM and Digital Terrain Model (DTM). 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 4 points per square meter. The accuracy in height is 0.01 up to 0.15 m *(Briese 2001, Wever 1999)*.

(a) *(b)*

Figure 1. (a) Orthophoto of test area, (b) cartographic map data draped onto digital surface model (DSM)

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. kilometers. The data has been regularized to a grid, the ground resolution is four points per square meter.

Figure *1* gives an overview of the test region. Fig. *1a* shows an panchromatic orthophoto which is only used for visual checks. Fig. *1b* shows the last echo DSM overlaid with labeled 2D lines derived from a cartographic database. Red colored lines denote road centerlines as present in the database. Darker color 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 (German: Autobahn) crosses the test region. Field tracks can be seen in the northern part of the rest region.

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. ATKIS DLM data is available in three different resolutions resulting in different scales. The finest scale being approximately 1:10.000 (BASE-DLM), medium scale 1:250.000 (DLM250), the coarsest being 1:1.000.000 (DLM1000). In this paper data from the BASE-DLM has been used.

Within a ATKIS DLM spatial entities are modeled by means of a object structured feature catalogue. It defines the objects semantics using attributes and relationships to other features. Features are categorized into different domains like vegetation, water, transportation or settlement.

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 every 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.

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 which are of interest here 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 ensure 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.

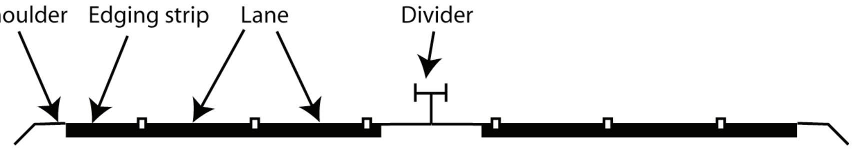


Figure 2. Cross section sketch

Besides from that additional 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 carriageway 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.

RELATED WORK

Basically, most techniques used for segmentation of laser scan data rely on two different concepts. One of them being based on the detection of discontinuities like salient points or edges. Classical approaches for finding discontinuities are point operators which try to find isolated points, corners, or points being part of a one-dimensional curve (*Haralick and Shapiro 1992*, *Canny 1986)*. Often, the extraction of linear structures is done in a second step by building contour chains from individual points. Alternatively, the discontinuity perpendicular to a linear structure can be defined in terms of the continuous areas to the left and right of the structure *(Brügelmann, 2000, Wild and Krzystek 1996)*, which in turn can be found using methods such as region growing *(Abo Akel et. al. 2003)*.

More reliable results can be obtained if zero, one and two dimensional primitives are extracted simultaneously. This process is called polymorphic segmentation *(Fuchs, 1998)*. Recently approaches which rely on prior information gain more importance *(Zhang et. al. 2001)*.

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 data features complies to the model *(Grimson 1990)*.

In this work the set of model features is given by a set of parameterized 2D segments denoting the roads surface. They are spread along the road perpendicularly. Each model feature is bound to prior information as available throughout the map database. The model feature segment position is derived from the road centerline. Additionally, the functional road class is used to select an appropriate cross section model proposed by road construction guidelines. Thus, it enables for further attributing the model segment by designated width, number of lanes and slope. All these data helps to improve interpretation results.

Processing along linear feature axis

Basically, 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 it helps to reduce the search space by restraining the process of segmentation and interpretation to those parts of the DSM which are covered by roads. Therefore all DSM input data is linear referenced along the centerline of a road. Second, this allows for a quite simple description of the underlying model which guides the interpretation process. Essentially, as will be shown later on, the interpretation technique depends on linear referenced data. Of course same results would be obtained without resampling the DSM along a roads centerline.

