AUTOMATIC BREAK LINE DETERMINATION FOR THE GENERATION OF A DTM ALONG THE RIVER MAIN

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ABSTRACT:

Due to world wide flood events hydrodynamic-numerical (HN) water flow simulation became a topic of highest public, political, economic, and research interest. In order to predict the water flow these complex spatiotemporal models have to consider, next to local physical parameters such as soil type, soil moisture, surface roughness, etc., the geometry of the run-off surface. For the description of the surface geometry a high quality digital terrain model supplemented by all objects that influence the water flow is essential. Furthermore, these surface models have to include the river bed of all present watercourses.

In the last years, airborne laser scanning (ALS, often referred to as airborne LIDAR) has become a prime data acquisition technique for the retrieval of topographic data and is widely used due to the implicit presence of this information (Briese, 2004a). By means of laser scanning one can think of extracting this linear feature information from the available ALS point cloud due to the fact that hydraulic simulation software is often restricted to a limited number of nodes and meshes that describe the surface geometry (Mandlburger and Briese, 2007, Mandlburger et al., 2008).

However, in order to fully exploit the capability of ALS sensors quality control has to be performed and fine georeferencing methods can be utilised in order to increase the precision, accuracy, and reliability of the acquired ALS points. Furthermore, full-waveform ALS, that allows to determine additional information per recorded echo, can be utilised to improve the task of filtering and DTM generation especially in areas with low vegetation structures, cf. (Doneus and Briese, 2006). Furthermore, the terrain points can be complemented by additional terrain observations such as topographic relevant linear feature lines such as break lines which describe a local surface discontinuity. The integration of these break lines can help to describe the surface geometry along these linear discontinuities in more detail and can therefore support the HN simulations in these often very sensitive areas. While break line information can be gathered by independent measurement campaigns (e.g. by terrestrial surveying or photogrammetric means) one can think of extracting this linear feature information from the available ALS point cloud due to the implicit presence of this information (Briese, 2004a).

This paper presents a full automatic process for the determination of break lines from ALS data for HN simulations. The determined break lines can be used within the filtering of the ALS data and can be integrated into the surface representation. Within the paper the method and processing chain for automated break line determination is shortly introduced and its practical application is demonstrated with the help of results archived within the project.
Geometric accuracy is defined by the quality of the georeferencing of the data and can be divided into an absolute and a relative part. Because of the sampling characteristics of laser scanning the points themselves can not be compared easily - but interpolated surfaces can. Therefore at first for each strip a digital surface model (DSM) is interpolated using moving planes interpolation (local least squares adjustment of a tilted plane). Whereas checking the absolute accuracy requires some sort of external reference data, the relative accuracy can be checked using only the data itself.

For checking the relative accuracy natural surfaces measured independently in different overlapping flight strips are compared simply by computing the difference \( dZ_{\text{pair}} \), of pairs of overlapping strip DSMs (termed strip difference). Because of the sampling distance of ALS points these natural surfaces need to have a certain smoothness otherwise the interpolated surfaces in the individual strips will be too different in shape for comparison. During the DSM interpolation for each strip the estimated accuracy \( \sigma_{Z_{\text{est}}} \) of the interpolated height is used to derive a roughness mask for each strip by a simple thresholding; see (Ressl et al., 2008) for details. Only the height differences outside this mask are considered for judging the quality of the relative georeferencing. This strip difference method can be applied provided the strips were flown with sufficient side overlap (typically 20%), which usually has to be done in order to guarantee a gapless data collection.

In this project for each strip a DSM with 1m grid width was interpolated by a moving planes interpolation using the 8 closest neighboured points. The roughness mask for each strip was derived using a threshold of 10cm for \( \sigma_{Z_{\text{est}}} \). Figure 1 shows an example of a colour coded strip difference \( dZ_{\text{pair}} \) for the original georeferencing with the roughness mask. Figure 2 shows the same section for the improved georeferencing after the strip adjustment. The left side of Figure 3 shows the histogram of \( dZ_{\text{pair}} \) (considering the roughness mask) based on all overlapping strips of the project for the original georeferencing. The right side of this figure shows the histogram of \( dZ_{\text{pair}} \) for the improved georeferencing.

