ASSIGNING THE 3RD DIMENSION TO ROADS BY USE OF LASER SCANNING DATA

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ABSTRACT:

Most geographic data sets available today mainly provide two-dimensional geometric information about topographic objects in different aggregation levels. Three dimensional information is distributed separately by means of digital terrain models. In contrast, many applications presume that integrated data sets are available. The extraction of man-made objects from images and laser scanner data has been in the focus of image processing research in recent years. In this paper an approach is presented to identify road objects in laser scanner data sets. The information that is of interest is the outline of the road, its height and further tributary properties like longitudinal and transversal slope, width and curvature. In order to derive the width and further properties of roads, features and attributes of 2D data sets have to be evaluated against their contribution to the integration of height information into a common data model. Planning and construction facilities make use of standardised longitudinal and cross sections. Topographic data sets only contain the middle axis of roads. In this paper the information will be detected, analysed and measured by a model based approach, investigating the neighbourhood of two dimensional road elements in terms of cross sections. After the optimal position of the section is detected, the road parameters can be refined by an estimation procedure. It is subject to further investigations where and how to introduce cross sections into a common data model with respect to handling, storage and quality aspects.

1. INTRODUCTION

Today, most geographic data sets available mainly provide two-dimensional geometric information about topographic objects. Popular examples are the European geographic data File (GDF) data set used by intelligent transportation systems for vehicle navigation or the digital topographic data set of the German national mapping agencies ATKIS (Authoritative Topographic Cartographic Information System). The third dimension is typically stored separately in terms of a digital terrain model (DTM) describing landscape's surface by regular, irregular or hybrid grids.

Recently, higher sophisticated solutions like digital city models became available to the market. They not only describe the terrain surface as a DTM but also contain additional information about buildings and roof structures. Such options are needed by carriers of mobile phone service networks like GSM allowing for more precise network cell planning. A high quality data source for the extraction of such information are high resolution laser scanner data. Also in car navigations systems there is a growing awareness for the necessities of enriched data sets in terms of 3D object descriptions including the detailed shape of the features (eg. roads, buildings, bridges).

Many applications like those mentioned in the previous section before presume that integrated data sets are available. In this paper an approach is presented to identify road objects in laser scanner data sets. The aim is to extract on the one hand the detailed height information and derived measures like slope, and on the other hand the exact road geometry. The approach relies on the integration of prior information from GIS, and has to take the different quality levels of the integrated information into account. Examples for the

extraction of the road geometry for two different road types will be given.

2. MOTIVATION

The integration of planimetric features with height information to is a demanding task, offering potential for the development of new techniques with respect to the third dimension. In comparison with conventional measurement techniques like tachymetry and photogrammetry, laser scanning has become an effective alternative for capturing digital elevation models (Ackermann, 1999; Baltsavias, 1999a). Because of the inherent measurement technique, laser scanner data based DTMs can provide dense height information. Although that makes it difficult for processing and demands new methods for data reduction, it offers new opportunities to disciplines being in need of high resolution data sets.

With respect to traffic systems, the third dimension can be applied to facilities related to transportation like roads. Such enriched topographic objects can help to improve the process of planning, construction, operation and use of roadway networks by several aspects. Applying height information to traffic related objects gives us the opportunity to record additional object attributes which are relevant for roads. Besides height, longitudinal and transversal slope form new attributes enabling for more precise description of the roadway network. Higher sophisticated attributes like the exposition or curvature of objects can be derived as well.

Applications could lie in the analysis of visibility ranges in the landscape. That information then to be used as hints or warnings by driver information systems for an increased safety. Changes in road curvature and gradient might be used to generate driver information for the readjustment of

vehicles velocity. Automobiles carrying heavy or dangerous load can be automatically decelerated in front of hazardous gradients.

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 typical height changes. In the context of car navigation, this allows for a lane-precise vehicle positioning and more precise route guidance.

Additional possibilities lie in the more precise prediction of emissions rates of harmful substances and noise depending on varying road gradients. Last but not least the exposition of lanes might be an indicator for glazed frost sections during cold seasons. This information can either be used as driver information or as an advice for gritters to spread salt on the affected roads.

