ROADS AND BUILDINGS FROM LASER SCANNER DATA WITHIN A FOREST ENTERPRISE

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ABSTRACT

Laser scanning with its ability to penetrate vegetation and its extremely high point density allows for a completely new approach to semi-automatically delineate man-made features ("objects") in forested areas as a basis for the management of such data in a GIS. In this paper, emphasis is laid on the detection of roads and buildings from laser scanning data. The basis of our analysis is the generation of a DTM actually representing the earth surface (no tree tops, no building roofs). From a slope model of the terrain, break lines can be detected by applying standard edge extraction techniques. However, the slope model is still too noisy to deliver "good" (long, continuous) break lines. Thus, a pre-processing step making use of an edge-enhancing filter becomes necessary. From the results of break line detection, a new, geomorphologically revised terrain model can be derived. The break lines contain the road edges which can be interactively selected by the user. With respect to roads, the line extraction results can be improved using a snake algorithm. Building candidate regions can be detected from the differences of surface models derived from the original "last-pulse" and "first-pulse" laser data and the rectified ground model. The algorithm is based on a classification of elevation difference models followed by the improvement of classification results by a despeckle filter, the main problem being the distinction of tree tops from buildings. In this paper the algorithms involved for the solution of the above tasks are described and first test results are presented.

KURZFASSUNG

Durch die Möglichkeit, Vegetation zu durchdringen sowie durch die extrem hohe Punktdichte wird es mit Hilfe der Laserabtastung möglich, völlig neue Methoden zur halbautomatischen Erfassung von Kunstbauten („Objekten") in bewaldeten Gebieten als Grundlage für die Verwaltung solcher Daten in einem GIS anzuwenden. In dieser Arbeit wird ein Schwerpunkt auf die Erfassung von Straßen und Gebäuden aus Laserscannerdaten gelegt. Grundlage unserer Analyse ist die Erzeugung eines digitalen Geländemodelles, das die tatsächliche Erdoberfläche repräsentiert (ohne Baumkronen und Dächer). Aus einem Modell der Geländeneigung können unter Verwendung von Standardalgorithmen zur Kantenextraktion Geländekanten abgeleitet werden. Da die Neigungsmodelle zu verrauscht sind, um „gute" (lange, zusammenhängende) Geländekanten liefern zu können, wird ein Vorverarbeitungsschritt mit einem kantenverstärkenden Filter nötig. Aus den Ergebnissen der Geländekantenextraktion kann ein geomorphologisch bereinigtes Geländemodell abgeleitet werden. In den Geländekanten sind auch die Straßenränder enthalten, die interaktiv als solche selektiert werden können. Weiters können in diesem Fall die Ergebnisse der Kantenextraktion durch Anwendung eines Snake-Algorithmus verbessert werden. Kandidatengebiete für die Gebäudedetektion können aus den Differenzen der originalen „last-pulse-" und „first-pulse-" Daten und des rektifizierten Geländemodelles abgeleitet werden. Der dazu verwendete Algorithmus beruht auf einer Klassifizierung von Differenzhöhenmodellen gefolgt von der Verbesserung der Klassifizierungsergebnisse mit einem Despecklefilter, wobei das Hauptproblem in der Unterscheidung von weit ausladenden Bäumen und Gebäuden besteht. In der vorliegenden Arbeit werden die Algorithmen zur Lösung der oben angesprochenen Aufgaben beschrieben sowie die Ergebnisse eines ersten empirischen Tests vorgestellt.