Hence the DSM denoted by figure *1b* is linear referenced along the road centerline as present in the database. Resampling is performed by linear interpolation. Finally, this leads to 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 width. This is obvious as different types of roads are based on different types of cross section prototypes. Practically, values range from 15 up to 100 m. Recalling that we are using linear referenced the DSM data we end up with a ordered list of vertices denoting the DSM surface for each particular cross section.

Segmentation by iterative end-points fit

Mapping our DSM data to model features considering to some 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)*. However, due to linear referencing, each section which traverses the DSM and perpendicular crosses a road is represented by a monotone increasing list of vertices regarding vertex position. This property should be exploited by a suitable segmentation technique.

One possible solution to this problem is given by applying a line simplification algorithm to each set of vertices. The measure of simplification is to be guided by external information. A well known line simplification algorithm is given by an iterative end-points fit technique used in image processing *(Duda and Hart 1973)*. It was independently discovered by Douglas and Peucker *(Douglas and Peucker 1973)* for use in a geographic information systems application and by Ramer *(Ramer 1972)* being used in an image processing context. We will refer to this as the Douglas-Peucker algorithm.

The algorithm performs by iteratively inserting vertices into an empty set that has been initialized by first and last vertex. Insertion of a candidate vertex is applicable if it shows maximum distance to the line denoted by the two enclosing vertices contained within the set. Insertion occurs if computed distance appears to be greater than a threshold value ε. In this paper the smoothness parameter ε is set to the noise of the DSM data. Computation can be done in $O(n \log n)$ time if P is planar where n denotes the number of vertices (*Hershberger and Snoeyink 1992)*. The algorithm ends up with a list of contiguous 2D segments that are smooth with respect to ε.

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 to the model feature defined per cross section and a check whether it satisfies a measure of compliance.

In order to decide whether one out of 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 best or worse. Appropriate thresholds limiting for a minimum of support can help to narrow down the search tree.

Consider the monotone set $S = \{s_1, \ldots, s_n\}$ 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 slopes values of parts of a section are limited to a certain range. Practically, those values range between ± 0.08 denoting the tangent of a segment. This criteria can also be expressed as a binary valued support function H_1:

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

Further on, consider the function H_2 denoting a measure of support for the minimal amount of gap between road centerline l and segments s_i endpoints. Computing support for the overlap of road centerline and segment centre makes no sense, since there may be solutions which might 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 front or back and the roads centerline. 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 position of the road centerline.

$$\Lambda = \begin{cases} 0 & |x| \geq 1 \\ 1 - |x| & |x| < 1 \end{cases} \tag{2}$$

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

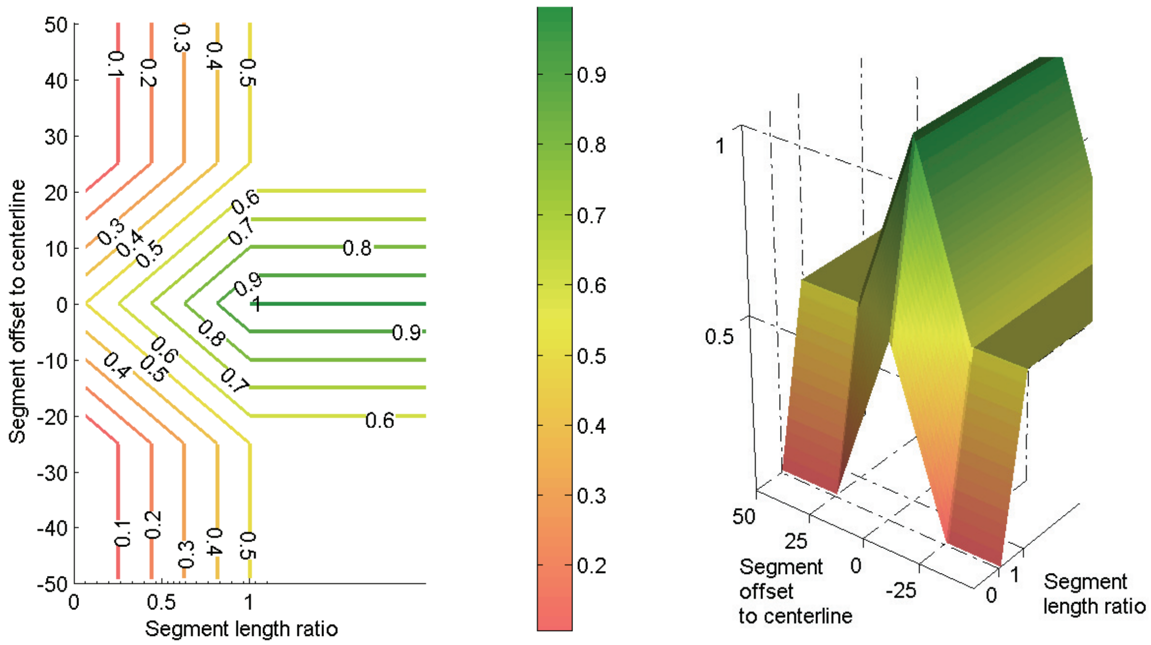
$$H_2(s_i) = \begin{cases} \Lambda(x) & |x| < \Delta_{\max} \\ 0 & |x| \geq \Delta_{\max} \end{cases} \tag{3}$$