3. PREVOUS WORK

The extraction of man-made objects from images and laser scanner data has been in the focus of image processing research in recent years (Grün, 1995). The interpretation of laser scanner data often relies on geometric properties that is analyzed and manipulated by use of filtering techniques.

Image based filter techniques closely related to mathematical grayscale morphology have been used by Vosselman (2000) as well as Kilian et al. (1996) and Lindenberger (1993). Results on road tracing by profile matching are given in Vosselman et al. (1995). Brügelmann (2000) and Wild et al. (1996) make use of slopes and even further derivatives. Procedures with respect to the data stochastics have been developed by Kraus & Pfeifer (1998) and Lohmann et al. (2000). Methods for separating man- made and natural objects from the terrain have been developed by Weidner (1997) and Pfeiffer et al. (2001)
Besides that several approaches make use of additional information in terms of GIS-information like Brenner & Haala (2000), Vosselman (2001) and Simonse (2000), or image data (Walter 1998, Schiewe 2000). Earlier efforts to extract buildings from laser data can be found in the researches of Haala et al. (1997a, 1997b).

4. SUGGESTED APPROACH

Existing geographic data sets provide detailed planimetric information on topographic features. The idea is to use both sources - 2D and 3D dataset - to describe roads more precise. The information that is of interest is the outline of the road, its height and further tributary properties like longitudinal and transversal slope, width and curvature. The information will be detected, analysed and measured by a model based approach, investigating the neighbourhood of two dimensional road elements in terms of cross sections.

4.1 Data Sources

4.1.1 3D Data Sources Three dimensional spatial data often is 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 (Baltsavias 1999b). 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. Several methods have been developed to calculate the difference between DSM and DTM. Many of these approaches use filtering techniques. Both DSM and DTM data sets are available by commercial companies.

The planimetric accuracy of the laser points is approximately 0.5 m (Balsavias, 1999c; 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 et al 2001, Wever & Lindenberger, 1999).

4.1.2 2D-data sources. There are different data sets available that contain information about roads. First of all, there are cadastral and topographic data, but also data sets used for road operation and maintenance and car navigation.

The most accurate information is available at the road operation and maintenance divisions. They provide precise information about the geometry of road objects and also the road furniture like traffic signs, street markings, etc. However, this information is typically only available in analogue form.

Another potential data source is the cadastral data set in Germany (ALK), that also contains road objects with high geometric accuracy (approximately 0.05 up to 1 m). Unfortunately, only the legal boundaries of the roads are given, not the real borders. Furthermore, this data set is not yet available in digital form for the whole country.

Two data sets that are available in digital form for the whole country are the digital topographic data set ATKIS Digital Landscape Model (ATKIS-DLM) (scale approximately 1:25.000) and Geographic Data File (GDF) with a similar resolution. In both data sets, roads are modelled as linear features, typically by their centre line. The accuracy of GDF and ATKIS is similar and lies in the order of 3 to10 m..

4.2 Analysing Feature Attributes

In order to derive the width and other properties of road features, the attributes of 2D data sets have to be evaluated against their contribution to the integration of height information into a common data model. As described above, in the data sets available nationwide, road objects are modelled as linear features. Both ATKIS-DLM and GDF provide different road categories on which conclusions related to the current feature extent can be drawn. Some of them provide this information even in an explicit way by storing its width as an attribute value. Those features and attributes have to be identified, which are suitable for storing the newly derived information like slope and curvature.

ATKIS-DLM, for instance, provides the following attribute information being suitable for describing and deriving the features spatial extent:

- Width of traffic route, which represents the features total width including side strips, classified in 3 m intervals,
- width of carriage way, referring to the features width including lanes and side strips, measured in decimeters (accuracy approx. 0.5 m), which depends on the feature type,
- number of lanes, denoting the number of strips per direction and
- category of traffic route, distinguishing the features administrative, maintenance and/or operation responsibility or construction principles according to design standards.

Three dimensional information is captured and distributed separately from the ATKIS-DLM by means of a digital terrain model. By its nature, the ATKIS Digital Terrain Model (ATKIS-DTM) usually describes the landscapes surface using regular grids. The resolution is about 12.5 meters including additional morphological information like breaklines. The vertical accuracy is about 0.5 m.