1 INTRODUCTION

1.1 Motivation

The intensive utilisation of forests leads to fast changes in cultivation. Especially the update of forest roads and clearcuts is usually very time-consuming and inaccurate, since neither photogrammetry nor GPS yield satisfying results in densely forested areas. The growing usage of geographical information systems (GIS) is another reason for the need of accurate co-ordinate determination. Laser scanning with its ability to penetrate vegetation and its extremely high point density allows for a completely new approach to semi-automatically delineate these man-made features, subsequently called "objects". For the

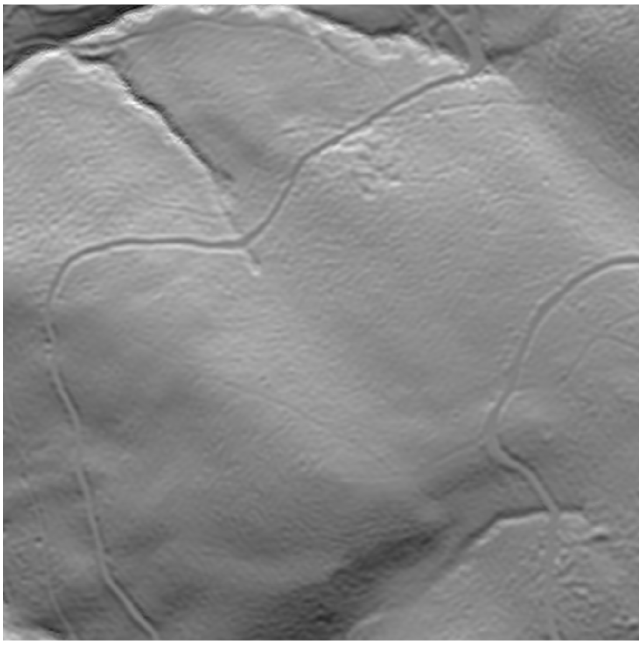

Figure 1: A hill shaded view of the terrain model.

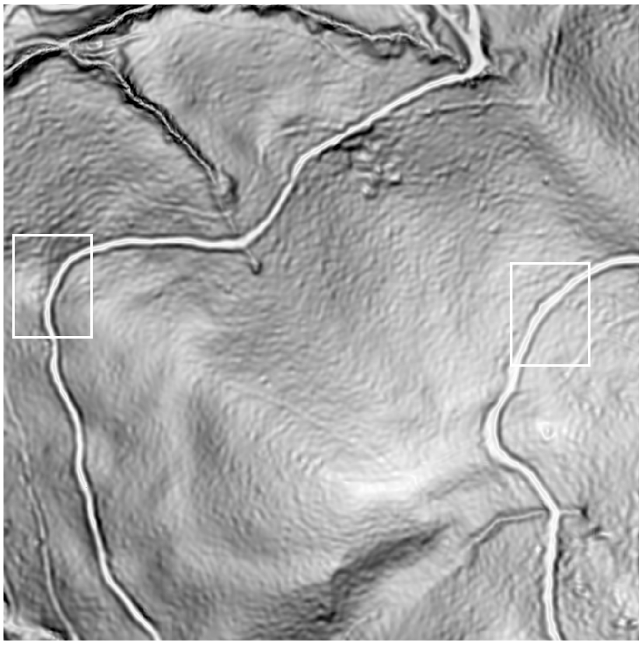

Figure 2: Slope model with position of detailed windows.

time being it is still a costly technique which is not feasible for large areas; but the technological development may soon bring new systems which allow to fly higher, and to have greater point density across track, so that it may be economically possible to have frequent laser scanner flights for large areas.

1.2 Test site and data

As test site the research forest of the Vienna University of Agricultural Sciences was used. The forest is positioned approximately 60 km south of Vienna in hilly terrain with elevations ranging from 350 to 750 m above sea level. The vegetation is typical for central Europe. More details can be found in (Rieger, 1999).

A laser scanner flight was taken during winter time (leafless period) with last reflected pulse recorded. This flight is necessary in order to obtain a high quality ground model. From that model roads can be delineated as is shown in section 2. The same flight may be used to create digital surface models which include the building surfaces. The difference between the surface and the ground models is used to extract buildings in the way described in section 3. Here, summer flights were used instead of the winter flight since they were available for the test site. The results may even be better if the surface model is derived from the winter data.

