PROCESSING OF LASER SCANNER DATA AND AUTOMATIC EXTRACTION OF STRUCTURE LINES

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ABSTRACT:

Airborne laser scanner raw data are unstructured and irregular points which need intensive post processing. The first step is the separation of valuable points which lie on the ground surface (ground points) from outliners which are located above it (non-ground points). Another task is the extraction of structure lines from the laser scanner. Structure lines play an important role for the construction of precise DEM. The presented and developed method for the extraction of structure lines is based on the digital image processing methods and on the differential geometry of curves. This operator was initially developed for image processing and is now used in a new context. The developed and implemented methodology is open for further extension and compatibility. It is hence possible to use it in other fields of application. The presented work shows that image processing methods yield good results for the extraction of structure lines without the need of specific knowledge of objects.

ZUSAMMENFASSUNG:

Die mit Flugzeuglaserscannern gewonnenen Daten stellen zunächst unstrukturierte und unregelmäßig verteilte Punkthaufen dar, die einer intensiven Nachbearbeitung bedürfen. Zur Nachbearbeitung von Laserpunkten ergibt sich als erste Aufgabe eine Separation der gewünschten Laserpunkte auf der Geländeoberfläche (Bodenpunkte) von den nicht verwertbaren Punkten (Nichtbodenpunkte). Eine weitere Aufgabe steht in der Extraktion von Strukturlinien aus Laserscannerdaten. Strukturlinien spielen eine wichtige Rolle beim Aufbau von präzisen DHM. Das hier entwickelte Verfahren zur Extraktion von Strukturlinien basiert auf den digitalen Bildverarbeitungsmethoden. Dabei werden die für Bildverarbeitung gültigen Modelle erweitert. Die Genauigkeit der Extraktion von Strukturlinien wird durch die Bestimmung der Subpixelposition auf Subpixelbereich gesteigert. Insgesamt zeigt die Arbeit zur Extraktion von Strukturlinien, dass durch die Einführung von digitalen Bildverarbeitungsmethoden in vielen Anwendungsgebieten gute Ergebnisse erzielt werden können, ohne objektspezifisches Wissen einsetzen zu müssen.

1. INTRODUCTION

Laserscanning is a sophisticated method for topographic mapping. It serves for the generation of digital elevation models (DEM). The following issues are of main interest for the scientific investigation of laserscanning: a) topographic immediate survey of ground in areas where photogrammetric methods fail or are difficult and not possible (e.g. coastal areas and forests) and b) implementation of a processing chain for the raw data which is automatic to a large extent. As a response to the increasing demand for DEM it is anticipated to provide final products in a short time with low personal costs and with a sufficient accuracy even for large areas.

Methods, based on mathematical morphology and robust parameter estimation, are explored for the detection of ground points and for the separation of ground points from non-ground points. For a first approximation the shape of the surface is estimated with the help of a morphological operator. As a result it is possible to postulate hypotheses for ground points and non-ground points. The following task is the modeling of the ground surface and hypothesis tests. Models, based on robust parameter estimation, are developed and studied. The developed models are verified in relation with test areas.

Structure lines belong to the additional form information which are of great importance for the construction of the precise DEM. According to (WILD 1983, BILL 1999) additional form information can be defined as follows:

- *Prominent height points,*
- *Fall lines, ridge and valley lines and*
- *Edge lines.*

In order to extract additional form information, digital remote sensing data or digital topographical maps can be applied for the evaluation and structuring. There were already some examinations for the extraction of structure information with the scanned outlines of the topographical maps where locations were taken from the topographical maps and the height from the optical laser scanning data. Unfortunately, a disadvantage is that the outlines -conditional through the creation type- were not everywhere geometrically perfect and not always current (HAHN 1999).

The attempts to extract structure lines with a special program from the laser scanning data have been not so successful now (HAHN 1999). It needs still to execute the intensive examinations about the reliability of edge investigation before sufficient qualified statements can be made (KNABENSCHUH 1999).

The edge extraction with aerial photos has long history and in this field very many procedures are available. This can also be divided into standard procedures and statistical procedures (FUCHS 1998). The standard procedures occupy oneself with the analysis of the edge strength and edge direction and the statistical procedures mostly with the likelihood or energy optimisation .