Geographic Data File provide explicit information on roads including three dimensional properties, too, in detail (ISO, 1996):

- Functional Road Class, which denotes a classification based on the importance of the role that the road plays in the connectivity of the total road network and
- the maximum number of lanes, describing the total number of lanes associated with one particular driving direction.
- The width of a road,
- the road gradient along the features axis,
- the road inclination perpendicular to the feature axis and
- the structures for storing three dimensional coordinates.

Although the data model itself provides several facilities for storing and retrieving three dimensional feature attributes, nowadays commercial products available to the European market do not provide such information (Marwitz, 2001). In case of feature width is not available, it has to be derived from more general information describing the objects function, then assuming a certain width depending on the objects functional road class.

4.3 Creating Cross Sections

One essential property of any operational road is its continuous surface along and perpendicular to its axis (Vosselman, 1995). Besides that, vehicles require this surface to be typically plane up to a certain degree. Additionally the surface probably will be curved or at least inclined to get the water running off in case of rainfalls. Planning and construction facilities make use of standardised longitudinal and cross sections for the encoding of these properties. The approach in this paper uses a very similar technique for the description of the three dimensional road

geometry because of two reasons. Firstly, sections are an efficient tool to describe the road geometry because of their two dimensional nature. Therefore, their properties can be described by use of existing geometric primitives supported by common GIS-tools that usually are capable of 2D analysis. Secondly, cross sections play a significant role during the merging process of two and three dimensional data sets, as will be shown later on. The length of the sections is obtained from the length of road elements and by feature width, respectively.

4.4 Merging 2D with 3D features

As 2D and 3D data are recorded separately with different measurement techniques and also different accuracies the objects typically do not match. A mere overlay of 2D and 3D data set will result in discrepancies that have to be solved by use of buffering and filtering techniques.

One common approach of merging height information and two dimensional data sets is by simply draping the planimetric geometry onto the DTM. The height at any position of features is assigned by use of suitable interpolation methods. The most naïve solution is given by linear interpolation between existing vertices. Higher sophisticated methods are based on surface approximation by use of spline functions (Fritsch, 1990).

In this approach height information has been derived by using the interpolation method of a common GIS-tool (here ArcGIS from ESRI) assigning heights to vertices depending on the DEMs resolution.

4.5 Cross Section Model

We are starting with an overlay of the 2D-geometry of ATKIS and the 3D surface data. At discrete distances, cross sections are established. The width of the cross sections is derived from the road class attribute, as well as from the width attribute given in the data set.

In addition to this, the accuracy of the centre line of the road is assumed to be 3-10 m, the positional accuracy of the laser scanner data is given by 0.5-1 m. This leads to a initial length of the cross section of up to 50 m.

The distance between successive cross sections depends on the expectance of how exact the shape of the road can be extracted: in dense city areas, there will be "obstacles" at the border of the road like parking cars or trees, which typically will not be the case on highways. In both cases, however, it can be expected that cars are on the road, that lead to peaks in the interpolated 3D cross section.

Often, slopes or ditches are located parallel to linear features like traffic routes. They form discontinuities of the landscape surface. This assumption can help to recognize the roads axis position by comparison with typical cross sections as given in figure 1. Based on this model template we are able to create more detailed road model and to perform exact merging of roads and DEMs.
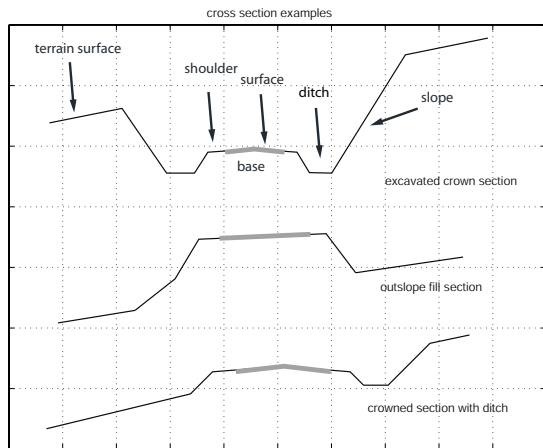
Figure 1. Cross section examples