2 EXTRACTION OF ROAD BREAK LINES

Digital terrain models (DTM) generated from laser points can be rather detailed due to a huge number of measured points. Despite, break lines in the terrain appear smoothed, unless they have been introduced into the DTM interpolation. Usually, these break lines are digitised manually in a stereo plotter. In this work we tried to extract forest roads in mountainous areas from the DTM in order to introduce them in a new DTM interpolation. Such roads are cut in the hill slope, so that in the resulting DTM, the road sides must appear as sharp breaks.

First a digital terrain model with a grid width of 20 x 20 cm ^{2} is calculated using only the laser ground points by applying a robust estimator with a skew error distribution function in the program system SCOP (Pfeifer et al., 1999). Figure 1 shows a hill shaded map of the terrain. The digital terrain model is used for the creation of a digital slope model which provides the first derivative of elevation. At each grid point, the elevation angle of the surface normal (“steepness”) is given in that model. This slope model is converted into a digital image, where the grey-levels represent the steepness of the terrain (figure 2). As no break lines have been considered yet in interpolating the DTM, a rather smooth slope model is produced with wide transition zones between flat areas and steep areas.

The images show two narrow roads in a mountainous, forested area. Figure 3 draws two profiles perpendicular to the roads. Up to four break lines may be detected. Beginning at the left side, the first break is between the hillside and the bank of the road (only in the right profile). At the two road sides the second and the third break appear. The fourth break is at the end of the ditch. Not all

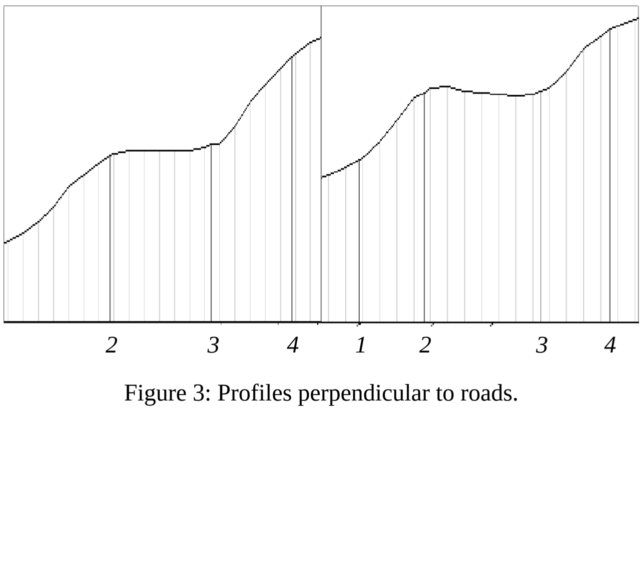

Figure 3: Profiles perpendicular to roads.

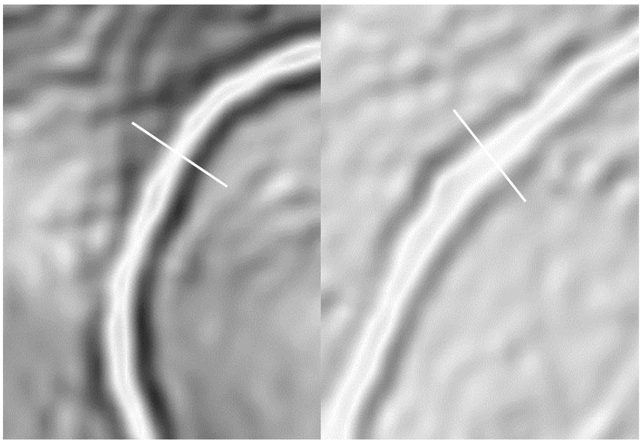

Figure 4: Two details from the slope model in figure 2.