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 chosen 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 roads 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's 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.

$$H_3(s_i) = \begin{cases} 1 & x \geq l \\ x & 0 \leq x < l \end{cases} \tag{4}$$

So far, we are able to rank the output of an iterative endpoints fit with respect to the support functions defined above. Data features next to the roads centerline are favoured over those ones being too much off. Erroneous data and not modeled 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 an submit it to further processing.

Figure 3 shows both a two dimensional contour plot and a 3D graphical depiction of support functions given by equations (3) and (4) using arbitrarily chosen values. Support values are added and normalized to *[0..1]*. The axes titled



(a) *(b)*

Figure 3. /a) 2D and (b) 3D plot of support functions given by eq. (3) and eq. (4)

"Segment length ratio" denote support values derived by equation (4). As this was built upon a ramp function, support cannot increase further for those segments whose length is greater than the threshold actually alleged. Hence its use is limited to those segments which are equal to or of shorter length than the given threshold value. The axes labeled *"Segment offset to centerline"* denote support derived by equation (3). In this case the maximum allowable offset has been set to 25 m, practically this threshold is derived from data noise. Obviously, maximum support is at zero offset, minimal support is assigned to those segments farther than *25 m*. It can clearly be seen that either function can provide same support, that is no weighting occurs. Global maximum support is achieved if both functions reach their maximum, meaning there is no offset at all and segment length is equal to predefined cross section width.