A model of the expected cross section will be set up, that depends on the prior information. A typical highway cross section is given in Figure 2a, whereas a cross section in a city will look like in Figure 2b. The two peaks that frame the road section can be interpreted as vegetation, which is growing on the road shoulder (The vertical green line shows the position of the road axis and the blue dotted red line represents the surface heights. Note the different scale for the two axes.)
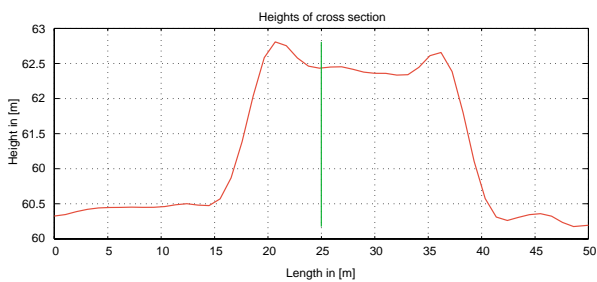

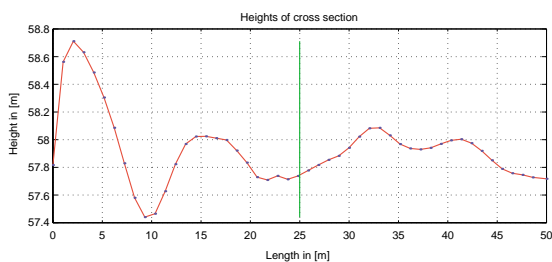Figure 2a. Typical cross section of a highway

Figure 2b. Typical Cross section in a city

Surface discontinuities can be interpreted as local minima or maxima of surface curvature. Besides that, curvature values usually will reach their maximum absolute value perpendicular to the linear features axis. Relying on that effect several basic types of geometries can be identified for use in sections (cf. fig. 1). They indicate surface discontinuities along transportation related linear features like roads. Within three dimensional data sets the appearance of this geometric shape may differ slightly as it can appear distorted and mirrored.

In the most simple case the morphology of a road cross section can be described as a straight line. Using the morphology of cross sections as a model it becomes feasible to achieve exact matching between two dimensional features like roads and three dimensional data sets. The assumption of a planar surface – which is sensible in order to make sure that vehicles can pass over – leads to rather constant differential height changes along the section.

These differential height changes can also be substituted by computing the values of the first derivative describing the slope along the section. Normally these values will vary within the sections length around a certain value characterising the transversal road inclination. A graphical example is given in figure 4.

Local maxima and minima of surface curvature are also indicators for the existence of a possible topographical breakline. Therefore the analysis of several successively arranged cross sections along the feature can also be used for breakline detection related to slopes or ditches.
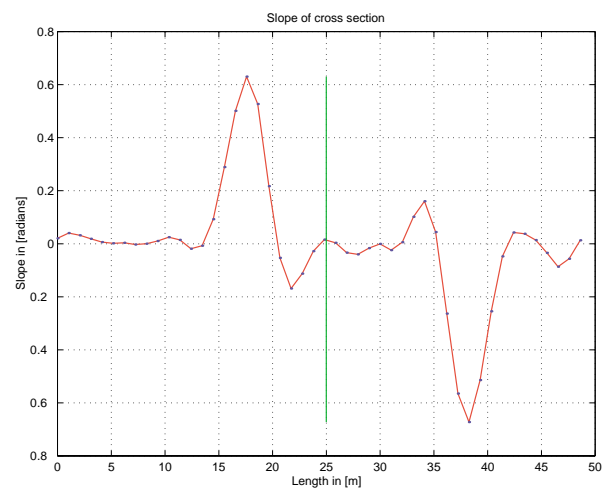

Figure 4. Slope of cross section of a major road

By computing the second derivative of the given heights one gets curvature along the cross section. As already mentioned before local minima and maxima of curvature indicate surface discontinuities while the value itself helps to figure out if it is a concave or convex curvature from above. The aim is now to search for these extreme values within the computed curvature (cf. fig 5). An exact road location and measurement is possible by matching the extracted profile with one of the given road section models.