The other procedures to the edge extraction base on the models of the scale space and as well as on the bases of the differential geometry. The differential geometry concerns oneself with the local qualities of curves and surfaces that depend on the behavior of the curve or surface in the surroundings of a point (JIANG 1997, WEIDNER 1995). Structure lines characterize a bigger surface curvature on the terrain surface. Therefore, structure lines can be examined by the analysis of the surface curvature.

About edge extraction from DEM data some examinations were enforced (ECKSTEIN et. al. 1995, ECKSTEIN 1996). With these procedures the good results were achieved for the building extraction for example (MAYER 1998, WEIDNER 1997) .

The present work for the extraction of structure lines from DEM data bases on the methods of the digital image processing. For this purpose the original data that are arranged in a digital elevation model (DEM) are converted and interpreted to the gray value of a picture matrix. Then the digital image processing algorithms can be used and developed to find structure lines.

2. PROCESSING OF LASER SCANNER DATA

The measured laser points contain consequently the points that lie on the topographically to lift terrain-surface (ground-points). In addition there are points that lie on those objects which are not relevant to the DEM-construction (not-ground-points). From this fact, the task of the processing of laser scanner data consists in the separation of the two laser point types, also in the separation of ground-points and not-ground-points.

The processing of laser scanner data in the work is divided into two steps. In the first step, a two-dimensional morphological operator is applied. The point-hypotheses are gotten by it. After this morphological operation the terrain-surface can be described and estimated using different methods.

This processing method of laser measurements that is apportioned in two steps delivers two advantages: A morphological Opening-Operator obtains the approximation-values of the ground-points. These points correspond to the sought terrain-surface as the first approximation. The second advantage is that all laser points can be determined with different weights after the morphological operation. The terrain-surface can be processed and estimated better with the ground-point-hypotheses, as if all laser-points are directly introduced in the settlement and calculation with the same weights at the start. All laser-points have different weights in dependence of the prior step. With help of robust estimation methods all laser-points are processed again then.

To the modeling of the terrain-surface and to the processing of point-hypotheses a ***n***ot-causal ***a***uto-***r***egressive process (shortened ***nar***-Process) and a ***c***ausal ***a***uto-***r***egressive process (shortened ***car***-process) are applied. Besides these two models, a robust ***M***-estimator that is often used in the statistics and for the processing of geodesic data is introduced.

The results of the developed procedures for the processing of laser scanner data can be illustrated on the basis of some examples. The **Fig. 1** shows a perspective view of the original-data of a test area. This area is mixed and covered with different objects. The **Fig. 2** represents the perspective view of the processed data with the nar-Model. From the illustration Fig. 2 and through the comparison with the Fig. 1 of the original-data it can be recognized that the disturbances are eliminated and the terrain-surface is remained well after the modeling and estimation.

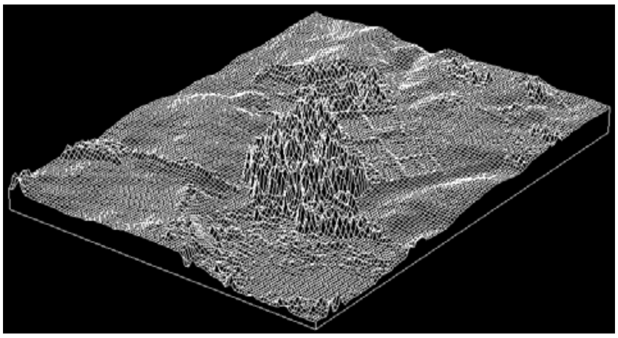


Figure 1. Perspective view of the original data

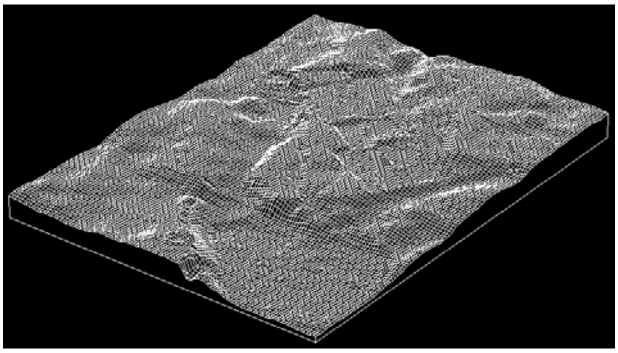


Figure 2. Perspective view of the processed data

In order to prove and to represent the developed procedures better, the following two illustrations are represented. The **Fig. 3** and **Fig. 4** represent two height-profiles of the original data and the processed data. From these illustrations it can be also represented that the disturbances are eliminated too.