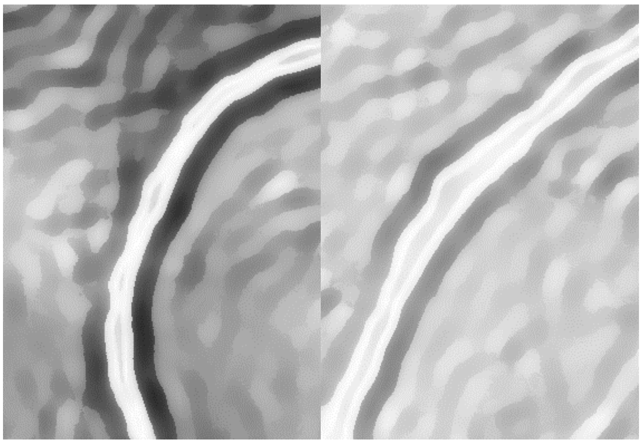

Figure 6: Results of the biased sigma filter.

four break lines are significant along the entire road, in fact the breaks at the road sides are usually stronger than the outer two breaks. Figure 4 shows two details from figure 2 with the position of the profiles of figure 3. The roads themselves are relatively flat and appear as bright strips in the slope image. They are surrounded by the road bank and indentation as dark strips.

As break lines in the terrain model correspond to abrupt changes in the surface normals, they can be detected by applying an edge extraction algorithm to the first derivative of elevation. Unfortunately, standard edge extraction algorithms deliver only short segments of break lines (figure 5) or even fail.

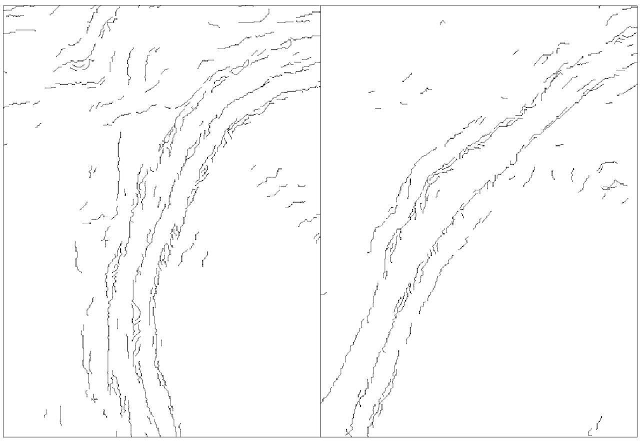

Figure 5: Edges extracted from the slope model.

2.1 Edge Enhancement

For achieving satisfying results the slope image has to be prepared by sharpening the edges. For this purpose an operator based on the ideas of the biased sigma filter (Lee, 1983) can be used. The biased sigma filter is an edge preserving and edge enhancing smoothing filter. In the original concept it determines the new grey-level value of a pixel (denoted as the central pixel) by calculating two measurements m_l and m_h using some of the neighbouring pixels. Those pixels in a square neighbourhood, that have a grey-level value in a defined range around the grey-level value of the central pixel (e.g. $\pm$ three times the standard deviation σ of the image noise), take part in the calculation. The measurement m_l is the average value of all such pixels that have a grey-level value smaller than the one of the central pixel. Analogously, m_h is the average value of such pixels having a greater grey-level value. Depending on which one is closer to the old grey-level value of the central pixel, either m_l or m_h is selected to be the new grey-level value.

This filter is quite powerful in smoothing while still preserving and even enhancing image edges. Unfortunately it often introduces artefacts. In our case we use the edge enhancing property of this filter for sharpening widely blurred edges. We choose a filter extent of 3 by 3 m^2 (corresponding to 15 by 15 pixels). The σ-range of the filter is ignored so that all pixels in the neighbourhood are used to calculate the two average values m_l and m_h.

The effect of the filter can be seen in figure 6 for the images of figure 4. The transition zones between flat and steep (between bright and dark) can be removed by this filter which strictly assigns either the bright or the dark value to each pixel. The resulting image is optimally pre-processed for subsequent edge extraction.

The danger in applying such a strong non-linear filter lies in a geometric displacement of image edges. In our case we could not find any evidence for this suspicion. The extracted break lines fit exactly to the ones measured in the field (c.f. section 2.4).

