Dense DTM Generalization Aided by Roads Extracted from LiDAR Data

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ABSTRACT:

The paper concerns the generalization of DTM extracted from LiDAR data. The essence of generalization is reducing details while enhancing important features at the same time; so for the purpose of terrain surface visualization special attention has to be given to the enhancement and generalization of topographic objects like dams, roads etc. The focus of this work is laid on the extraction of road objects and their contribution into the enhancement of the generalized terrain model. An algorithm for the extraction of roads is developed and is followed by a generalization algorithm that weights together road networks and filtered LiDAR point clouds. Following the presentation of the algorithm results for this approach are shown and evaluated.

1. INTRODUCTION

Reducing the processing time of mass amount of data to an acceptable degree requires simplification or approximation of the original information. With Light Detection and Ranging (LiDAR) data such simplification refers to the surface that is reconstructed by the laser points. As advances in technology give rise to further growing volumes of data sets, automatic simplification techniques for highly detailed surface models are of considerable interest. Over the past years, several effective techniques have been developed, providing powerful tools for tailoring large datasets to the needs of individual applications and for producing more economical surface models (Garland, 1999). The often cited survey from Cignoni et al. (1998) compares different mesh simplification algorithms and gives a good overview on existing methods. Heckbert & Garland (1997) also present a comprehensive summary on polygonal surface simplification, in which they attempt to categorize previously described algorithms. Luebke (2001) describes and evaluates the most important simplification algorithms from a developer standpoint. Despite availability of several surface simplification algorithms, over the simplification process single objects within the surface model might become unclear or edges will get blurred, unless such phenomena are accounted for. Consequently, appropriate methods of generalization must be applied to guarantee the perceptibility of significant object types.

Generalization is one of the major tasks in cartography (Weibel, 1989) considered also as a key component of the graphical design (Hake et al., 2002). With the reduction of scale, objects represented to scale are shifted towards each other. This results in a declining legibility of individual objects. For this reason, minimum object sizes are of great importance in the context of thresholds for recognition. Furthermore, there are several regulations that determine thresholds for minimum widths or distances between objects (Hake et al., 2002). In digital cartography, the type of representation is not restricted to the output of printed maps. Furthermore, visualization via computer monitors has to be taken into consideration. In comparison to printed maps, the electronic visualization is limited by the size of the usable area on screen as well as the smaller resolution (Brunner, 2001). The interaction of input and output media has to be taken into account with regards to the resolution and the graphical minimum size has to be determined accordingly.

In this paper we propose an algorithm for generalization of DTM extracted from LiDAR data. The high quality DTM sets generated from laser altimetry bring about a massive amount of data that is hardly manageable or accessible. Particularly the efficient graphic representation of this data in real time appears to be difficult. To reduce the three dimensional information and make it manageable, methods of generalization and simplification are needed. During the generalization process, important objects within the DTM have to be emphasized, to guarantee their perceptibility. The objects to be emphasized differ according to the intention of the generalization. For the purpose of terrain surface visualization for instance, special attention has to be given to the enhancement and generalization of topographic objects like dams or roads while changing scale. This work is focused on the enhancement of road objects. The roads in the DTM are enhanced by widening them to either side of the middle axis. As the collected raw data are merely represented by clouds of 3D points inexplicitly describing the surface, a method to extract the road network has to be deployed. Changing the height values within the broadened street brings about discontinuities in the adjacent regions. Nonetheless, the objective of the generalization process is to maintain the fundamental geometric proportions in the non-road areas and to change the overall appearance of the DTM as small as possible. For this reason, displacement operations have to be employed. The chosen method uses an affine transformation based on the triangulation of the interspaces in between the enhanced street axes. Following the description of the road extraction algorithm and the subsequent generalization process results for this approach are presented and discussed.

2. DTM GENERALIZATION

2.1 Extraction of the Road Network

For the automatic detection and extraction of the roads within the raw data, a region growing segmentation on the basis of normal directions and height difference is used. The resulting segments undergo a classification with the extracted roads as an outcome. The road extraction process is composed of a segmentation of the data and then a classification of the extracted segments into road and non-road segments. And finally the centerlines of the roads network extracted by morphological operations.