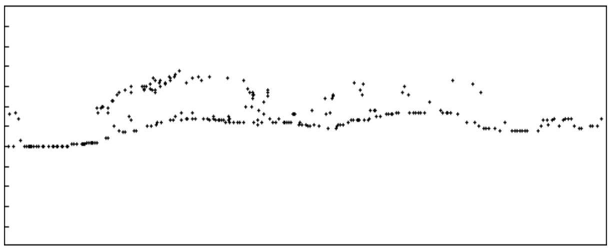


Figure 3. Height-profiles of the original data

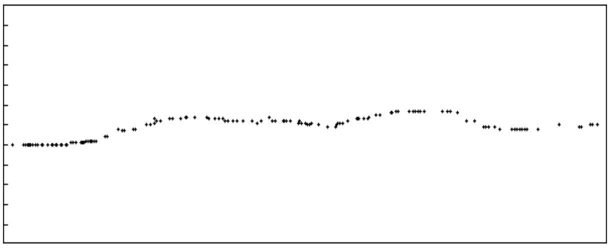


Figure 4. Height-profiles of the processed data

3. EXTRACTION OF STRUCTURE LINES WITH LASER SCANNER DATA

3.1 Data Pre-processing

If the identified, irregular distributed laser points are used as entry data, these points must be interpolated at first. If the raster DEM data are available and exist as height values, these data can be converted into the form of gray values. So a single conversion form can be used:

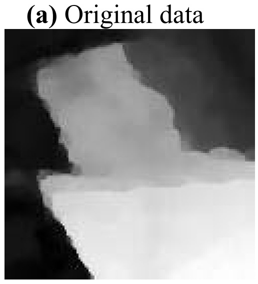
$$G_i = \frac{255}{H_{\max} - H_{\min}} * (H_i - H_{\min}) \tag{1}$$

where $H_{\max}$ *and* $H_{\min}$ represent the highest and deepest height value within DEM data.

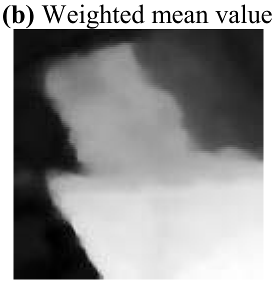
Another pre-processing of the data is the so-called smoothing and the edge reinforcement of the data. These two processes form the improvement together. The improvement of image has the goal to reinforce the selective information through the highlight of geometrical structures. In order to avoid the influence of the edge smearing by smoothing on the following processing of the edge extraction, a reinforcement process can be enforced. In this case, two possibilities are available. Either a high pass filtering is carried out after smoothing or a preserving filtering procedure can be used for the filtering and improvement of the original data. This process reinforces discontinuity of the edge then again. The different smoothing methods are tested and examined in the work. The Fig. 5 represents some results with the different filtering methods. The Fig. 5 (a) is a original data without filtering. The remaining three Fig. 5 (b), (c) and (d) give the results of the known filtering methods of the weighted mean value smoothing, the adaptive gradient and the SUSAN-filter again. With these illustrations and from our experiences it can be recognized that the methods of the adaptive gradient and SUSAN-filter for edge preserving filtering can achieve a better result than it from the method of the simple weighted mean value.

