

INTEGRATION OF STREET NETWORKS AND LIDAR FOR MODELLING AND VISUALISATION OF TERRAIN DATA

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ABSTRACT

The generation of realistic 3D landscape visualisations is already feasible, if data from airborne laser scanning, which allows for a dense and accurate acquisition of the terrain surface, is combined with additional textures from aerial images. While this is true for open areas, the presentation of more complex areas like urban landscapes requires additional processing of this original data. As an example, during the visualisation of buildings from close virtual viewpoints, even small geometric errors which can result from a non-planar triangulation of a building façade may heavily disturb the degree of realism. Another problem is street surfaces, where the laser-based point measurement is disturbed by objects like vehicles, traffic signs or trees. These erroneous points have to be eliminated by suitable filter algorithms, otherwise they will result in disturbing height discontinuities in the street surface to be visualised. Within the approach presented in the paper, the required filter process is supported by the integration of existing street networks. By these means a smoothed 3D shape of the longitudinal axis of the streets can be estimated and expanded to the complete street region. In addition to demonstrating the DEM filter process in street regions, the paper discusses its application to continuous level of detail approaches which are commonly used in the real-time visualisation of such terrain models.

1. INTRODUCTION

Over the past years, applications based on the real-time visualisation of 3D urban landscapes have spread considerably. Interactive virtual presentations of urban environments are used in fields like tourism, architecture, city planning and marketing, or car navigation and location based services. Frequently, the required data base is collected from airborne LIDAR. These systems provide information on the geometry of objects by densely distributed and accurate 3D points. If they are combined with aerial cameras, object colour is additionally available. In principle, the resulting surface description can be directly used for visualisation purposes. One problem is the huge amount of data; still this can be reduced efficiently by approaches based on the generation of multiple levels of details. (Heckbert and Garland, 1997) give a comprehensive overview on simplification algorithms that are applicable for such visualisation purposes.

For vertical surfaces, the limited spatial resolution of the LIDAR points from airborne data collection, however, will frequently result in geometric errors due to interpolation effects. LIDAR points relating to building objects need therefore be eliminated and replaced by 3D

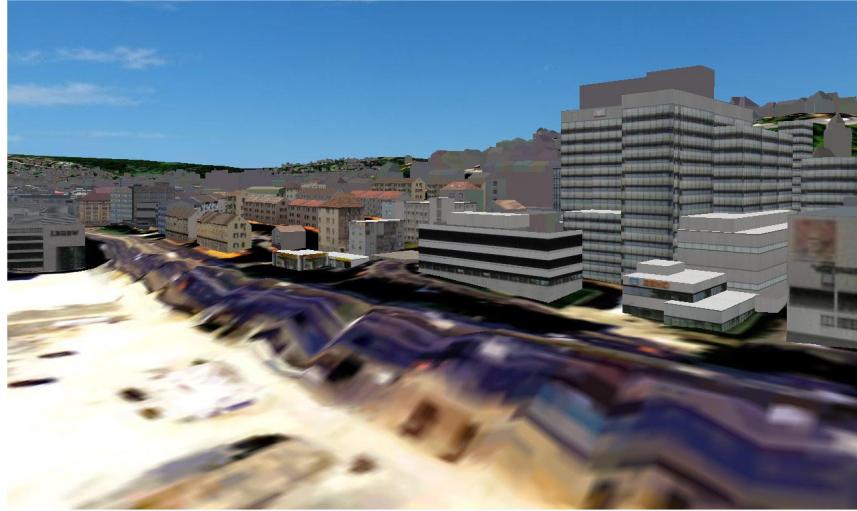


Figure 1. 3D landscape model of Stuttgart rendered in a real-time visualisation environment. The street in the front appears tilted and wavy because of the low resolution of the sub-sampled LIDAR data.

building models. In addition, the processing of the airborne LIDAR data is also required to eliminate other surface points, which do not correspond to the terrain surface.

Frequently, the terrain surface is occluded by trees or other vegetation. Especially in urban areas small objects like pedestrians, vehicles or traffic signs additionally result in LIDAR points, which do not represent the required terrain surface. Thus, a number of filter algorithms have been developed, which are aiming on the extraction of the so-called bare-Earth surface from the originally measured LIDAR points. An overview on recent approaches as a discussion of the performance of the available filters is given in (Sithole and Vosselman, 2004). In summary, despite of the reported considerable success of these algorithms, an absolutely error free classification of these point clouds is not feasible, especially for difficult terrain like steep slopes and discontinuities. This mainly results from the complexity of automatic data interpretation, the sometimes low number of bare-Earth points and potential errors during point measurement.

