Derivation of Digital Surface Models and Digital Terrain Models from Airborne Laser Scanning Data

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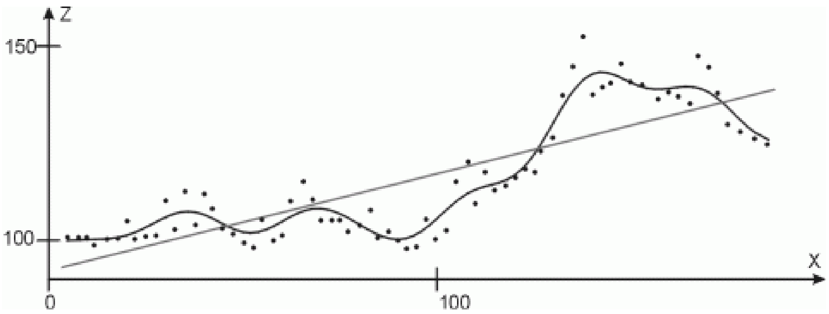
1. Theoretical Background

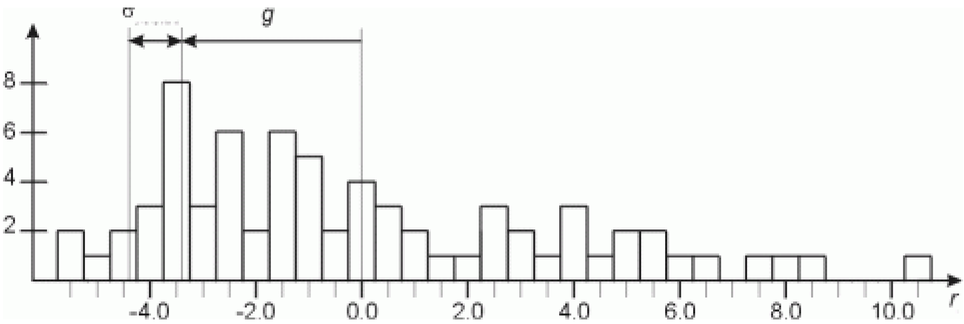
This section will give an overview on the special methods for DTM computation from laser scanner data. It will present the theoretical aspects in compact form. More detailed information is available in the SCOP++ manual and references to it will be given in the text.

Filtering of Laser Scanner Data

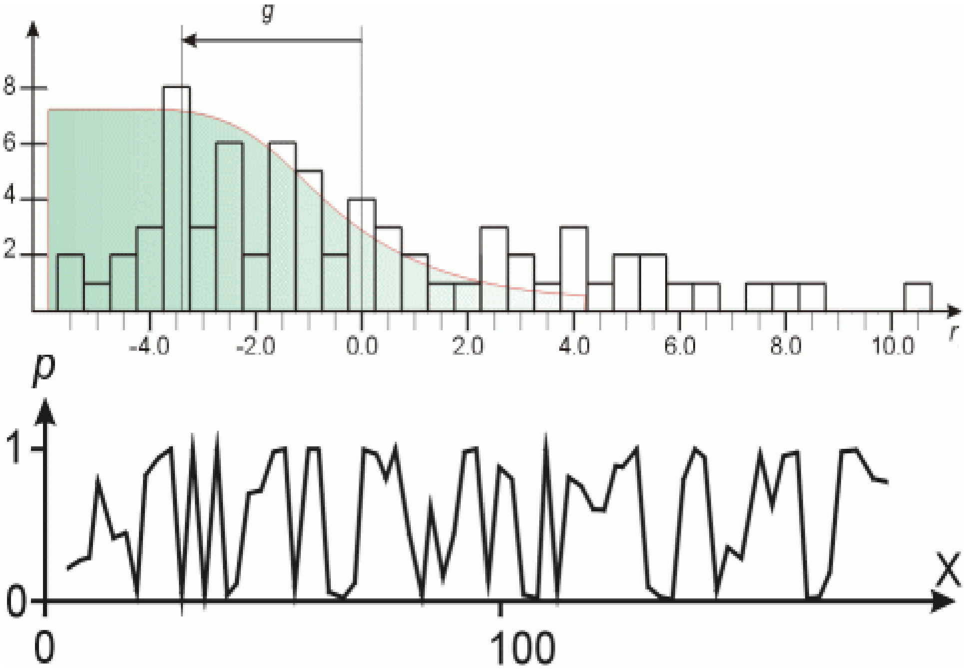
The principles of the classification of laser scanner data are very simple. The first step is to compute an averaging surface which runs in a medium layer between terrain and off-terrain points. The terrain points will generally lie below this intermediate surface and the off-terrain points above it. For a profile this is shown in the next figure.