(a) Original data

(b) Weighted mean value



(c) Adaptive gradient



(d) SUSAN-filter

Figure 5. Filtering with laser scanner data

3.2 Extraction of Edge Lines

3.2.1 Detection of Edge Lines

The first derivation of derivation operators has a local maximum at a edge, the second derivation represents a zero crossings. For the two-dimensional gray images the partial derivations $\partial f(x,y)/\partial x$ and $\partial f(x,y)/\partial y$ are computed. The first partial derivation is a measure for the change of the gray values and therefore for the edge strength. It is at the strongest normality to the derivation direction. Our goal is to search a filter operator that can extract the edge independently from their orientations. From the spatial derivations in the different directions of the coordinate we can form a vector operator, also as a gradient vector:

$$\nabla g = \left[\frac{\partial g}{\partial x_1}, \frac{\partial g}{\partial x_2}, \ldots, \frac{\partial g}{\partial x_n} \right] \tag{2}$$

Because the gradient is a vector, its amount

$$\left| \nabla g \right| = \left(\sum_{k=1}^{n} \left(\frac{\partial g}{\partial x_k} \right)^2 \right)^{1/2} \tag{3}$$

is invariant during a rotation of the coordinate system. The vector ∇g represents in the direction of the strongest change. The direction of the gradient is then valid:

$$\phi = \arctan\left(\frac{\partial g(x,y)}{\partial y} \Big/ \frac{\partial g(x,y)}{\partial x} \right) \tag{4}$$

The filter function is written as a mask. A rectangular, cross shaped or approximatively circular shadow mask are customarily for example. A rectangular mask is usually applied to the edge detection. As a selection according to Canny-operator the standardized two-dimensional Gauss's function

$$G_\sigma(x,y)=e^{-\frac{x^2+y^2}{2\sigma^2}} \quad (5)$$

can be introduced and applied.

In imitation of the classical introduction of a edge operator, the image function can be folded in the continuous form $f(x,y)$ with the direction derivations of the Gauss's function in x- and y direction with smoothing filter and derivation operator as follows:

$$\begin{aligned} D_x(x,y) &= \frac{\partial}{\partial x}(G_\sigma(x,y)*f(x,y)) \\ &= \frac{\partial G_\sigma(x,y)}{\partial x}*f(x,y) \\ D_y(x,y) &= \frac{\partial}{\partial y}(G_\sigma(x,y)*f(x,y)) \\ &= \frac{\partial G_\sigma(x,y)}{\partial y}*f(x,y) \end{aligned} \quad (6)$$

The first derivations in x- and y-direction are the result of the equation (7) and the gradient $D(x,y)$ of the smoothed image function and the orientation of the edge lines on the place (x,y) are the result of the equation (8).

$$\begin{aligned} \frac{\partial G_\sigma(x,y)}{\partial x} &= -\frac{x}{\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}} \\ \frac{\partial G_\sigma(x,y)}{\partial y} &= -\frac{y}{\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}} \end{aligned} \quad (7)$$

$$\begin{aligned} D(x,y) &= \sqrt{(D_x(x,y))^2+(D_y(x,y))^2} \\ \Phi(x,y) &= \arctan(D_y(x,y)/D_x(x,y)) \end{aligned} \quad (8)$$

The orientation represents the direction of the tangent at the outline which is described by the individual edge elements. The gradient $D(x,y)$ expresses always in the direction of the strongest ascent and in this way it is always vertical to the edge direction at the examined point (x,y). The scale parameter σ (standard deviation) determines the smoothing strength. A greater smoothing effect can be achieved by the enlargement of the parameter σ and the filtering masks that can bring the disadvantage of a bad localization of the edge lines with itself. Furthermore, several fine points or single shorter lines arise within an edge line, if this parameter σ is chosen too small. In order to avoid both disadvantages in this case, we can use a processing after the edge detection (post processing) that consist of the process of non-maximum-suppression by the analysis of the edge directions and strength, the process of hysterics-threshold-method and a process of the constraint-thinning-method, if this is necessary. As follows both post-processing steps are explained briefly.

3.2.2 Post-processing of the Detected Lines

One of the post-processing of the detected edge lines is the non-maximum-suppression. In this case, the possible edge points should be reinforced by the suppression of the non-edge-points. This procedure to the edge post-processing puts on the information of the potential edge-points, the edge direction and strength. The procedure of the non-maximum-suppression supplies a better possibility to the post-processing of the edge lines.

Other procedure of the post processing is the hysteresis-threshold-method. Not only one threshold value, but also a threshold value range with a higher threshold value *THhigh* and a lower threshold value *THlow* is used to the post-processing. The points on which the gradient amount exceeds the high threshold value *THhigh* are used in order to begin to search a new outlines. The edge points and outlines below the threshold value *THlow* are then discharged. The choice of the two threshold values must be decided according to the different data or images.