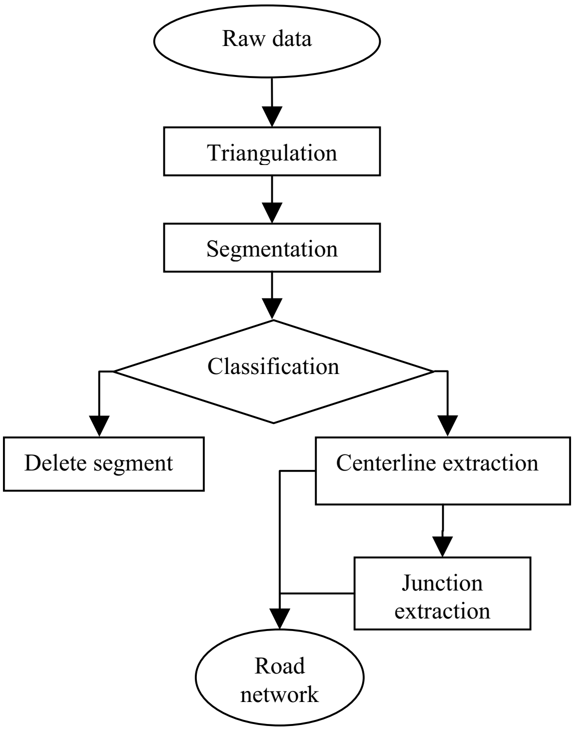

Figure 1. Road network extraction

2.2 Data segmentation

The process of segmentation uses the original data. First a TIN model of the surface is calculated using the Delaunay Triangulation. For each triangle within the TIN, the direction of the normal and the mean height of the three points that compose it are calculated. Then, a region growing approach that is based on comparing each triangle (T_0) individually to all of its neighbors (T_i: I=1,2,…,n), is used. If the difference in the normal direction is below a preset value (Δn) and so is the difference in mean height (Δh), the two triangles are considered to be part of the same segment. This procedure is performed for each triangle added to the segment. The Segmentation algorithm is therefore implemented as follows. First an unsegmented triangle that is chosen at random initializes a new segment. Then the neighbors of each triangle in the segment (which are not part of any segment yet), are analyzed. If the difference in the normal direction is below Δn and the difference in mean height does not exceed Δh, the neighboring triangle is added to the analyzed segment. This process is repeated until no further triangles can be added into the segment.

Segmentation parameters

Based on experiments with data sets of various densities and different topographic characteristics, parameters for the normal variation and height differences were derived. Their derivation was based on studying the properties of the road characteristic in relation to the data density and the area topography. Table 1 summarizes these parameters.

Topographic characteristics	**Density** [point/m^2]		
	0.15 > D	0.15 < D < 1	D > 1
Flat	Δh = 0.8 m Δn = 9°	Δh = 0.5 m Δn = 6°	Δh=0.3m Δn=3°
Mountainous	Δh = 1.5m Δn = 18°	Δh = 0.9 m Δn = 12°	Δh=0.5 m Δn=6°

Table 1. Segmentation parameters as a function of the data density and topographic characteristics

Segmentation results by normal directions and height difference are demonstrated in Figure 2.