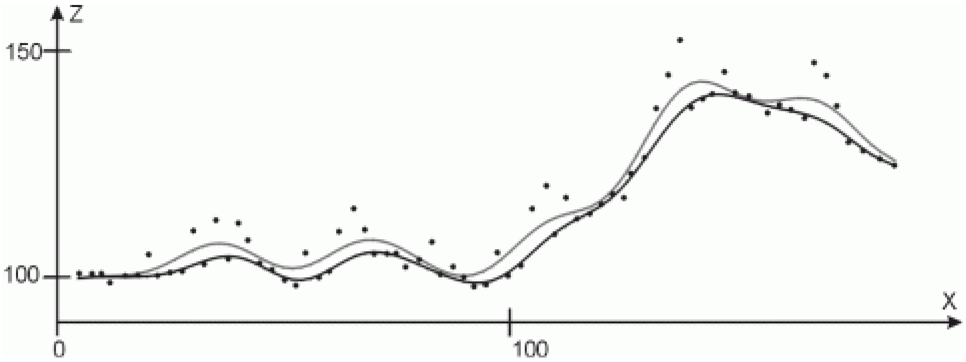
The gray line is the trend which is split off before the computation. In the next figure a histogram of the residuals is shown. For positive values the point lies above the surface.



Now, the key idea is the following: Compute weights, individual for each point, depending on the signed distance from the point to the surface. If the distance is positive, the weight shall be low (close to zero), if the distance is negative, the weight shall be high (close to one). The images show the weight function overlayed to the residuals and the weights over the profile ground plan positions.



Then repeat the terrain computation under consideration of the weights. Points with high weight will attract the surface while points with low weight will have only little influence on the run of the surface.

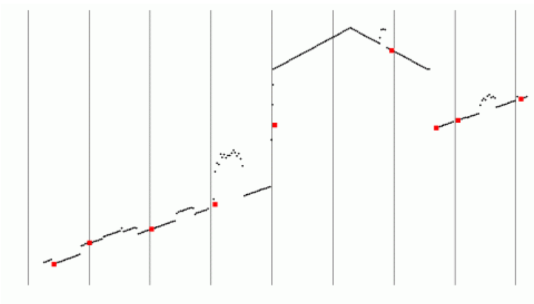


The gray line is the surface from the first iteration where all points had the same weight. The black line is the resulting surface after a few iterations.

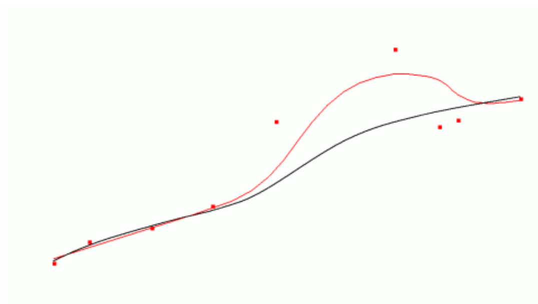
Remarks
This method works well for wooded areas, even if the penetration rate is about 50% or below. In such a case the off terrain points are vegetation points, and the number of required iterations is three or four. In the first iterations the canopy points are eliminated, in the next iterations the under story points are found.
The method fails if the points are not mixed thoroughly. This means that the vegetation points must not appear in clusters without one terrain point. Especially if the method is applied to city areas, the off-terrain points show this systematic behavior (e.g. at house roofs).

Hierarchical Approach

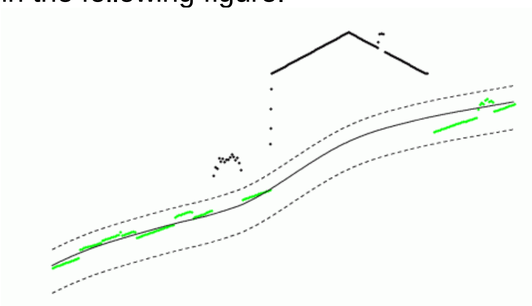
For the above reasons, and also in order to make the computation more robust, a hierarchical approach is applied. For this, the original data is thinned out and the filtering is performed at different levels of resolution, starting with the coarsest level.
First, the data set with the lowest resolution is generated by a **thin out** of the originally given points. In this **thin out** step different methods can be applied. In SCOP++ a raster based thinning is provided which works by laying a grid over the complete domain and determining one point for each cell. This point can be computed in different ways e.g. taking the lowest or the mean point in each cell. Schematically this is shown in the figure showing a profile.



The red points are the selected points for each cell. The vertical bars denote the grid width.
In the next step the **Robust Filtering** - as explained above - is applied. This generates a coarse terrain model.



The red surface is obtained with equal weights for all points and the black surface is determined after a few iterations. It is a rough approximation of the terrain surface.
In the third step the original points are compared to this coarse DTM, the aim of this step is to **sort out** the original points which are close to the coarse surface. These points provide a finer description of the terrain than on the previous level. It is shown in the following figure.