Taking the aforementioned data processing, (Kada et al., 2003) show that literally a complete city can be interactively displayed in 3D on today's consumer PC systems (see Figure 1). In order to improve rendering performance, speed-up techniques like continuous level of detail are used for the terrain model whereas image based rendering techniques and generalisation is applied for the 3D building models. Especially for terrain visualisation, a multitude of algorithms are available based on the triangle bintree (Lindstrom et al., 1996), quad-tree structured triangulation (Roettger et al., 1998) or the progressive meshes (Hoppe 1998). All these algorithms have in common that their underlying data structure is a sub-sampled, regular grid of height values that are triangulated for rendering. Unfortunately, this simplification will destroy the features of important objects. For example, streets are unlikely to maintain their horizontal position and become tilted and wavy (see Figure 1).

One option to improve this simplification is the use of additional information. The work presented in this paper is especially focussed on the filtering of LIDAR data in street regions. Within these regions LIDAR points measured on vehicles or traffic signs will lead to height discontinuities and bumps in the interpolated surface, which will considerably disturb the visual impression. For this object type, *a priori* information on street networks is frequently available and thus can be integrated to data processing (Kreimeike, 2004). The enhancement of street objects is another topic addressed in order to improve the visual perceptibility of street data.

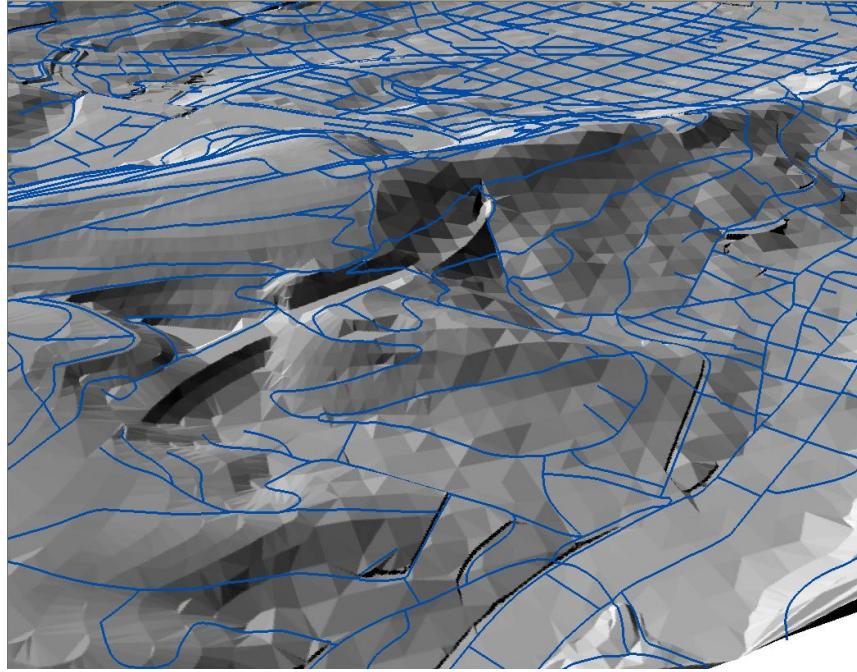


Figure 2. DTM overlaid with the ATKIS street network.

2. DATA SOURCES

2.1 ATKIS

Especially the wide spread of car navigation applications has lead to a growing availability of road data in different formats. One example is the Geographic Data File (GDF), which is a European standard that is used to describe road networks and related data especially for car navigation purposes. Similar information is available from the so-called ATKIS-DLM. ATKIS (Authoritative Topographic Cartographic Information System) has been developed by survey offices of the federal states of Germany (AdV, 1998). It is structured into seven functional classes like e.g. settlement, vegetation and traffic. Each functional class is again subdivided into object groups. Concerning traffic, its object groups are road traffic, railway traffic, air traffic, etc. An object group includes several object types. Object types specify the geometrical representation and the attributes of real world objects. In case of road traffic, available object types are for example roads, squares or footpaths. Both formats are acquired in an approximate scale of 1:25.000 with a positional accuracy below three meters. The street regions are defined by street axis and width as attributes.