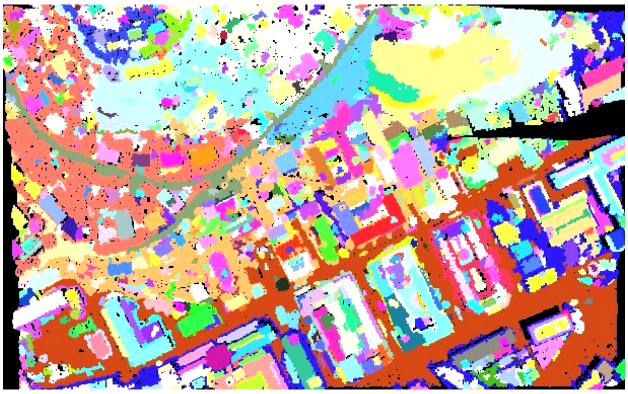

Figure 2. Results of the segmentation by normal direction and height differences

2.3 Classification

Relying on segmentation by normal directions, the outcome may include the road network but also roofs or other objects. To distinguish between roads and other objects segmented during the foregoing process a set of decision rules are checked. Primarily the property that road segments are considerably larger than any other segment and the property that area-to-boundary ratio of roads approaches zero are tested. From this follows the first rule: if the area of the analyzed segment exceeds the area of the largest house (provided as a predefined value) then the segment may be considered a road. The next property to look at is the solidity of the segment, which is the ratio of pixels inside the convex hull to the ones that are part of the segment. If the value of the segment solidity is close to zero, then the segment is classified as a road (that is because of the formation of a network by the roads). Following this procedure, the segments have been classified and the roads have been detected (Figure 3). For these segments the centerlines should now be computed in order to reduce the amount of data and to define the roads topology.

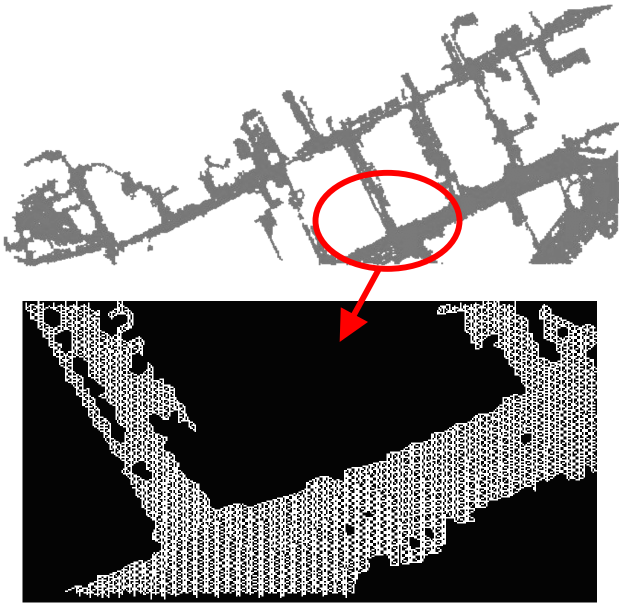

Figure 3. Classified road segments. **Top**: classified segments **Bottom**: Connectivity among the road segment triangles

2.4 Extraction of the Road Centerlines

The extraction of the road network centerlines is performed via morphological operations. To fill and complete gaps in the rasterized road network filling and bridging operators are applied to the dataset. Following this the data is skeletonized (Lam et al., 1992) and cleaned from dangling pixels to provide the road network centerlines. Figure 4 shows the result of the morphological operations on the segmented and classified data that was given in Figure 3. As can be seen the holes that appear in the segmented data (most likely originating from cars and, vegetation) have no effect on the extracted road network.

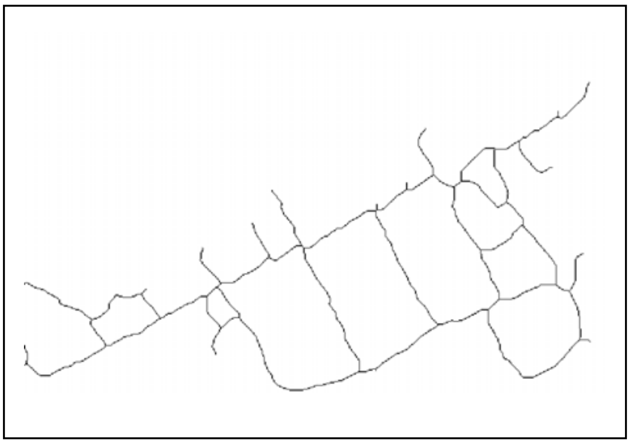

Figure 4. Extracted road centerlines

The raster road map is then automatically vectorized and undergoes vector editing operations to provide a complete network. The vector editing processes consist of thinning (in a vector sense, in contrast to the raster one) and handling undershoots and overshoots, thus providing a road network..

2.5 DTM Generation

The points derived from the road network detection can be used as the first approximation of the DTM. Iteratively comparing the skeletonized version of the DTM with the other laser points, if the height difference is less than a given value (ΔH) the points are added to the DTM. With this extended version of the DTM we apply the robust interpolation approach (Kraus and Pfeifer, 2002) for a complete computation of the DTM.

