Development of an algorithm to generate a Lidar pit-free canopy height model

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Extended Abstract

Lidar-derived Canopy Height Models (CHMs) are commonly used for extracting relevant forest information. Often irregular height variations – also called data pits or simply pits – are present in the CHM. These pits typically appear when the first Lidar return is far below the canopy which tends to happen for two reasons. The first reason is that a laser beam deeply penetrates through the branches and the foliage before producing the first return (Persson *et al.*, 2002). The second reason is multiple laser beams – possibly from different flight lines – produce their first return in close horizontal proximity but with a great height difference because they "see" the canopy or the ground from different angles (Leckie *et al.*, 2003). These pits hamper the correct extraction of forestry metrics from the CHM.

Previous studies recommend to apply smoothing such as a median filter or a Gaussian filter to reduce pits. However, smoothing modifies all height values of the CHM not just those corresponding to pits and a filter may "smooth away" small trees when its support is on the order of the crown diameter (Solberg *et al.*, 2006). We now describe the implementation of a new algorithm for generating pit-free CHM rasters from different density Lidar point clouds and visually compare them to those obtained with standard Gaussian smoothing.

1. Description of pit-free algorithm

Our algorithm consists of three stages. The first stage normalizes the height of the Lidar data by replacing the elevation of each point (i.e. the original z coordinate) with its vertical height above the ground. The second stage constructs a standard CHM from all first returns and – most importantly – a number of partial CHMs from only those first returns that correspond to higher-up vegetation hits. The third stage composes all the standard and the partial CHMs into one CHM by keeping only the highest value across all CHMs for each x and y raster position. This algorithm is easily implemented in the command line with a batch script (see Appendix) using a combination of the efficient *lasheight*, *blast2dem* and *lasgrid* modules of LAStools.

First, the Lidar points are height-normalized by replacing the elevation of each point with their vertical distance to a triangular irregular network (TIN) of the ground points that is constructed by Delaunay triangulating their x and y coordinates in 2D.

Second, a standard CHM raster is computed by triangulating all first returns and rasterizing the resulting TIN. A set of partial CHM_{XX} rasters is computed by excluding all returns below a certain height threshold. We triangulated only those first returns into a TIN whose height exceeds the respective threshold XX and moreover by rasterizing only those triangles whose edge length are all below a certain rasterization threshold (see Figure 1). With the right combination of thresholds the partial CHM_{XX} represent increasingly high parts of the canopy.

Third, the final pit-free CHM raster is created by combining the partial CHM_{XX} rasters (CHM_{00} to CHM_{15}). This process can be imagined as stacking the CHM_{XX} on top of each other with CHM_{00} at the bottom and CHM_{15} at the top. The pit-free CHM has at each cell location the maximum value across all input rasters CHM_{00} to CHM_{15}.
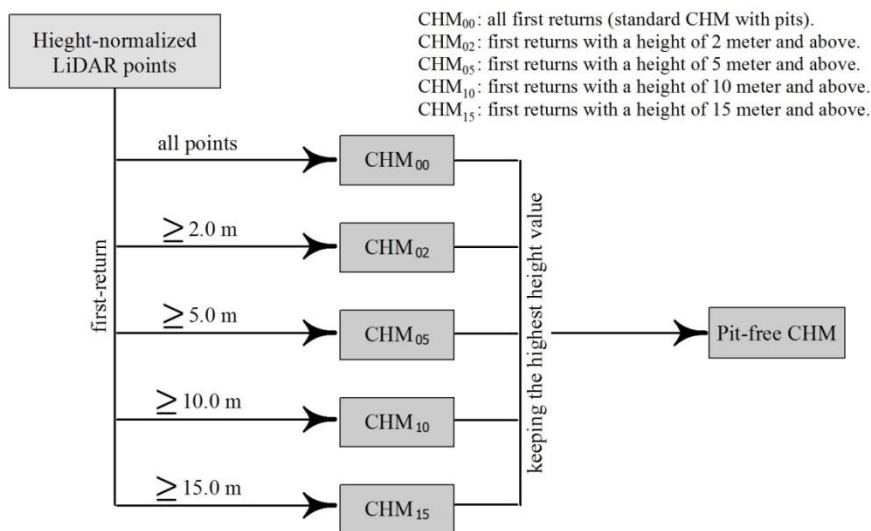

Figure 1. Simple diagram of the pit-free algorithm's work-flow

2. Results

We applied our pit-free algorithm to Lidar data from the Bois Noir (black wood) forest in the Barcelonnette basin located in the southern French Alps (44° 23′ N, 6° 45′ E). The size of the study area is about 1.3 km^2 which is mainly covered by coniferous plantation forests. The Lidar data was acquired during the leaf-on season in July 2009 flying at about 300 m above ground level. The mean point density was 160 point/m^2 with an average distance between laser points of 0.08 meters. We created a CHM with a resolution of 0.15 meters from this data using a rasterization threshold of 0.45 meters.