Deriving a roads outline

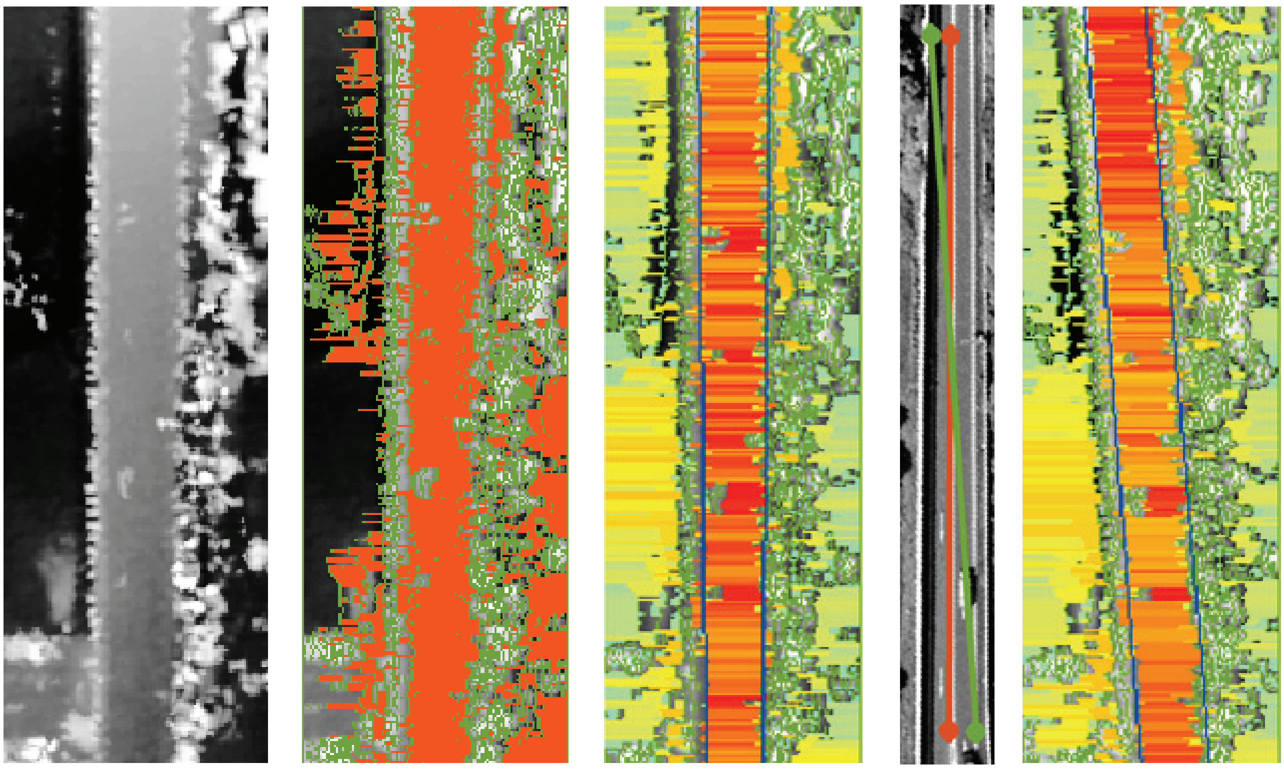
In the next step we add all those segments which show best support within a single cross section to an initially empty set. The upper limit of elements contained within this lot is bounded by the number of sections drawn from the linear referenced DSM. Assuming the ideal case, each front and back of any segment would denote the roads real world border and, in addition to this, two different segments would be enough to derive the outline of the road. Unfortunately this does not hold due to erroneous data, neglected phenomena and missing discontinuities. Thus, a model is needed which can cope with this concept.

Hence, we describe each border as a straight line and search for the best fit of a set of segments against this model. Heavily jagged left and right borders show up within results while just merging the set of segments derived above. As a consequence least square estimation probably will not perform well, since the number of outliers is large. This is due to missing discontinuities, the segments position distribution distorting support functions and a lack of cross section model properties that are incapable of dealing with events like cars, etc. Thus, we choose a robust estimation technique based on the random sample consensus principle first described by *Fischler & Bolles (1981)* in order to derive the borders.

For all best solutions two samples are drawn which front and back vertices uniquely define two straight lines, one for the left and one for the right border. The consensus is obtained by the set of segment fronts and backs 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 suitable segments. If the sample set is chosen