The strip differences \( dZ_{\text{pair}} \) represent for all errors in the georeferencing their summed effect on the heights. However, this does not directly reflect the height accuracy of the ALS data; e.g. horizontal errors induce height differences at inclined surfaces. While \( dZ_{\text{pair}} \) gives a quantitative information about the quality of the heights, the color coded strip differences provide only qualitative information on the horizontal quality; e.g. Figure 1 clearly indicates horizontal errors at the roofs of the buildings but does not tell their size. Therefore 3D difference vectors between corresponding points in the strips were computed additionally. The corresponding points were measured in the overlapping strip DSMs using least squares matching (LSM). In order to avoid the disturbing influence of vegetation and occlusions on LSM (e.g. (Maas, 2000)) the roughness mask was used again and thus only smooth surface cells were used for LSM.

Table 1 shows the RMS values of the coordinate differences of the corresponding LSM points in overlapping strip DSMs before and after improving the georeferencing. There the large planar errors...
of 59.3 cm in X and 23.4 cm in Y for the original georeferencing are striking. After the strip adjustment a dramatic improvement with RMS values for X and Y of 7.1 cm was derived. It is interesting to point out that actually the RMS in Z is already for the original georeferencing quite good with 4.5 cm. After the strip adjustment RMS(Z) improves to 2.2 cm. This may be explained by height control areas (e.g. football fields) which were used by the flying company to adjust the vertical alignment of the strips. Again, this example demonstrates the usually worse accuracy in X and Y compared with Z. An observation also reported by other authors; e.g. (Maas, 2000).

<table>
<thead>
<tr>
<th>georef</th>
<th>RMS(X) [cm]</th>
<th>RMS(Y) [cm]</th>
<th>RMS(Z) [cm]</th>
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</thead>
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<tr>
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<td>23.4</td>
<td>4.5</td>
</tr>
<tr>
<td>improved</td>
<td>7.1</td>
<td>7.2</td>
<td>2.2</td>
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Table 1: RMS values of the coordinate differences of corresponding LSM points in overlapping strip DSMs before and after improving the georeferencing by strip adjustment. 811 point pairs were used.

In combination, the strip differences and the 3D differences at LSM derived corresponding points, constitute a very good tool for checking the relative geometric accuracy of ALS data: the strip differences, as colour codings and via the histograms, continuously describe the remaining height errors in the data, and the 3D differences describe the accuracy in XYZ at discrete points.

As mentioned in the beginning of this section checking the absolute accuracy requires external control data, which was only partly available for this project. Only three horizontal control surfaces existed, where the vertical discrepancies ranged from 4 cm to 10 cm. Only a 2D vector layer (ATKIS digital landscape model) was available, which contained features (street borders, terrain edges, etc.) that can not be easily used to compute 2D offsets. A visual comparison of this layer with a shading of the strip DSMs of the original georeferencing did not show any severe discrepancies. Therefore the absolute georeferencing was considered to be acceptable - however, due to the limited external reference data the absolute accuracy could not be checked to the same degree as the relative one.

3 AUTOMATIC BREAK LINE MODELLING

In the past several different solutions for the determination of break lines from ALS data were published. Most of these approaches determine the break lines with the help of raster based operations (e.g. first and second order derivatives, Laplacian operator; cf. (Brügelmann, 2000, Gomes-Pereira and Wicherson, 1999, Gomes-Pereira and Janssen, 1999, Sui, 2002)). Typically, these raster based algorithms are applied to a previously generated (filtered) DTM and the result of these detection methods are pixels marked as edge pixels. Subsequently a raster to vector conversion is applied and 2D break lines are generated. In a final step, the height of the break line is typically independently extracted from a slightly smoothed vegetation free DTM at the planimetric break line position. A different approach for the determination of break lines from ALS data starting from the irregular distributed unclassified ALS points was presented in (Briese, 2004a) and (Briese, 2004b). This process allows the simultaneous determination of all three co-ordinates of points along the break lines within one process and automatically allows to reduce the local influence of off-terrain points by robust adjustment. However, compared to the raster based approaches this process works in a semi-automated way and requires one manually set 2D-start-point or one 2D-start-segment in the vicinity of each line in order to estimate the whole 3D break line.
The following proposed full-automatic procedure for the modelling of break lines from irregular ALS point cloud data can be basically split into two steps. In the first step potential break line segments are detected (see Subsection 3.1), whereas in the second step the modelling of the whole 3D break lines starting from the detected segments is performed (see Subsection 3.2). For the break line modelling the break line growing concept presented in (Briese, 2004a) and (Briese, 2004b) is utilised. For the first step a new approach is introduced that allows to determine start-segments based on the irregular distributed ALS point cloud, whereas the second step is extended to handle multiple start segments per resulting break line.