The essence of the robust method is computing the height of the measured points by means of an interpolation function on the basis of neighboring points and comparing the resulting height to the measured height. Points describing buildings will be characterized by a large positive difference whereas surface points characterized either by a large negative or a small positive difference. For computing a new height of a certain point, we use a bi-dimensional interpolation function, the coefficients of which will be extracted by a correlation process in which all the points within a certain radius around the point under consideration take part (Abo-Akel et al., 2004). For a function of higher order, a singularity in the coefficient matrix is possible; the resulting solution (if resulting at all) is unstable and influenced by the measurement errors. Using orthogonal polynomials allows the usage of interpolation functions of the polynomial kind, with no restriction on the degree of the polynomial, this make it easier to remove buildings or other objects from the DTM. The process is iterative, where between iterations a smaller ΔH (difference between original points and the polynomial) is set. The same processing is made in two directions and the final DTM is a combination of the two. Note that the process of DTM generation can also be understood as a generalization process, when the factor ΔH is the value controlling the degree of generalization.

2.6 Enhancement of roads within the DTM

To maintain the perceptibility of street objects in the DTM during the generalization process, they have to be emphasized. Otherwise, when strong generalization is applied, they would simply vanish. The same is true when streets are viewed from larger distances: road elements in the background may no longer be visible, as their width is below the visibility threshold. Thus, if roads are considered to be important objects, they can be artificially widened and thus emphasized in such a manner, that they are still perceivable from a given distance. The distance to choose corresponds to a scale value.

Based on the two dimensional roads resulting from the extraction procedure, the roads are broadened to both sides of their middle axes, i. e. their width is exaggerated. The exaggeration is undertaken using the straight skeleton algorithm described in Haunert and Sester (2004). In a first step, the road lines are converted into polygons. The broadening of the roads corresponds to a reduction of the surrounding polygons. The neighboring polygons undergo a shrinking process, which is performed by simultaneous parallel shifts of all edges to the interior of the polygon. The width of the broadened streets is arbitrary and is set to a value corresponding to the perceptibility of the roads. For the buffer created around the axes of the streets, the height values are recalculated based on the course of the street axes.

In Figure 5 the original dataset is compared to the result of the enhancement for a section from the DTM of the city of Stuttgart. Both scenes hold the same amount of triangles. The image at the bottom demonstrates that the perceptibility of the enhanced street is superior to the representation without enhancement, especially when looking at it in small scale or from great distance.

In general the exaggerated width depends on screen resolution and the distance to the observers` position. No additional information concerning the relative importance of the streets was taken into consideration. In a more detailed differentiation main roads have to be stronger emphasized than minor streets.

Altering height values within the broadened streets without considering adjacent height values brings about discontinuities between the modified regions and the bordering areas.

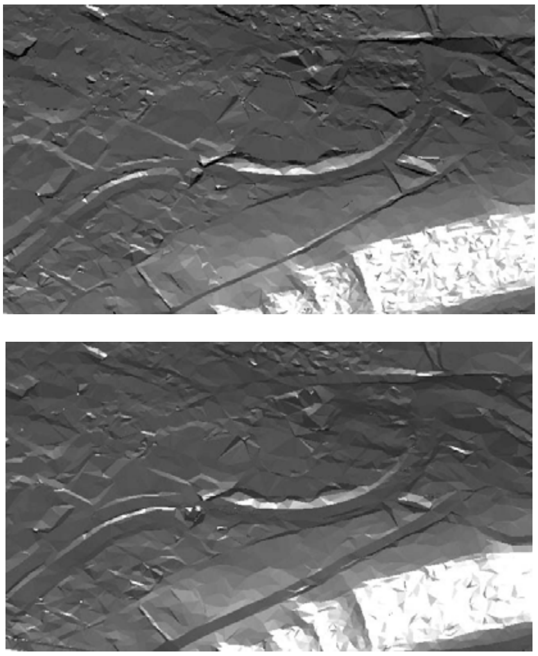

Figure 5. DTM with original roads (top) and broadened roads (bottom)

In Figure 6 a cross section demonstrates the principle of the enhancement. The point positioned in the center marks the middle axes of the street, the black line shows the original cross section. In grey, the enhancement of the street is illustrated.
The problem of the discontinuities is clearly visible: The former smoothly shaped slope shows sharp edges where the enhanced road ends.