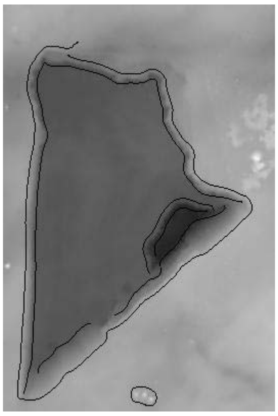
3.2.3 Determination of the Sub Position for Edge Points

The localization of the edge points can be increased to the sub pixel accuracy when a balancing parabola is placed by the three gradient values laying on the gradient direction. This calculation of the sub position for the edge points is especially important if the stitch-width of DEM data (the DEM grid distance) is very great.

The execution of this calculation for the sub pixel position starts from the assumption that the three gradient values laying on the gradient direction are detected. From the three gradient values a parabola-equation can be clear determined unequivocally which an **u-v**-coordination system is introduced as local line system: the **u** lies on the edge-line-direction and **v** is vertical to this edge-line-direction, therefore it lies on the gradient direction. The optimal sub position of a edge point lies on the maximum of the balancing parabola. The searched sub position of a edge point is the results of the maximum value then (Fuchs 1998).

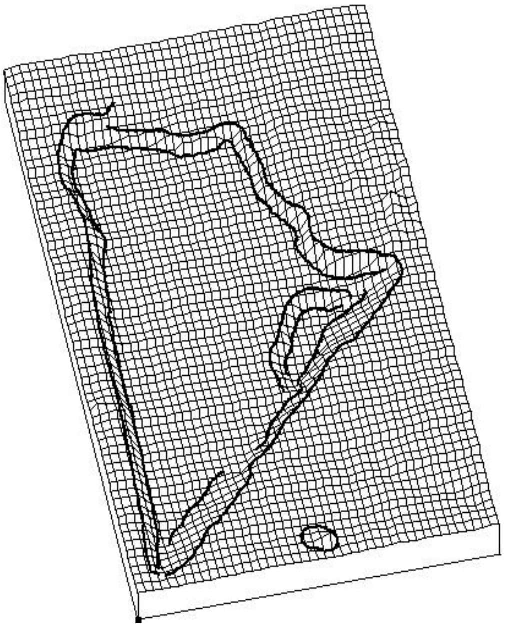
3.2.4 Results of the Extraction of Edge Lines

Usually we can select the threshold values interactively. It is reasonably to develop a quantitative procedure to the selection of the threshold values. In work a threshold value is approximately determined at first. From this approximated threshold value the two threshold values are computed then. To the determination of the two threshold values *THhigh* and *THlow* the two procedures are be used: an empirical procedure and a procedure with the histogram calculation. Both procedures supply the approximated values of two threshold values. The correct choice should be carried out interactively. The **Fig.6** represents some results of the extraction of structure lines. The Fig.6 (a) shows the detected edge lines with the overlapping of the height value image. Compared to the topographical map of the Fig.6 (b) it can be recognized that the developed procedure for the extraction of the structure lines with the laser scanner data can supply the reliable results. The Fig.6 (c) shows a perspective view. These results have reminded the procedure for the extraction of the structure lines.



(a) Detected edge lines

(b) Digitalized topographical map



(c) Perspective view

Figure 6. Extraction of the structure lines with laser scanner data

3.2.5 Extraction of the Valley Lines

The fall lines as the strongest terrain-inclination play an outstanding role for the hydrological examinations of a terrain. It is important to the determination of the rive lines, to the identification of the drain lines of a certain point or the area (the spreading of the flood). In addition they play an important role in the agrarian area to the planning and establishing of the development direction in the inclined terrain and in the street construction to the regulation of the behavior of cold-air in the fog basins (RIEGER 1992).