3.1 Break Line Detection

As demonstrated by the previously mentioned publications, for the detection of break lines raster based methods can be utilised. However, this makes a rasterisation of the irregularly distributed ALS data necessary. The advantage of these methods is that they can be applied in a very fast way due to the given raster topology, but the disadvantage of the rastered ALS point cloud is that this advantage is bought by a loss in precision (Axelsson, 1999).

Break lines that are represented in the point cloud sharply might be smoothed by the rasterisation process and by the usually previously applied filtering processes. In order to avoid these pre-processing steps, a break line segment determination based on the irregular distributed last echo point cloud is proposed in the following.

In contrast to the raster based approaches, the detection of potential local break line segments can be performed by the analysis of a locally determined 2.5D second order surface (quadric) \( q \):

\[
q = f(x, y) = \sum_{i+j \leq 2} a_{ij} x^i y^j
\]

This quadric can be determined on the position of each given point by the selection of \( k \) nearest neighboured points. The adjustment can be performed in a robust way in order to reduce the influence of off-terrain points on the estimated parameters. The resulting surface patch represents the local surface characteristic and allows to determine the local minimal and maximal main curvature \( \kappa_{\text{min}} \), \( \kappa_{\text{max}} \) with the help of a principal axis transformation. This allows to classify the points in the form of break line or surface point based on the local curvature values. For this classification a threshold for the maximal curvature value \( \kappa_{\text{max}} \) and the main curvature ratio \( \kappa_{\text{min}}/\kappa_{\text{max}} \) can be utilised. Furthermore, next to the determination of the main curvature values, principle axis transformation allows to estimate the main curvature directions. Another important advantage compared to other raster based or point cloud based operations is that this approach allows to refine the position of the local break line by the determination of the symmetry point, i.e. the point on the quadric with the maximum curvature value. As a result this procedure delivers the point with the local maximum curvature and the local break line direction (pointing into the direction of the present minimal curvature). The refinement of the position of the local break line is a big advantage compared to other raster or vector based approaches, because instead of a relatively thick band of break line candidate positions along the lines (e.g. several pixels that indicate a high curvature value near the break line) the described procedure allows to determine accurate break line point positions together with its local break line direction in a very small band around the finally estimated break lines. A practical result of this procedure in an area near the Main river is displayed in Figure 4.

Within this example the local break line determination was performed in each 5th point in order to save computation time.

3.2 Break Line Modelling

In order to generate a linear representation of one break line one can think, in analogy to the raster based methods, of connecting the determined start segments and interpolating the height of the 2D points with the help of a previously generated DTM. However, in contrast to this independent two step process, the following proposed break line modelling concept allows the simultaneous determination of all three co-ordinates of the break line point (and additionally the local tangent direction) simultaneously within one step by the determination of a local valid plane pair that is robustly estimated with the help of the local surrounding last echo point cloud. Furthermore, the delineation of the whole line is not performed by the connection of neighboured and similar oriented break line segments. Instead of this procedure the concept of break line growing was utilised. As mentioned previously, this procedure is based on a semi-automated procedure published in (Briese, 2004a) and (Briese, 2004b). In contrast to the semi-automatic approach with manual user defined start segments, a full automatic processing chain can be generated by the usage of the previously automatically detected break line segments.

In contrast to the semi-automatic solution, where the processing of multiple lines is controlled by the user, within this automatic procedure the redundant modelling of the break lines has to be considered due to the fact that the break line detection step, as described in the previous subsection, delivers multiple break line segments per line. Therefore, it has to be analysed during the break line modelling procedure if the corresponding break line of the next processing segment is already modelled. This additionally check can be performed with the help of a spatial tree (in our implementation a R-tree is used) which stores the already modelled lines and allows nearest neighbourhood queries. This addi-
3.3 Influence of Georeferencing Errors on Break Line Determination

As mentioned in the introduction, in the first computations based on the original delivered ALS data a significant influence of systematic relative georeferencing errors on the process of automated break line determination could be observed. As already shown in Subsection 2.2, significant strip differences could be observed prior to a strip adjustment of the available ALS data. The present planar errors result in height differences near break lines (e.g. on embankments, dams, dikes, etc.) due to the presence of surface inclination in these areas. While the planar errors hardly affect the DTM in flat regions, a significant effect in inclined regions (see Subsection 2.2) could be observed. Next to the influence on the break line modelling these errors may affect the filtering process (were typically the lowest points will get a higher influence than the others) as well as the final DTM generation process.