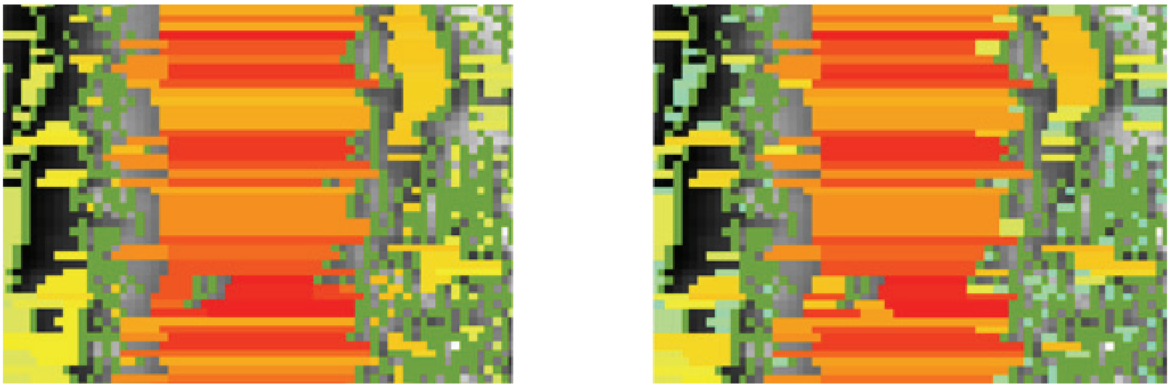
(a) *(b)* *(c)* *(d)* *(e)*

Figure 4. (a) DSM, (b) intermediate results, (c) final results, (d) original and erroneous centerlines draped onto orthophoto and (e) final results derived from erroneous centerline

large enough, this will lead to the probably best solution for straight line parameters. Thus, maximum consensus and therefore best parameters *a, b, c* are given by the maximum number of segments for which equation (5) holds.

RESULTS AND DISCUSSION

Figures *4,5* and *6* show resampled cut-outs of Figure *1b*. Resolution is set to 0.5 m. Cut-out figure *4a* represents the DSM of a highway exit. The image has been resampled along the roads centerline, darker color values denote lower terrain. The total difference in elevation is about 20 m, size is 150 x 50 m. Figure *4b* 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 threshold value of 0.4 m. Segments which comply to a slope not steeper than 0.08 radians are shown in orange. So far, the roads surface has been surprisingly well identified by just applying smoothness and slope constraints. However, the result still has some flaws denoted by holes contained within the results achieved up to here. These arose 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 *4c* 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 colored using a temperature scale. That is best ranked segments are shown in red, poorly evaluated ones appear by yellow or even worse cyan pixel values. Finally, left and right road borders are derived by applying the formerly mentioned RANSAC method to the full set of best segments so far detected. 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 reasonable results. In figure *4d* the original, red colored centerline of the road has been displaced by hand. The resulting polyline is shown in green. Centerline vertices have been shifted to the left and right border of the road as denoted by the orthophoto in order to show the effect of a data capture error. Threshold values are the same for figure *4c* and fig. *4e*. It can be seen that the erroneous outline has been derived quite well once again by comparing results given by figure *4e* to those from figure *4c*. Hence, to some extent the method is able to detect errors which are given through centerline deflection. However, one should keep in mind, that if such a displacement is too large the slope constraint will not hold anymore. This is because it is applied to segments which are located perpendicularly next to the centerline. If deflection becomes to large we would no longer be able to achieve meaningful results, especially when terrain shows steep slopes along the road track.



(a) *(b)*

Figure 5. (a) label image showing intermediate results by eq. (3),
(b) label image showing intermediate results by eq. (4)