In the curvature area fall lines represent a biggest surface inclination on the terrain-surface. Therefore a fall line represents a positive or a negative maximal curvature value. To the description of three-dimensional surfaces the 2.5D-repräsentation form is often chosen (WEIDNER 1995). For example the digital elevation model (DEM) can be given by

$$\chi = (\chi_1, \chi_2, \chi_3). \quad (9)$$

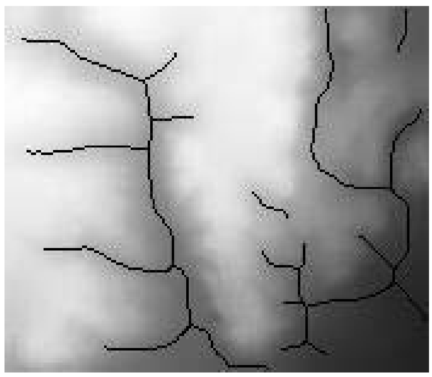
Through this representation the above stated equation of the differential-geometrical quantity can be simplified in the curvature area. The first derivations according to the surface-coordinates **(u,v)** are given by

$$\begin{aligned} \chi_u &= (1, 0, \chi_{3,u}) \\ \chi_v &= (0, 1, \chi_{3,v}) \end{aligned} . \quad (10)$$

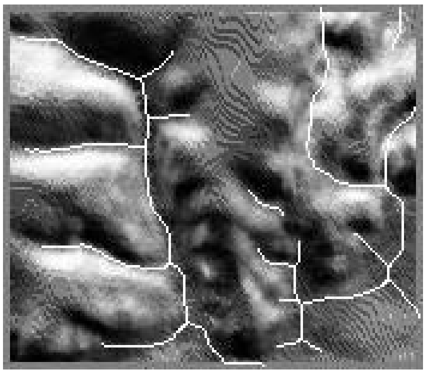
The second derivations show then in following

$$\begin{aligned} \chi_{uu} &= (0, 0, \chi_{3,uu}) \\ \chi_{uv} &= (0, 0, \chi_{3,uv}) \\ \chi_{vv} &= (0, 0, \chi_{3,vv}) \end{aligned} . \quad (11)$$

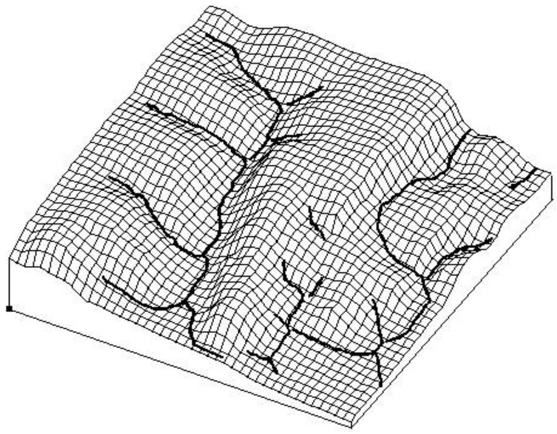
Based on these equations the Gauß's and middle curvature or maximum and minimal curvature can be used for example as in (WEIDNER 1995, JIANG 1997, HAALA 1997, WILD and KRZYSTEK 1996). The Following **Fig. 7** show some results of the extraction of drain lines with the curvature measurements.



(a) Drain lines on the gray image



(b) Drain lines on the relief image



(c) Perspective view

Figure 7**.** Extraction of the drain lines with laser scanner data

4. OUTLOOK

The motivation of the work consisted in the analysis of laser scanner data. The processing of the measured laser points consisted in the separation of the usable laser points and the topographically not interesting laser points. The solution of this task was based on two mathematical theories, the mathematical morphology and the robust processes. With the models of the morphological operators the terrain-surface was approximated. The real ground-points were identified by the subsequent hypothesis-test.

The digital image processing methods were applied to extract the additional form information on the one hand, the developed and realized procedure to the extraction of the structure lines allowed the expansions for other demands in simple way. On the other hand, some aspects of the procedure could be performance-enhancing integrated in other procedures. The extracted structure lines will improve the quality of the precise DEM. Furthermore, it will supply the additional information for GIS and for the 3D reconstruction of objects.

Localization, reliability and precision are the important criterions to the checkup and judgement for the extraction of the structure lines of the procedure. Through the determination of the sub pixel position, the accuracy of the procedure has reached the sub pixel sphere. Simultaneously, the quality of the localization and the reliability are increased.

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