The negative influence of an inadequate georeferencing could be especially observed in the break line detection step, where the local surface curvature was estimated. The georeferencing errors resulted in high curvature values in areas were two or more strips overlap. Therefore, the determined break line segments were determined next to correct ones along surface discontinuities also in smooth areas. Furthermore, the determined break line directions within this wrongly determined segments showed a very random distribution. The negative influence of georeferencing errors present in the original delivered ALS data on break line detection can be inspected in Figure 6.

Next to the previously mentioned effects on break line detection, the mentioned relative planar errors do also affect the break line modelling process. Due to the different shifted band of points from the individual strips the resulted local plain pair might lie in between both bands or if the height off-set is big enough (on very steep slopes) the lower points will become a higher influence to terrain points (that are assumed to be lower than vegetation echoes (further details see (Briese, 2004a))). This results in systematic planar and height errors of the resulting lines. Practical studies documented these significant effects. They varied within the project area significantly due to the fact that the resulting error was influenced by the actual relative georeference errors, the local surface structure as well as the ALS strip layout.

All this observations in the initial project phase demonstrated the need of strip adjustment in order to determine reliable break lines that could be used as an additional information source within the geometric description of the landscape. The strip adjustment procedure as presented in Subsection 2.2 allows to reduce these effects to a very high degree. Finally, break lines with a low amount of systematic errors caused by planar relative georeferencing errors could be determined.
DISCUSSION AND FUTURE WORK

This paper presents a full automatic method for break line determination based on ALS data. The practical application of the developed method showed that break lines can be extracted automatically based on the unclassified irregular ALS last echo data. The resulting break lines show up a high degree of detail and completeness. Especially long straight lines, e.g. on road embankments, can be extracted quite well and nearly do not need any manual correction work. Problems in the break line modelling mainly occur on small curved lines and on parallel lines where the point density is sometimes too low resp. the modelling parameters are not flexible enough to avoid that the growing procedure jumps from one line to the other. Further problems can be found in areas with very dense vegetation, where the growing sometimes stops too early or the robust adjustment is not able to eliminate all off-t terrain information. The practical evaluation of the results with independently terrestrially acquired reference data showed similar results (long straight break lines fit very well, while smaller highly curved lines may show up a higher difference). A more detailed accuracy report concerning this analysis will be presented in subsequent publications.

The practical application of the developed methods for break line detection and modelling showed up that a high quality georeferencing prior to any modelling step is important. Systematic errors (planar as well as height errors) in the data can lead to significant systematic effects (planar errors can result in height errors on inclined surfaces) in the derived products. Especially in the break line detection phase this became obvious (visible strip boundaries when looking on the planar distribution of the extracted break line segments). Within the modelling step the problems were not so obvious, but a detailed analysis showed up significant systematic effects introduced by the original georeferencing errors. Therefore, this paper highlights the importance of quality control and strip adjustment. The practical application of this process showed up the potential of a high quality georeferencing of the data. The final improved point cloud was a good basis for the subsequent modelling of the break line and most of the effects caused by the relative georeferencing errors of the original ALS point could be eliminated.

Furthermore, the practical application of automated break line determination showed up that further research work is necessary in the local adoption of the processing parameters. At the moment all relevant parameters have to be fixed at the begin of the processing and are fixed for the whole processing chain. Practical tests showed that a local variation of the parameters can be very useful in order to consider different surface properties (e.g. the presence of parallel break lines). Furthermore, the process of break line growing in areas of strongly curved lines has to be improved in the future. Finally, the line topology has to be considered. In the current implementation each line is treated independently and correct line intersections are not supported. Future research work is necessary in order to determine a reliable break line network.

REFERENCES