2.2 Automatic Feature Extraction

We use an algorithm for simultaneous extraction of point and line features based on the Förstner Operator (Fuchs, 1995). From the first derivatives of the grey levels a measure W for local texture strength and a measure Q for isotropy of texture can be computed. The average squared norm of the grey level gradients in a small (e.g. 5 x 5 pixels) neighbourhood can be used for W. By applying thresholds W_{min} and Q_{min} to W and Q, each pixel can be classified as belonging either to a homogeneous region, to a point region or to a region containing a line. As the classification result is especially sensitive to the selection of the threshold W_{min} for texture strength, this threshold is selected in dependence on the image contents. The selection of Q_{min} is less critical because Q is bound between 0 and 1 (Mischke et al., 1997).

The results of classification have to be thinned out. Points are found at the positions of relative maxima of texture strength in the point regions. Line pixels are relative maxima of texture strength in the direction of the gradient of the grey levels (Fuchs, 1995). Neighbouring line pixels have to be connected to line pixel streaks by an edge following algorithm. Finally, these streaks are to be thinned out and approximated by polygons. Both for line pixels and points, the co-ordinates are estimated with sub-pixel accuracy. The algorithm was also tested in an engineering surveying environment and gave promising results (Mischke et al., 1997).

In the case of break line detection, we are only interested in extracting lines. However, the sound statistical background of the algorithm makes it quite applicable for our purposes. As in our case the grey levels represent the elevation angle of the surface normals, the first derivatives of the grey levels correspond to the changing rate of the terrain steepness, i.e. to the curvature of the terrain. The positions of maximum directed texture thus correspond to regions of maximum terrain curvature, and the thinned-out regions (the results of edge extraction) correspond to break lines in the terrain model.

This approach for extraction of break lines contains a simplification because we only use the elevation angle of the surface normal as an input for edge extraction. Actually, the elevation can be derived by both co-ordinate directions, and a more sophisticated way of detecting edges has to make use of both derivatives. For example, the input could be stored as a digital image containing two bands, each band corresponding to the first derivative of the terrain in one of the co-ordinate directions. Geometrically, our simplification means that we can not detect break lines between flat terrain regions with equal steepness but different slope directions. Such break lines typically appear at symmetrical ridges. As we are especially interested in extracting roads and because with respect to roads there are no symmetric ridges, our simplification does not influence the results of edge extraction with respect to our goals.

2.4 Semi-Automatic Extraction by Snakes

Still, some of the detected lines are broken, and separated segments appear. Snakes can be used for bridge gaps and deriving longer segments (Kass et al., 1988). They are commonly used as semi-automatic line extraction tool in digital images. It is the task of an operator to provide an approximation of the edge to be extracted by some seed points. Then the snakes try to detect the exact edge location automatically by minimising an energy functional. By this energy functional, a balance between internal forces (enforcing a smooth shape of the curve) and image forces (pulling them to salient image features such as edges) is reached. Gaps in the image edges are bridged in a smooth way by emphasising the internal terms of the energy functional. For the specific task of extracting parallel road sides, an extension to the snakes concept, the twin snakes approach can be used (Kerschner, 1998). This method is less sensitive to the approximation of the position and shape and has some potential for full automation for this task. First investigations show promising results.

2.5 Results of Automatic Break Line Extraction

Figure 7 shows the resulting break lines. Compared with the lines in figure 5 they seem smoothed and connected to longer segments. This is the merit of the biased sigma filter. The heights of the extracted break lines have to be derived from the original laser data.

