Estimating Forest Canopy Height using Photon-counting Laser Altimetry

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The “early days” – simulated ICESat-2 data
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Challenges

- Signal noise
- Dense canopy – occludes the ground
- No canopy – gaps need to be detected
- Lots of data
High-level framework
“Snakes”: Active contour models

Image from: https://raw.github.com/pmneila/morphsnakes/master/examples/starfish.gif
“Snakes”: Active contour models

- First introduced by Kass et al. (1987)
- We are extending a technique introduced by Chan and Vese (2001) known as Geodesic Active Contours (GAC)
- The problem of finding an object boundary is cast as an energy minimization problem
“Snakes”: Active contour models

- The contour is defined in the \((x, y)\) plane of an image as a parametric curve
  \[ \mathbf{v}(s) = (x(s), y(s)) \]

- A contour is said to possess an energy \((E_{\text{snake}})\) which is defined as the sum of the three energy terms
  \[ E_{\text{snake}} = E_{\text{internal}} + E_{\text{external}} + E_{\text{constraint}} \]

- Define the energy terms in such a way that the final position of the contour will have minimum energy

- Energy minimization:
  Iteratively move the contour in an attempt to minimize \(E_{\text{snake}}\)
GAC approach

The “external” term

\[ E_{external} = \int_{inside(C)} \left| I(x, y) - c_1 \right|^2 dxdy + \int_{outside(C)} \left| I(x, y) - c_2 \right|^2 dxdy \]

where

- \( c_1 = \) average of \( I \) inside \( C \)
- \( c_2 = \) average of \( I \) outside \( C \)

Fit > 0

Fit > 0

Fit > 0

Fit ~ 0
General problem
General problem – with good result
What we obtained initially using Chan-Vese active contours
What we obtained initially using Chan-Vese active contours
Gradient-descent search

\[ - \nabla E = \begin{bmatrix} -\frac{\partial E}{\partial x} \\ -\frac{\partial E}{\partial y} \end{bmatrix} \]

Figure from: http://www.csd.uwo.ca/courses/CS4487a/Lectures/lec05_snakes.pdf
Chan-Vese active contours
Data sets

<table>
<thead>
<tr>
<th>Sigma Space Micro Pulse LiDAR (MPL)</th>
<th>Multiple-Altimeter Beam Experiment LiDAR (MABEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operates at 532 nm</td>
<td>Dual-wavelength (532 nm and 1064 nm)</td>
</tr>
<tr>
<td>Low altitude</td>
<td>High-altitude</td>
</tr>
<tr>
<td>Data is downsampled and noise is simulated</td>
<td>Specifically developed as a validation tool for ICESat-2</td>
</tr>
<tr>
<td>15 transects (2-4 km each)</td>
<td>142 transects (12-15 km each)</td>
</tr>
<tr>
<td>Taken in October, 2009</td>
<td>Taken in September, 2012</td>
</tr>
</tbody>
</table>
Some G-LiHT lines were coregistered manually to the MABEL data by Mike Lefsky at Colorado State University.
MABEL: Multiple Altimeter Beam Experimental Lidar

Flight lines used here:

<table>
<thead>
<tr>
<th>FLIGHT (yyyy-mm-dd_location)</th>
<th>TARGET</th>
<th>POINT OF INTEREST</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012-09-14_NewEngland</td>
<td>Forests and Ocean</td>
<td>P&amp;R Maneuvers; NYC run (9/14); Chesapeake run (9/14)</td>
<td>Flight recorded deciduous forest biomass measurements over New England and Fort A.P. Hill, Virginia. Clouds moving in from the west. CPL and CATS also used during this flight. This flight continued on 9/15/2012, and data for it is found in the folder 2012-09-15_NewEngland.</td>
</tr>
<tr>
<td>2012-09-20_Modified_Southeast</td>
<td>Forests</td>
<td>No POIs identified</td>
<td>Dense clouds for first half of flight (SE of the Appalachian Mountains); clear NW of the mountains. CPL and CATS also used during this flight. This flight continued on 9/21/2012, and data for it is found in the folder 2012-09-21_Modified_Southeast.</td>
</tr>
<tr>
<td>2012-09-22_Modified_MidAtlantic</td>
<td>Calibration and Forests</td>
<td>NC; SERC AP Hill and Chesapeake Bay</td>
<td>Weather was very clear over most of the targets. We did eastern North Carolina (3 lines plus E-W transect near Pamlico Sound), AP Hill (4 passes), SERC and Chesapeake Bay on the return leg of the flight. This flight continued on 9/22/2012, and data for it is found in the folder 2012-09-21_Modified_MidAtlantic.</td>
</tr>
</tbody>
</table>
Chan-Vese Active Contours
Consider horizontal projection
With variable terrain?
Multiple horizontal projections
General h/v projection
Example results

Results using Sigma Space MPL LiDAR data from Pine Barrens, New Jersey.
Example results

Results using Sigma Space MPL LiDAR data from Smithsonian Environment Research Center, Maryland.
Example results

(a) Original MABEL data for an 8-km section.

(b) The result of automatic estimation of ground and top of canopy.

(c) Zoomed version of (b).

Profile view of a section of northeastern Kentucky
Example results

(a) Original MABEL data for a 12-km section.

(b) The result of automatic estimation of ground and top of canopy.

(c) Comparison between the estimated canopy height for MABEL (red) and ground-truth values obtained from G-LiHT (green).

Profile view of a section of North Carolina, near Wilmington
Example results

(a) Original MABEL data for a 12-km section.

(b) The result of automatic estimation of ground and top of canopy.

Error (mean) = 1.2m
Error (median) = 0.48m

Error (mean) = 2.29m
Error (median) = 1.5m
Drawbacks (so far)

(Thanks to Amy Neuenschwander, UT-Austin)
Drawbacks (so far)

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Recent results (2-phase approach)
Recent results (2-phase approach)
Quantitative Results (F-measure)

N-cut | N-cut + snakes | h/v proj + snakes

<table>
<thead>
<tr>
<th>MPL File</th>
<th>F-measure</th>
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</thead>
<tbody>
<tr>
<td>Cedar2-un5</td>
<td>0.8</td>
</tr>
<tr>
<td>Cedar2-un2</td>
<td>0.9</td>
</tr>
<tr>
<td>Cedar2-un5</td>
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<tr>
<td>Cedar4-un0.5</td>
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<tr>
<td>Cedar4-un2</td>
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<tr>
<td>Cedar4-un5</td>
<td>0.7</td>
</tr>
<tr>
<td>SRRC1-un0.5</td>
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<tr>
<td>SRRC1-un2</td>
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<tr>
<td>SRRC1-un5</td>
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<tr>
<td>SRRC3-un2</td>
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</tbody>
</table>
Comparison with other techniques

![Bar chart comparison with other techniques](image)

- N-cut
- N-cut+snakes
- ChIF
- LCV
- R-SE
- SPM
- LRS
- TVD
- Checker-board
- l/h proj + snakes
Synergy with Landsat?

- Landsat data may provide prior knowledge of cover type

- Can ICESat-2’s 3D structure improve Landsat-based cover maps?

- Use physics-based modeling to improve ground/TOC localization?
Conclusion

- Novel framework to automatically estimate ground and TOC contours within simulated ICESat-2 data
- Special techniques to initialize a GAC (Geometric Active Contour)
- 2-phase approach to distinguish ground from canopy (important for gaps in canopy)
- More than 150 noisy LiDAR point clouds have been tested, with good results.
Publications


(See http://icesat.gsfc.nasa.gov/icesat2/ and click on Publications)
Thank you

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