2.2 DTM and LIDAR

The Digital Terrain Model (DTM) used in our research was already available from terrestrial and photogrammetric measurement. With a ground resolution of approximately 10m the DTM is rather coarse with the exception of some isolated spots that have been manually captured at a higher resolution. As the resolution is generally good enough for a real-time visualisation of large-scale landscapes, the streets are not visible in the geometry itself. If an aerial or satellite image is superposed, the roads look tilted especially around hills. Figure 2 shows the DTM with overlaid ATKIS street network data. The LIDAR data set is from the state of Baden-Württemberg and is pre-processed with a morphological operator as described in (Schleyer, 2001). Small objects like buildings and trees were eliminated approximately. The point distance of the data is around 1.5m.

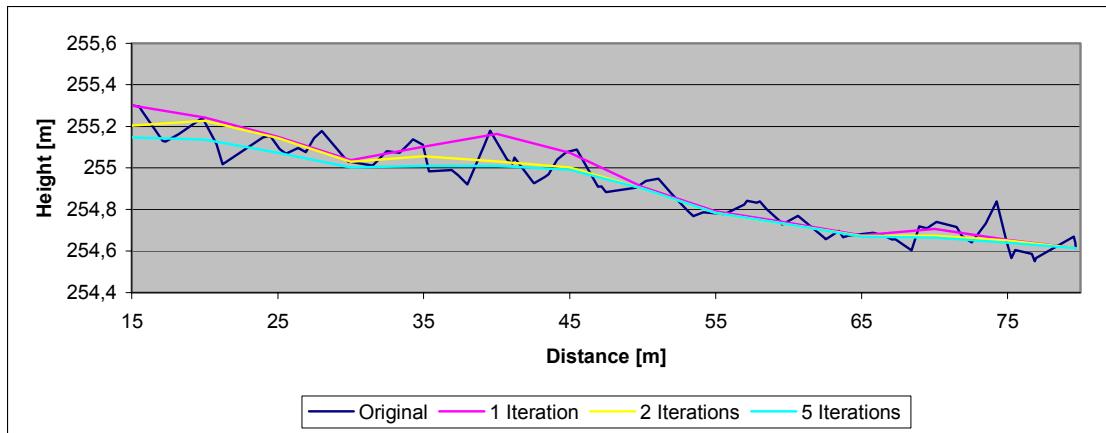


Figure 3. Original and filtered longitudinal street axis.

3. FILTERING OF STREETS

The street data found in ATKIS is initially a 2D network of longitudinal street axes. By combining these lineal objects with the LIDAR height values, the result is a 3D polyline. Depending on the resolution of the LIDAR data, a large number of line segments are created in the process. In order to reduce the number of line points and at the same time smooth the height profile, the polyline is filtered by a line estimation approach which bears resemblance to the algorithm of (Briese and Pfeifer, 2001). The assumption is an unsymmetrical error distribution, meaning that points that lie above an approximated line are presumed to be erroneous due to points measured on cars or other obstacles. These points are given a small weight in an iterative estimation process.

Our algorithm works by creating a new polyline for each street with small line segments to preserve the original street characteristics. Whereas the horizontal positions are taken from the given polyline, the height values are newly computed. For this purpose, the heights of all line points within a given horizontal distance are taken into a least squares adjustment to approximate a straight line. The functional model of the line is a piecewise approximation by a simple linear polynomial of the form

$$h_i = al_i + b$$

where a and b are the unknown line parameters, l_i the distance between consecutive line points and h_i the observed height values. Initially, the observations are equally weighed, but the impact of points that lie above the resulting line is then lowered for the next iteration. In this way, the recomputed line moves towards the lower points. The iteration stops when the line does not change significantly. The height of the point can be computed so that it lies on the resulting straight line. See Figure 3 for an example where a street segment is filtered with a maximum of 5 iterations.

The next step is the broadening of the streets from the longitudinal axes to the actual street width, which is an attribute that is stored in the ATKIS dataset. For this purpose, both roadsides are created by computing new points that are half the street width from the middle axes. Before these points are inserted into the DTM, the points that lie in the same area are identified by a buffer operation and subsequently removed. Another application is the replacement of street points in the LIDAR data set with the smoothed street regions in order to filter the roughness of the data points.