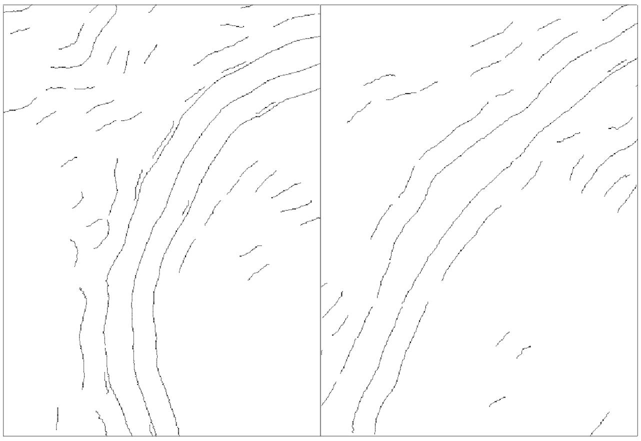

Figure 7: Edges extracted from the pre-processed slope model.

For an accuracy analysis of the break lines extracted from the preliminary DTM, we compared them with geodetically measured break lines. Thereby we found out that the whole terrain model had a systematic shift of 2 m in y-direction and 1.2 m in x-direction (figure 8, left). The reason was an insufficient geo-referencing of the original laser points because of lack of suitable control features. The extracted road sides compared to the measured ones could be used to determine the shift. After correcting the geo-reference of the DTM the extracted break lines are very close to the manually measured road sides (figure 8, right). The roads are found with the correct width while the banks seem to be wider. The reason for this is that the edges of the roads are much sharper defined than the edges of the banks. Even during the terrestrial recording it was difficult to determine the edges of the banks. The discrepancies lie in the range of 1-2 m, which is smaller than the definition accuracy of these lines in nature.

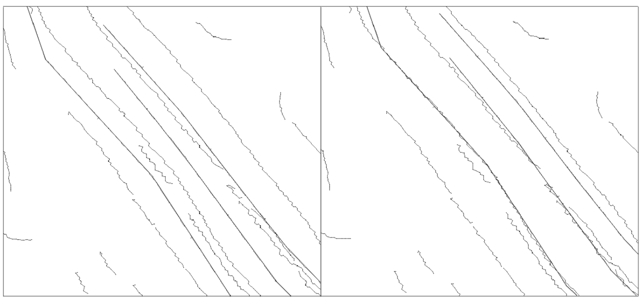

Figure 8: Comparison between terrestrially measured and automatically detected road edges before and after correcting the geo-reference.

In the end we derive a new DTM from both the laser point cloud and the break lines, and a geomorphologically revised digital terrain model can be obtained.

3 EXTRACTING BUILDINGS FROM LASER DATA

The method suggested here has been partly published in (Kraus and Rieger, 1999). At first an accurate ground elevation model is needed which was done according to (Pfeifer et al., 1999). Secondly, a “ground biased” (referred to as “last pulse model”) and a “crown biased” (referred to as “first pulse model”) grid elevation models are created. These elevation models are derived from the raw laser data by a moving maximum respectively minimum filter. Both models show vegetation, yet the amount of tree points is much less in the last pulse model.
The models are called last and first pulse models since they were basically derived from summer last pulse and summer first pulse laser data, respectively. However, since there is very little difference between the two flights (Rieger et al., 1999), it is well possible to derive the elevation models from only one flight, even from the winter flight. Here, the two models were derived from summer first and last pulse, respectively, and used as provided by the company “TopoSys” which took the laser flights.

The grid models were used instead of the raw laser data for several reasons:

- the approach is much easier and is based on standard software;
- there is a necessity to analyse the data in some neighbourhood which is difficult to undertake with the huge number of laser dots;
- the position of the laser dots is completely arbitrary, and it is difficult to find topological neighbours. In a grid there is a clearly defined neighbourhood between points;
- the raw laser data must be filtered towards ground respectively surface which is done as a preprocessing step through the creation of the grid models. Work on the raw laser data would not easily allow to do so.