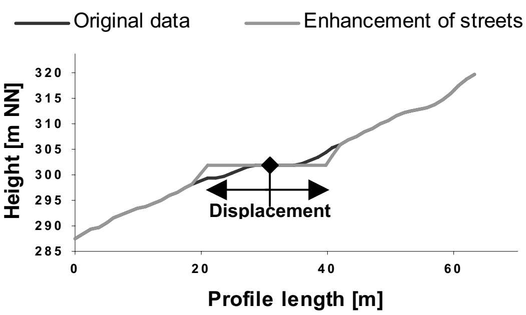

Figure 6. Cross-section of the original DTM with and without the enhanced street.

To preserve the inherent height information as good as possible, methods of displacement have to be applied in combination with the enhancement procedure

2.7 Adjustment of the DTM

Displacement operations can result in deformations within the data set. Deformation in connection with the displacement becomes the more apparent, the smaller the region is in which the modification takes place, because the overall alteration is spread over a wider area. This leads to the conclusion that a sphere of action with maximum size results in minimal deformation regarding the entire data set. For this reason, the whole DTM has to be taken into consideration for the displacement procedure. The original height values have to be moved in such a manner, that no overall height information is lost (Kremeike, 2004). In case of objects existing on top of the terrain surface, they have to be preserved in cognizable form.
One possible solution for this problem is the employment of a simple affine transformation, where all original height values from the DTM are mapped to the terrain areas off the widened road axes, which result from the broadening of the roads. This process is shown in Figure 7.

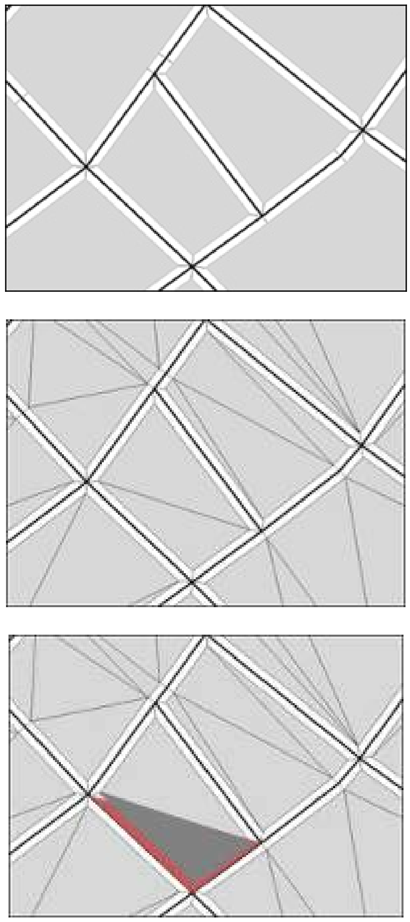

Figure 7. Middle axes of roads (black) and broadened roads (white).
Top: Broadening of roads,
Middle: Triangulation of the resulting polygons,
Bottom: Transformation of height values from original triangle (red) to the new (grey) triangle.

The black lines show the middle axes of the roads. In a first processing step, these lines are converted into polygons. Following the enhancement of the roads, the areas in between the road axes are smaller. Consequently, the height values within these shrunk polygons resulting from the broadening of the roads have to be newly calculated. This is done by performing a simple transformation for each polygon, using the so called "indirect method". To this end, each polygon is triangulated using the Delaunay Triangulation (Figure 7, middle). For each triangle, the x- and y-values for the three vertices as well as the vertices of the original triangle are known.

Using these values in the resampling process, the height values for each raster cell within the shrunk triangles can be newly calculated by transforming the point back to its original location and getting the original height value at this position. With this method, no height values are lost.

3. EXPERIMENTAL RESULTS

The application of the algorithm is demonstrated on a laser scan with a density of about 1 point/m^2 covering a suburban part of Stuttgart with area of ~5000m^2. Figure 8 shows a shaded-relief overview of the scanned area. The area has varying topography, mixture of detached objects (e.g., buildings and vegetation), and roads with varying shapes and dimensions.

Figure 8. Shaded relief of the laser point cloud.

Figure 9. Segmentation of the point cloud.

