REIN Algorithm and the Influence of Point Cloud Density on nDSM and DEM Precision in a Submediterranean Forest

Andrej Kobler andrej.kobler@gozdis.si
Peter Ogrinc peter.ogrinc@gozdis.si
Slovenian Forestry Institute

ScandLaser 2007, Helsinki, September 13, 2007
Aims

- To estimate the influences of lidar point density on
  - the precision (i.e., spatial detail) of DEM extracted in a submediterranean karstic forested relief using the REIN algorithm*,
  - the precision of the corresponding forest canopy nDSM.

* REIN (Kobler et al., Remote sensing of Env. 108, 2007) is a recent algorithm used to extract DEM from point-cloud in dense forests
Description of REIN algorithm (1)

- REIN was designed especially for steep, forested areas where other filtering algorithms typically have problems distinguishing between ground returns and vegetation returns.
- REIN is applied after an initial filtering of the point cloud, which involves removal of all negative outliers and removal of many, but not necessarily all, off-ground points by some existing filtering algorithm.
Description of REIN algorithm (2)

- REIN makes use of the redundancy in the initially filtered point cloud (FPC) to mitigate the effect of the residual off-ground points.
- Multiple independent random samples are taken from the initial FPC.
- From each sample, ground elevation estimates are interpolated at individual DTM locations.
Description of REIN algorithm (3)

- The lower bounds of the distributions of the elevation estimates at each DTM location are almost insensitive to positive outliers.
- The true ground elevations can be approximated by adding the offset to the lower bounds.
- The offset is estimated from the data as global average.
Study area

Submediterranean Slovenia

Area: 400 m by 250 m
Elevation: 71 m - 233 m
Study area (cont.)

- Karsic limestone geology
- Submediterranean coppice forest
- Average tree height: 9 m
- Average canopy coverage: 64%
- Main tree species: Ostrya carpinifolia, Pinus nigra, Corylus avellana, Ulmus minor

Panorama

Aerial photo

Shaded DEM

Shaded DSM

Vegetation heights
Point-cloud data

- Acquired at the beginning of vegetation
- Optech ALTM-3100 lidar mounted onto a helicopter
- Ground speed 120 km/h
- Flying height 1000 m above ground
- Pulse rate was 100 kHz
- Scan frequency 30 Hz
- Scan angle 20°
- Beam divergence 0.3 mrad
- Obtained point densities:
  - First returns: 5.15 m²
  - Intermediate returns: 0.56 m²
  - Last returns: 7.64 m²
  - Only returns: 3.21 m²
Methods

- Different lidar point densities simulated by thinning the lidar dataset by factors of 2, 4, 8
- Resulting point densities:

<table>
<thead>
<tr>
<th>Point type</th>
<th>Point density ([m^2])</th>
<th>Data thinning factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>First</td>
<td>5.15</td>
<td>2.58</td>
</tr>
<tr>
<td>Intermediate</td>
<td>0.56</td>
<td>0.28</td>
</tr>
<tr>
<td>Last</td>
<td>7.64</td>
<td>3.82</td>
</tr>
<tr>
<td>Only</td>
<td>3.21</td>
<td>1.61</td>
</tr>
<tr>
<td>L + O</td>
<td>10.85</td>
<td>5.43</td>
</tr>
<tr>
<td>F + I + L + O</td>
<td>16.56</td>
<td>8.29</td>
</tr>
</tbody>
</table>
Methods (cont.)

- Separate DEMs, DSMs, and nDSMs were calculated for each thinning factor
- nDSM = DSM - DEM
- Raster resolution 1 by 1 m. sq.
- REIN parameter values used:
  - threshold slope for the initial slope filtering: 60°
  - number of repetitive TINs used to interpolate DEM elevations: 20
  - percentage of lidar points used to build each TIN: 10%
“Non-thinned” DEM and nDSM (i.e., DEM1, nDSM1) used as the reference for the “thinned” DEMs and nDSMs (DEMx, nDSMx; x = 2, 4, 8)
DEM results

- The DEM height errors:

- **DEM1 - DEM2**
  - DEM2 avg. error = 2 cm
  - st. dev. = 11 cm

- **DEM1 - DEM4**
  - DEM4 avg. error = 3 cm
  - st. dev. = 13 cm

- **DEM1 - DEM8**
  - DEM8 avg. error = 5 cm
  - st. dev. = 17 cm

-1 m and lower

+1 m and higher
DEM results (cont.)

- Visualizations

Shaded DEM

 DEM1

 DEM2

 DEM4

 DEM8
### nDSM results

<table>
<thead>
<tr>
<th>[m]</th>
<th>x = 2</th>
<th>x = 4</th>
<th>x = 8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum error</td>
<td>-18.04</td>
<td>-18.62</td>
<td>-20.54</td>
</tr>
<tr>
<td>Maximum error</td>
<td>1.63</td>
<td>1.55</td>
<td>2.13</td>
</tr>
<tr>
<td>Avg. error</td>
<td>-0.41</td>
<td>-1.39</td>
<td>-2.62</td>
</tr>
<tr>
<td>St. dev.</td>
<td>1.18</td>
<td>2.72</td>
<td>3.95</td>
</tr>
</tbody>
</table>
nDSM results (cont.)

- nDSM errors (thinning factor 8)

Negative errors

Positive errors

\[\geq -0.5 \text{ m} \quad 0 \text{ m} \quad \leq +0.5 \text{ m}\]
Vegetation heights correlation between the reference and “thinned” nDSMs:

![Graph showing correlation with Lidar point density (m2). The x-axis represents Lidar point density in m2, ranging from 0 to 20, and the y-axis represents correlation with nDSM1, ranging from 0.50 to 1.00.]
nDSM results (cont.)

- Percentage of empty nDSM pixels (1 m raster):
Conclusions (DEM)

- Lowering the density of the input point-cloud reduces the size of the randomly selected point subsets that REIN uses as TIN nodes.
- This in turn affects the precision (i.e., spatial detail) of the generated DEMs.
- The largest DEM elevation errors are at sharp break-lines and at locations of pronounced micro-relief, e.g., rock outcrops, terraces.
- DEM height bias increases from 2 cm to 5 cm for DEM2 and DEM8 respectively, due to a more biased estimate of REIN’s global mean offset calculation at lower point densities.
Conclusions (DEM, cont.)

- Visual evaluation of the wireframe suggests a coarser DEM raster resolutions than 1 m would be advised for the tinned point-clouds.
- DEM generalization is partly due to the use of aggressive REIN filtering in order to exclude all DEM errors related to positive outliers.
Conclusions (nDSM)

- Because nDSM = DSM - DEM, a factor in nDSM precision is also the underlying DEM precision
- Therefore spatial coincidence of nDSM (positive) errors with the DEM break-lines and micro-relief features
- Quasi-random pattern of (negative) differences due to varying fidelity of “thinned” nDSM forest canopy
- A strong effect of lidar point cloud thinning on nDSM precision can be observed in decreasing correlation of the reference and the “thinned” nDSMs
Thank you for your attention