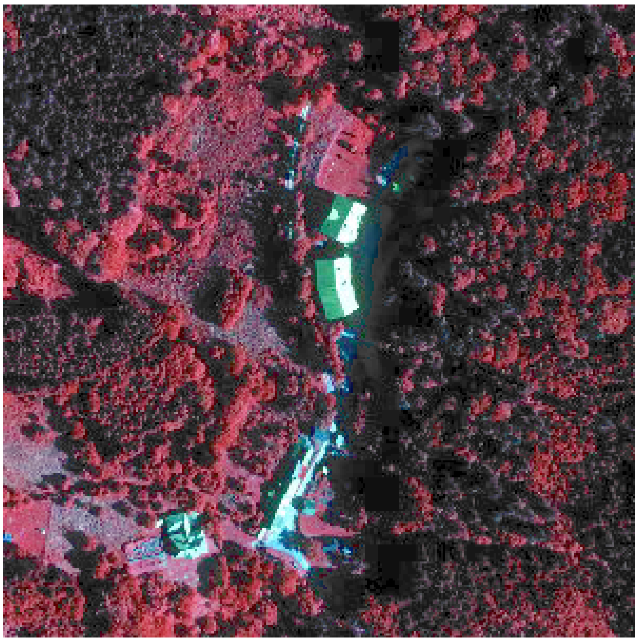

Figure 9: Digital orthophoto of part of the research forest.

The laser elevation models show absolute elevations which are not feasible for the extraction process. In order to obtain “object heights” it is necessary to reduce the surface models by the ground elevation models which is done by simple subtraction. The resulting models show first pulse respectively last pulse object heights.

The following grid models are needed for the extraction process:

- first pulse – ground;
- last pulse – ground;
- first pulse – last pulse.

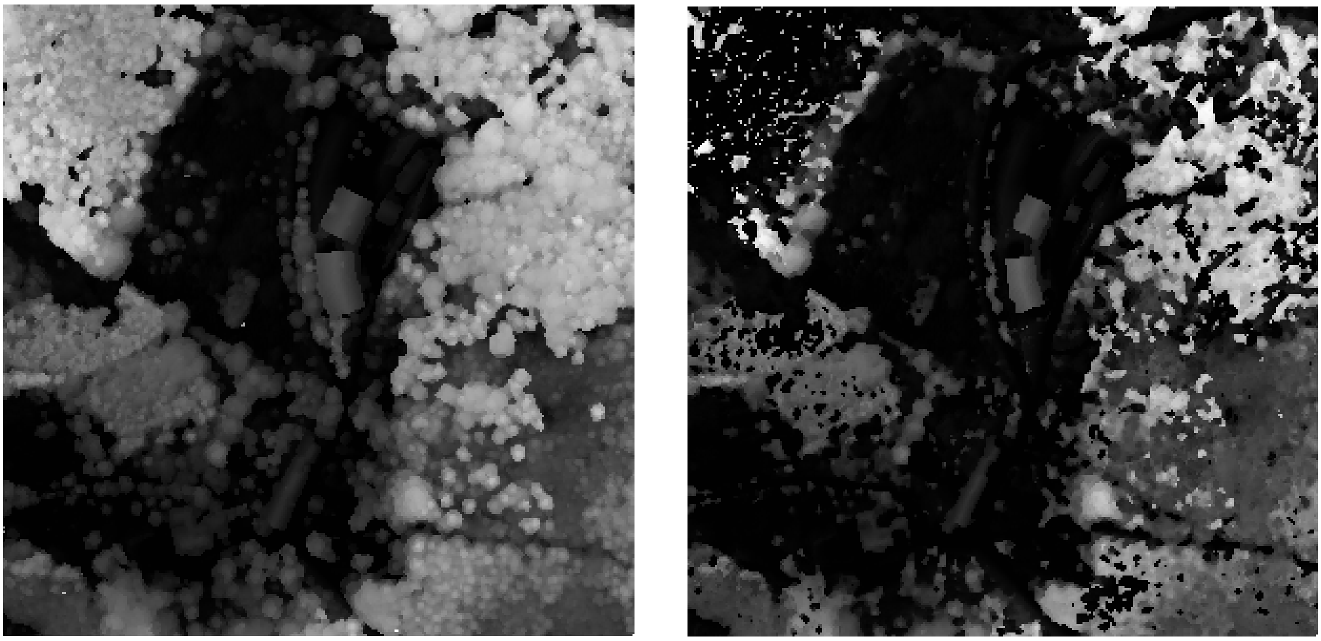

Figure 10: DEMs from laser data. Grid width 1 m. Left: first pulse – ground; Right: last pulse – ground.
Linear gray coding for heights: Black means a height value of 0 m, white a value of 40 m.