To demonstrate the robustness of our algorithm we artificially created a lower-density version of the Lidar data at 7 point/m^2 that is teeming with pits by applying simple point thinning using the *first only* and the *keep_every_nth* filter of LAStools (the order is important here). We created a CHM with a resolution of 0.5 meters from this data using a rasterization threshold of 1.5 meters. Our pit-free CHMs derived from both Lidar datasets were evaluated by visual comparison with the standard CHMs smoothed with a 5×5 Gaussian filter. The pits – small dark squares – that are clearly visible in Figure 2 within the tree crowns of the standard CHMs are not present in the pit-free CHMs. The Gaussian filter shows little visual effect on removing pits for the high-density dataset as the smoothed CHM appears identical to the standard CHM. However, for the low-density dataset the Gaussian filter over-smoothed the CHM especially on the shoulders of tree crowns. In contrast, our pit-free algorithm operates robustly for Lidar dataset of different density and quality. The algorithm not only effectively removed the pits but also preserved the edges of canopy gaps and crowns for both the high and the low-density dataset.
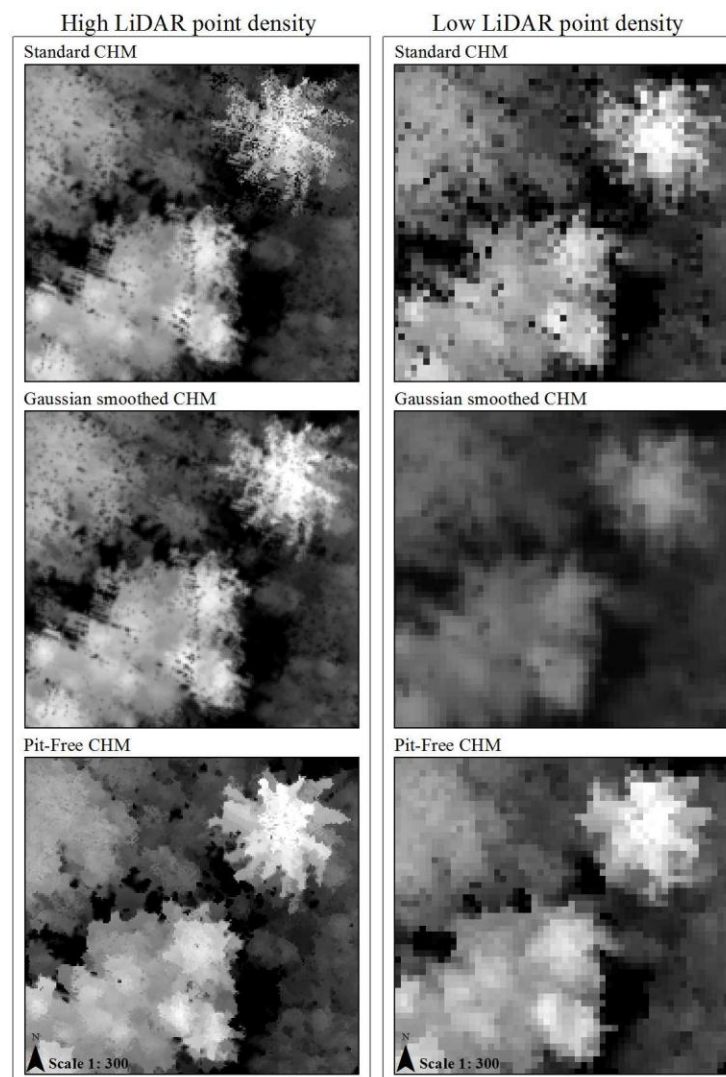
Figure 2. The pit-free CHMs versus standard and Gaussian filtered CHMs on high- and low-density Lidar data.

3. Discussion

Our algorithm is able to efficiently remove pits from a CHM raster. The algorithm is novel in that it removes the data pits directly from the Lidar point clouds during the CHM creation and because it exploits the 3D structure of the tree crowns when removing these height variations. Approaches using Gaussian filtering do not accurately target only the pits but alter all pixels of the CHM raster which often affects the original structure of the tree crown. Our result indicate that our pit-free algorithm is especially successful for low-density Lidar data full of pits such as our artificial example data which corresponds to a small footprint laser beam sampling the canopy with low density.

In current work, we quantitatively analyse how our pit-free CHMs improves measurement of biophysical tree parameters such as tree detection and height estimation.

References

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Appendix

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:: script for removal of pits in CHM using LAStools

set HEIGHT_NORMALIZED_LIDAR=bois_noir_normalized.laz
set STEP=0.15
set KILL=0.45
set TEMP_CHM_DIR=temp_chms
set PIT_FREE_CHM=chm.bil

blast2dem -i %HEIGHT_NORMALIZED_LIDAR% ^
        -keep_first ^
        -step %STEP% ^
        -odir %TEMP_CHM_DIR% -odix _00 -obil

blast2dem -i %HEIGHT_NORMALIZED_LIDAR% ^
        -keep_first -clip_z_below 2 ^
        -step %STEP% -kill %KILL% ^
        -odir %TEMP_CHM_DIR% -odix _02 -obil

blast2dem -i %HEIGHT_NORMALIZED_LIDAR% ^
        -keep_first -clip_z_below 5 ^
        -step %STEP% -kill %KILL% ^
        -odir %TEMP_CHM_DIR% -odix _05 -obil

blast2dem -i %HEIGHT_NORMALIZED_LIDAR% ^
        -keep_first -clip_z_below 10 ^
        -step %STEP% -kill %KILL% ^
        -odir %TEMP_CHM_DIR% -odix _10 -obil

blast2dem -i %HEIGHT_NORMALIZED_LIDAR% ^
        -keep_first -clip_z_below 15 ^
        -step %STEP% -kill %KILL% ^
        -odir %TEMP_CHM_DIR% -odix _15 -obil

lasgrid -i %TEMP_CHM_DIR%¥*.bil -merged ^
      -step %STEP% -highest ^
      -o %PIT_FREE_CHM%
```