A tolerance band is laid around the coarse surface. The green points are selected. As it can be seen, not only the terrain points are chosen, but also points on the low vegetation.
The three steps from above (**thin out** - **filter** - **sort out**) are repeated. The first **thin out** operated on the original points, but for further runs of **thin out** the points from the previous sort out are thinned out. After the last sort out only another filter is applied and the final terrain model is obtained from the classified terrain points in the original resolution.
In our example no intermediate (**thin out** - **filter** - **sort out** `triples') are necessary and the points are filtered robustly. The result is shown in the figure.

The red line shows the surface with equal weights for all points. After the robust interpolation the black surface i.e. the final terrain model, is obtained.

Remarks
This approach cannot only be used to filter (classify) laser scanner data, but also in order to eliminate grossly false points from other data sources, including terrestrial laser scanning and tacheometry.

For airborne laser scanning data usually three levels are sufficient. Thus the sequence of steps is: **ThinOut - Filter - SortOut - ThinOut - Filter - SortOut - Filter**

2. Instructions for DTM derivation and visualisation with SCOP++

Start SCOP++ with the icon .

New project

Project* ► *New…* ► *Name enter project name, ***Location*** enter location for saving ► ***ok***

At the location for saving, a folder with the name of the project appears. It contains the files "project name.spr", "project name.TOP", and "project name.cmf".

Attention: The project name may exist only once on a computer!
HINT: Leave the default directory in ***Location*** to ease the overview on the already used names.

Open an existing project

Project* ► *Open…* ► *Browse project name.spr ► ***ok***

Add a Model overlay (This dialog opens automatically after creating a new project)

Overlays* ► *Add model overlay* ► *Name enter overlay name ► ● ***Both* ► *ok***

Model-only: Enables the visualisation (shading, height coding, isolines) of a DSM/DTM (*.dtm).
Data-only: Enables to edit and visualise the data set (*.xyz, *.wnp, etc.).
Both: Enables DSM/DTM derivation, visualisation of the data set and of the DSM/DTM, editing of the data set.

A button with the overlay name appears on the left side of the window (from now on called ***ModelOverlay***)

In the project directory, a folder with the overlay name appears. The results of the DSM/DTM derivation are written into this folder.

Data import (This dialog opens automatically after creating a new overlay)

ModelOverlay* ► *Import/Export* ► *Data* ► *Import…* ► *Browse (set ***Filename*** and ***Data format***) ► ***ok***

Limits

Either the whole area or a smaller part can be considered for DSM/DTM derivation or visualisation. You can digitise the area of interest in ***Limits...***, set coordinates with ***Limits...* ► *Edit*** or take the whole area with ***Limits...* ► *Set to max.*** The limits are valid for the checked options in ***Limits for*** (Screen, Model, Views, Data).

Attention: Limits are always set for all overlays!

Hierarchic robust interpolation

ModelOverlay* ► *Model* ► ● *Robust filtering* ► *Details robust…

Window ***DTM*** overlay name***: Robust filter strategy***:

Parameter persistence
Select Robust filter strategy "**Lidar DTM Default**" instead of the default strategy ***Li-dar Default****, then a sequence of steps appears in ***Steps*** (EliminateBuildings StepX, ThinOut Step X, Filter Step X, Interpolate Step X, SortOut Step X, Edit Step X). The sequence of these steps can be changed in ***Modify strategy*** (***At position* ● *Insert step*** or ● ***Remove step***; ***Position*** 0 to last; ***Add* ●*EliminateBuildings* ● *ThinOut***, ● ***Filter***, ● ***Interpolate***, ● ***SortOut*** or ● ***Edit* ●*FillVoidAreas***; ***Realize*** fulfills the change; Attention: a Filter or Interpolate step has to be set before a SortOut step, the whole sequence has to be terminated with an Interpolate or Filter step)

The steps may be activated resp. deactivated and the parameters of these steps may be changed by pressing the respective button and selecting ***Properties...***

EliminateBuildings Step X...
Morphological (shape-based) filter for the elimination of points on buildings. The filter is based on a grid of width **Cell size**. It detects connected cells as building areas, if the area is >= **Minimal area**, if the slopes between the suspected cells is low, and if the slopes to the bordering, presumably non-building cells is >= **Minimal slope**.

ThinOut Step X...
Thin out of the data: Take the ***Lowest***, ***Highest***, ***Mean***, or ***Center*** point in each cell (***Cell size***). ALS data demand the ***Lowest*** point due to their height distribution.
Result: stepX.tho

Filter Step X…
In this step the robust interpolation is applied. First, a DTM from the point cloud is computed without weights. Afterwards, the ALS data are weighted on the basis of their residuals. After some iterations, the terrain and off-terrain points are written off.
The user may influence the weight function and the interpolations.