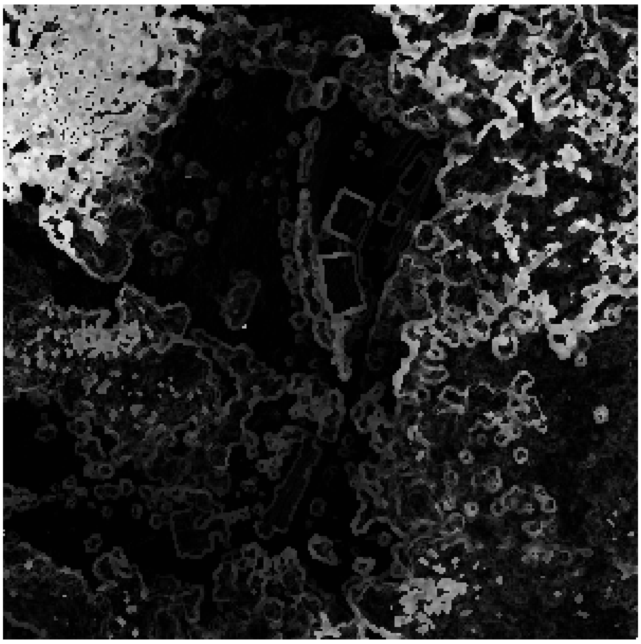

Figure 11: First pulse – last pulse model. Gray shading and grid width as in figure 10.

Figure 12: Building mask.

These models are now used for a classification step. Figure 9 shows a digital orthophoto of the area with the buildings of the research forest. Figure 10 shows difference models first-ground and last-ground, Figure 11 shows the model first-last. Now all areas that exhibit differences larger than one meter in the model first-last are assumed to be vegetation points. The threshold value of one meter was chosen because it corresponds to the grid width of one meter; buildings in Austria usually have roofs tilted less than 100%, thus the difference between first and last pulse models should not exceed 1 m.

Areas with values lower than 1 m in the data set last-ground are assumed to be ground points which normally cannot be penetrated by the laser. The threshold of one meter here corresponds to the medium hillslope and ground vegetation. Those areas with values lower than 1 meter in the data set first-last and higher than 1 m in the data set last-ground are assumed to be building points. Figure 12 shows the resulting mask after applying a 3x3 despeckle filter. This mask can further be improved by expanding the building areas (black) to the area that shows values larger than 1 m in the data set last-ground (dense areas). The resulting mask is shown in Figure 13.

Figure 13: Building mask enlarged with first pulse model.

The usage of aerial or satellite imagery may be of great help in distinguishing between vegetation an man-made objects. Yet, the proposed algorithm shows good results and works fully automatic. It could be used to automatically find those areas were there may be buildings (or rocks or other solid off-terrain features). Manual inspection could then allow to further distinguish between different object types.

4 CONCLUSION

Roads can be well extracted from laser scanner data of mountainous regions. For deriving complete road networks (e.g. for a GIS) a semi-automatic approach is advantegeous. The most significant road sides, which are extracted automatically, can be used to produce a geo-morphologically corrected DTM. Further investigations will concentrate on extending the concept for extracting general break lines (where only the direction of the slope changes abruptly).

For buildings, the candidate regions can be detected fully automatically. Visual inspection is still necessary to distinguish buildings from large isolated trees and in order to assign additional attributes for classifying them in a GIS. In addition, the grid points inside the candidate regions have to be matched to geometric 3D-building models.

Our results have shown the high potential of extracting spatial information from laser scanner data.

5 ACKNOWLEDGEMENTS

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