4. GENERALISATION

The process of generalisation is to simplify the three-dimensional information, but at the same time emphasize important objects in order to guarantee their perceptibility. Depending on the application, buildings and the street network are usually most significant in the context of 3D city models. In real-time visualisation of 3D urban landscapes, simplification is an important technique to speed up the rendering process. This comes from the fact that even modern 3D hardware is still not able to render highly dense data sets like laser scanning data in full resolution for large areas. Rather, the data is sub-sampled to a lower resolution and rendered in a continuous level of detail approach. Street regions can easily disappear in the process. In order to improve the visual appearance, the street objects are enhanced in our approach by using an oversized street width in the filtering process. The filtered data is then be integrated either in the DTM or back into the original LIDAR data set.

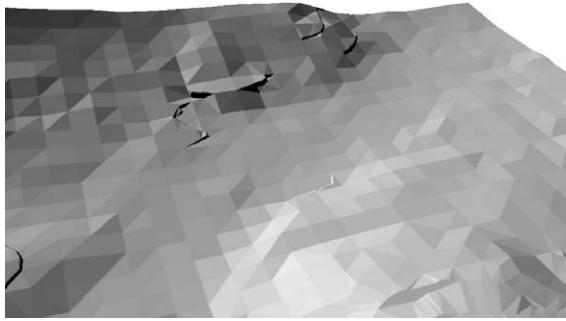


Figure 4a. Original DTM of Stuttgart.

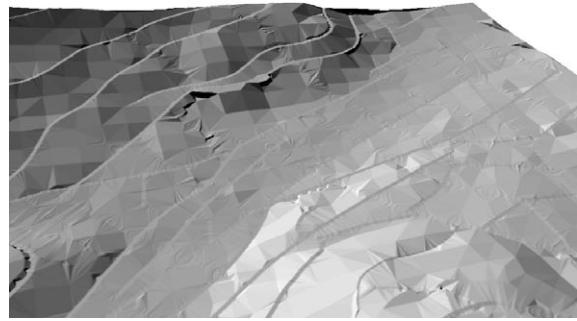


Figure 4b. DTM with integrated, filtered street network.

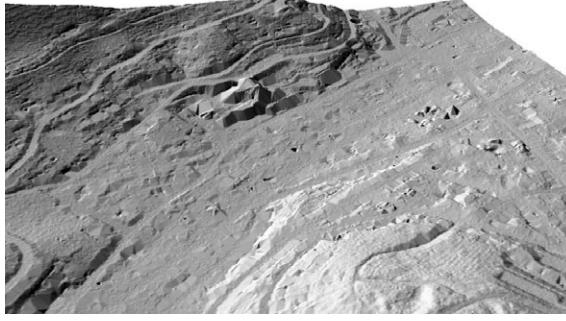


Figure 4c. LIDAR data of Stuttgart.

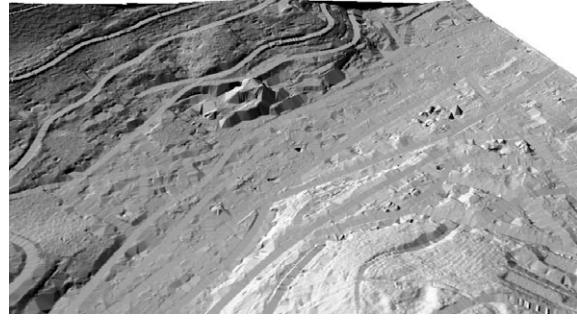


Figure 4d. LIDAR with filtered streets and enhanced street width.

5. CONCLUSION AND FUTURE WORK

This article described the concept of a filter algorithm for smoothing airborne laser scanning point clouds by using additional data sources like street network data that is commonly found in geographic information systems like ATKIS. It has been shown that streets that have been filtered by an iterative least-squares adjustment process appear less bumpy. Through enhancement of the street width, the perceptibility of streets can be improved for simplified or generalized terrain models (see Figure 4).

The work presented in this article is still ongoing. Even though the smoothing of streets and roads improved the visual impression and the enhancement of the street width results in a bet-

ter perceptibility, the resulting DTM or LIDAR data is not well suited to continuous level of detail approaches. These speed-up techniques rely on regular height grids as the data basis which is then rendered as triangles. So our future work is to apply the smoothed middle axes of the streets directly to such a triangular data structure. Also, new displacement operators are to be investigated to counteract deformation problems that may occur.

6. ACKNOWLEDGEMENTS

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