Weight function
Using ALS data low points get high weights (Lower branch no descent) because they most likely represent terrain points (exception: "long ranges").
Halfweight: Size of the residual which should be weighted with 0.5.
Slant: Slant of the weight function, the smaller this value, the steeper the function..

Interpolation
Trend: For every CU a tilted plane is computed.
Prediction: Basis of the DTM derivation is the linear prediction.

Number of Iterations: Maximum number of iterations.

Model-points relative to preliminary surface:
Here, you can set the origin of the weight function below, on, or above the prelimi-nary surface. Using ALS data the origin of the weight function should lie below the preliminary surface.

Penetration rate Estimation of the penetration rate, i.e. how many terrain points are existing (percentage)? Is used to define the origin of the weight function, as well.

Details Interpolation... Vide linear prediction. The grid width has to be set within the window.
Result: stepX.grd, stepX.veg, stepX.dtm

Interpolate Step X…
Vide linear prediction. The grid width has to be set within the window. This step is necessary after the robust interpolation to derive a DTM from the declared terrain points without robust weights.
Result: stepX.dtm

SortOut Step X…
Specification of the tolerance band surrounding the earlier derived DTM. ***Below surface***/***Above surface***: set respectively the maximum allowed distance to the DTM or no limit).
Result: stepX.sog, stepX.sov

Edit Step X...
The program GVE opens automatically, there is the possibility to edit the data.
Attention: Save the resulting point cloud as stepX.edt and close the GVE, otherwise the DTM derivation is not continued.

FillVoidAreas Step X...
Large areas without data may result from the filtering of ALS data, which in turn may generate problems in the high resolution inerpolation. In order to avoid them, those areas may be filled with additional, estimated points using **FillVoidAreas**. In doing so, **Sampling interval** determines the minimum distance to the next original data point, above which a new point will be inserted. Additionally, this parameter specifies the distance among the filling points. **Bridging distance** defines the maximum distance to the next original point, above which no filling points will be generated. For the estimation of filling point heights, three methods are available: **Linear prediction**, **Moving planes**, and **Triangulation**. The first two start with a temporary thinning of the original data. Subsequently, the filling point heights are interpolated at a low resolution.

Attention: To get a calculation protocol check in ***Options ► Protocol*** (you can find the protocol in ***ModelOverlay ► Model ► Protocol*** after sDTM computation)

In order to analyse the results of intermediate processing steps the individual steps can be de-activated by clicking on the respective step. It is useful to never deactivate the last **Interpolate** step. In order to check the accepted points of a certain **SortOut** Step just deactivate all steps after the respective **SortOut** step and just activate the last **Interpolation** step. For the final DTM a **FillVoidAreas** should be used in order to close data holes.

Difference model

Requirement: DSMs/DTMs do exist already in two overlapping ModelOverlays (except you want to add or subtract a horizontal plane).

Tools ► Difference models...

Window ***Difference models***

Remove the check mark from ***Use constant plane*****;** choose a ***ModelOverlay*** respectively for ***Second overlay*** *a*nd ***First overlay*** (Second overlay minus First overlay); set file name and path in ***Save as***; set check mark at ***Add*** in ***Add as model overlay***, set a new overlay name for the difference model

Further information can be found in the SCOP++ notes included in the description of the first part of the exercise and in the SCOP++ Manual.

3. Handling of error messages and program crashes

Error messages are explained in the SCOP++ manual (section 12.3).

Crash of SCOP++:
Kill the processes scop++.exe and RPC_TdmServer.exe in the task manager, start SCOP++ again (possibly twice).
Delete all *.TOP and *.TTT files in the directories d:\ScopProjects\topdb\cfg, cvt, dpm, grf, mkt, sys.
Deregister the project (***Project*** ► ***Deregister*** ► mark the respective project ►***ok***) and possibly delete the project.

4. Further Information

SCOP++ Manual

EuroSDR distance learning course: http://www.ipf.tuwien.ac.at/eurosdr/

Publications:

Kraus K., Pfeifer N., 1998:
„Determination of terrain models in wooded areas with airborne laser scanner data“. ISPRS Journal, Volume 53, 1998, pp. 193 - 203.

Briese C., Pfeifer N., Dorninger P., 2002:
"Applications of the Robust Interpolation for DTM determination".
Presentation: Symposium der ISPRS-Comm. III, Graz; 09-09-2002 - 09-13-2002; in: "International Archives of Photogrammetry and Remote Sensing", Volume XXXIV / 3A (2002), ISSN 1682-1750; 55 - 61.