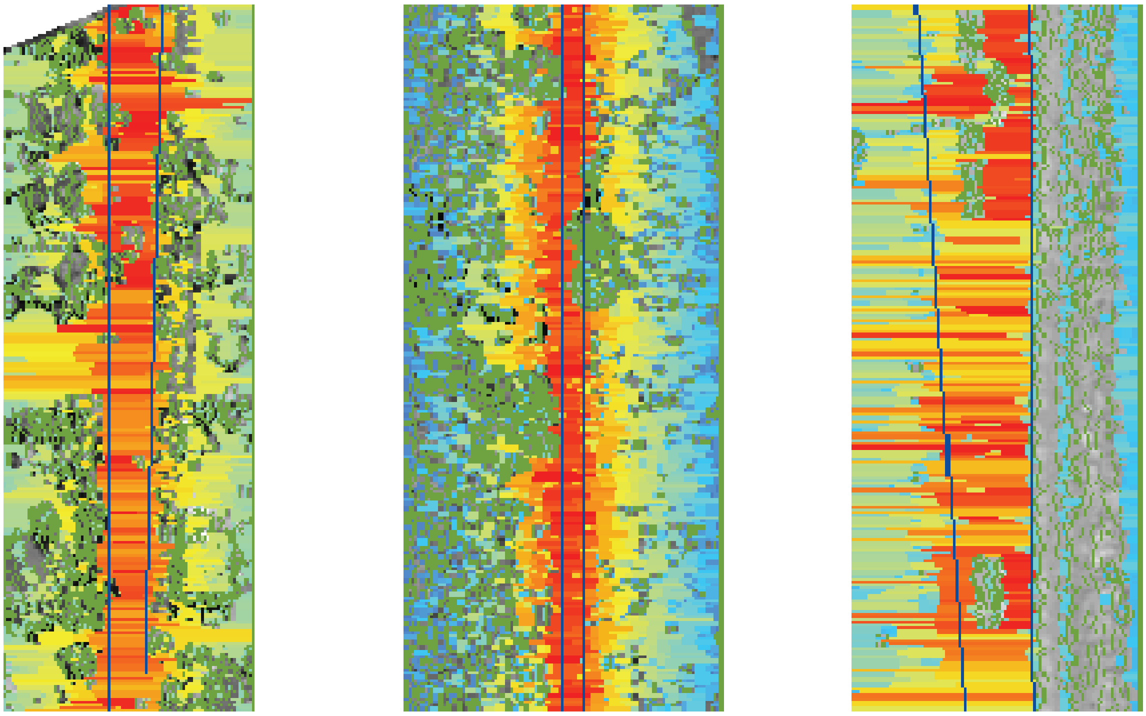
Figure *5a* and *5b* show a zoom in of figure *4c*, left and right borders have been omitted. Pixel values show support values using a thermal scale color coding, highest support values are shown in red, lower ones in orange, then yellow and finally the worst ones colored cyan. Figure *5a* shows computed support values according to equation (3). Figure *5b* shows computed support values according to equation (4). The major difference between these two images is given by lowered support for those segments which are of shorter length than their competitors. This makes the algorithm always selecting those segments for which the maximum evidence has been found within the DSM data. Another approach would be the merge of 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 *6* shows results for different types of roads. Figure *6a* shows a cut-out 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 center 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, it becomes clear that vertices which have been inserted by the Douglas-Peucker algorithm often do rely on steep slopes originating from vegetation and not terrain surface. Left and right border given in blue do not appear as parallel lines, thus demanding again a "parallel" constraint. Image *6b* is a cutout of a tarred country lane with a total length of 750 m. The cut-out 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, border lines 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 centerline. This is admissible since capturing rules of road centerlines 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 *6c* shows a 125 m long cut-out of a three-lanes carriageway (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 only if we meet the conditions imposed by the Nyquist sampling theorem. Accordingly outline estimation should be restricted to those segments which are well bordered on both sides, head and tail.

CONCLUSION AND OUTLOOK

Segmenting a DSM perpendicularly along a road centerline by iterative end-points fit enables for road surface detection. The set of resulting segments is used by an interpretation technique which relies on support measures derived from prior information. Support function design makes the method preferring well affirmed and next to the centerline positioned segments. The outline of a road is derived by robust aggregation. This is achieved by searching for the maximum consensus of a set of segments end points which fit best to two straight lines, denoting the left and 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



(a) *(b)* *(c)*

Figure 6: Results for different types of roads, (a) local access street, (b) country lane, (c) highway

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 or trees 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 centerline has to be taken into account. Hence threshold values have to be updated accordingly. While estimating the outline of a road either consecutive centerlines or fractional parts should be considered. This procedure should at least depend on the varying section width along the centerlines. 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.

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