Given approximate values for the road width, as well as the assumption of a constant inclination and a low curvature of road surfaces along their axes gives us the opportunity to estimate an optimal position for the centre of the road, its axis.
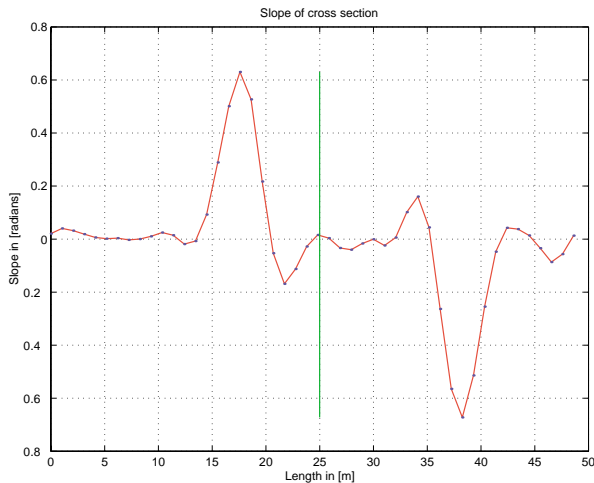
Figure 5: Curvature of a major road

After the extraction of zero crossings of curvature – indicating zero curvature – their position along the axis of the cross section has to be analysed and intervals bigger than the corresponding feature width and accuracy have to be built. Inlying local extreme values of these intervals denote the beginning of the road surface. If any one of the road section models is applicable, the distance between the extreme values should be in the range of the features width. Even if there is only one extreme value or zero crossing to be found, its neighbourhood along the section should distinguish itself by reasonable low inclination and curvature values in the range of the features width. The search ranges applied in this matching procedure take the accuracy of the original data into account. Only if there is no significant extreme value or zero crossing available, the original position of the features axis has to be maintained and the model cannot be applied. In this case the road feature cannot be improved with the given 3D data.

4.6 Estimation of Optimal Cross Section and Assignment of Attributes

After the optimal position of the section is detected, the road parameters can be refined by an estimation procedure. On the one hand, the exact width of the road can be determined. Furthermore, the shape of the section can be refined by estimating an optimally fitting curve – either a straight line, or a parabola opened downwards. Also, optimal position and heights for 2D linear features can be obtained by interpolation at any position between given heights. In this way sections can be built in the direction of and perpendicular to the features axis.

Within the ATKIS-DLM data set changes in road feature width only can occur after 500m as predefined by capturing rules. Therefore, it makes sense to refine this attribute, too. Comparing the distance between the zero crossings of slope to the initial feature width, updated values can be obtained. The differences between estimation and original values are in the range of two up to three meters. Assuming only smooth changes in the geometry of the road the estimated values of consecutive sections is expected to be similar. Thus the integration of results from neighbouring sections will lead to a more robust and reliable result.

4.7 Data Model

As a result of this integration of 2D and 3D-data, it is expected that the accuracy of the 2D-planimetry will be enhanced. Furthermore, additional information will be available, that was – up to now – not available or foreseen in the given data models. An open question therefore is how the refined, more accurate, road information on the one hand, and the enriched data on the other hand can be integrated into the given 2D-data sets.

None of the investigated data models, neither ATKIS nor Geographic Data File are able to completely integrate the derived information. Besides that only few attributes seem to be suitable for partly integration of height information to makes users benefit from the results.

It is subject to further investigations where and how to introduce cross sections into a common data model with respect to handling, storage and quality aspects. One simple approach is to store evenly spaced cross sections and one longitudinal section as poly lines together with the features identity into a common data model. Another possibility is given by storing the information using segmented attributes (Marwitz, 2001; ISO, 1996).

5. FUTURE WORK

It is obvious that by varying the spacing between the sections similar results for the estimation of section models will be achieved. Further investigations will be undertaken in the analysis of this effect for aims of data reduction with respect to quality and topographic morphology.

The concepts presented in this paper will be implemented and thoroughly tested with respect to the reliability and accuracy of the derived information. In addition to this, the results will be classified about their function within the roadway network.

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