The segmentation of the road is performed with the following parameters: for the allowed normal variation (Δn) 6^o tolerance is set, and for the height difference a value of (Δh) 0.5m (see Table 1). Results of the segmentation and classification are given in Figure 9 and 10 respectively. Figure 10 shows that the road network was generally classified correctly and that most of the roads (detectable with this resolution and building occlusion) were detected.

Figure 10. Results of the road classification.

Figure 11. The extracted road network overlaid on the laser point cloud (red-road centerlines, background- shaded relief of the laser point cloud).

Conversion of the classified points into a road network is demonstrated in Figure 11. One can notice that some roads are missing (for some of them the existence of trees on both sides of the road appears to be the reason) but in general the important roads in the dataset were detected and correctly extracted.

Figure 13 show the results of the undertaken road enhancement in connection with the displacement. The results can be compared to the original (non-generalized DTM) given in Figure 12. From comparison it becomes obvious that the broadened roads are more clearly perceivable although all surface characteristics are maintained.

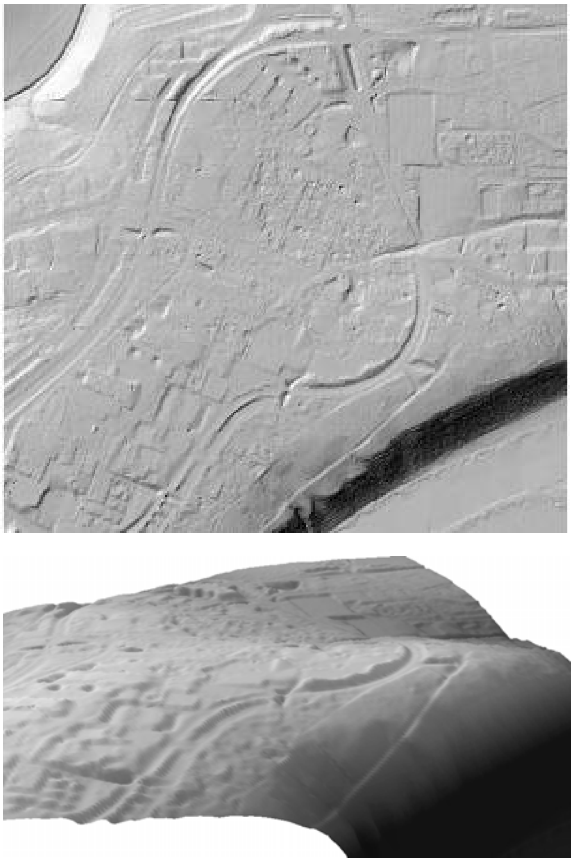

Figure 12. Shaded relief of the filtered Digital Terrain Model (DTM) in original appearance; (top) – top view of the filtering result, (bottom) – perspective view.

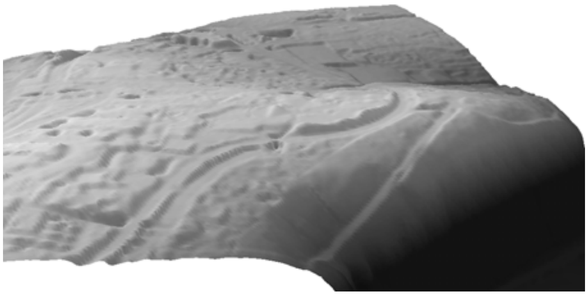

Figure 13. Shaded relief of Digital Terrain Model (DTM) with enhanced streets.

CONCLUSIONS AND FUTURE WORK

While generalizing a DTM the enhancement of relevant objects is of great importance. The presented work has focused on the road network as the object to be enhanced. Roads were generally derived from the LiDAR data, thus making this a self -contained algorithm. The road extraction algorithm has managed to detect the significant roads within the data, those that have an actual effect on the results of the generalization.

Enhancing the objects require their enlargement, thus leading to problems with adjacent areas and objects. For this reason, displacement operations must employed. The approach presented here was using the straight skeleton, Delaunay Triangulation and a simple transformation delivers acceptable results.

Nonetheless, the use of the triangulated polygons may lead to problems in those regions, where different triangles adjoin. Especially when thinking about displacement with objects on top of the terrain surface, a more global approach using the polygons as a whole seems to be appropriate. For such a calculation, a rubber sheeting algorithm might be suitable.

4. ACKNOWLEDGEMENT

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