Validation of airborne LiDAR intensity values from a forested landscape using HyMap data: preliminary analyses

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LiDAR Intensity

Most commercial scanning LiDAR systems provide information on range and intensity per laser pulse.
LiDAR Intensity

• Provides a record of the backscattered intensity of reflection for each laser pulse.

• Information supplied on the reflecting surface or object at sampled points across the landscape.

• This ability to capture backscattered reflectance from returning pulses has proved useful…….
Use of LiDAR intensity

• These include the identification and mapping:
  – age of lava flows from active volcanoes;
  – glacial features;
  – features of archeological interest such as palaeochannels;
  – vegetation types.

• Within forestry, lidar intensity has been used:
  – estimate forest volume and biomass in a temperate forest of coniferous, deciduous, and mixed stands;
  – predicting basal area and tree density of coniferous forests;
  – filter lidar-height to estimate the basal area of northern hardwood forests;
  – as a predictor in tree species classification.

• Lidar intensity values are being utilized in ways beyond perhaps originally intended – there is much potential.
Factors determining LiDAR intensity:

• **System variables:**
  – target-emitter distance, peak pulse power, beam divergence, laser footprint size, angle of incidence, atmospheric attenuation and signal processing.

• **Target variables:**
  – Cross sectional area of target within laser footprint, target bidirectional properties, target reflectivity, and surface roughness.
  – Within forests this is mainly a function of leaf area, leaf inclination, species type, and tree density.

• **Post-processing procedure:**
  – Interpolation technique and selected output cell size will influence the nature of the resulting surfaces.
Factors determining LiDAR intensity:

Target variables:
- target reflectivity,
- surface roughness & bidirectional properties
- the size and distance of the target
Realising the potential: current limitations

- Airborne LiDAR intensity data is supplied un-calibrated.
- Currently a lack of operational calibration techniques.
- Progress has been made to calibrate intensity both under laboratory and field conditions (e.g. using calibration targets).

BUT:
- Lack of validation for LiDAR intensity values obtained over a particular environment (e.g. forests).
Realising the potential: current limitations

The challenge for validating LiDAR intensity data over forest:
The lack of reference data at appropriate spatial, spectral and temporal resolution to compare with LiDAR intensity values.

Our aim:
To validate LiDAR intensity by means of comparison with a similar product derived by more “conventional” means.

HyMap data were acquired concurrently with small-footprint scanning LiDAR data over a woodland area in the UK.
Monks Wood NNR
157 ha of semi-natural deciduous woodland in Cambridgeshire, UK.

Mostly: Common ash
Also: Silver birch
English oak Aspen
Field maple Small-leaved elm

Bevill’s Wood
36 ha of mostly conifer plantation (1950s-60s)

Scots pine
Norway spruce
Beech
Data: LiDAR

- Optech ALTM 1210

- Laser pulses: NIR wavelength of 1.047 μm.
- Scan angle range of ±10°

- Average post-spacing: 1 per 4.83m²
- Footprint size: ca. 0.25m at nadir.

- First & last return data recorded (range & intensity).
- The intensity values are unitless as no method was applied to calibrate them.

- Individual flight lines were supplied merged together into a single point cloud.
Data: HyMap

- Flown coincident with the ALTM
- 126 wavebands
- 4-m spatial resolution pixels

- The reflected radiation in Band 42:
  band centre 1.0475 μm, width 0.0188 μm

- The HyMap provides a signal to noise ratio of >500:1

- HyMap sensor operates close to backscatter providing similarity to the laser scanner which operates practically at exact backscattering

- HyMap Band 42 provides a reliable validation dataset for use in this study.
Data: Pre-processing

HyMap Band 42: converted to radiance

LiDAR intensity data interpolated into 4m resolution raster by
1. Delaunay Triangulation (DT),
2. Inverse Distance Weighting (IDW)
3. Ordinary Kriging (OK)
Data visual comparison

HyMap Band 42 (NIR)

LiDAR intensity data interpolated into 4m resolution raster by Ordinary Kriging (OK)
Illustrating the differences in LiDAR intensity values derived from three interpolation methods (stand 5)

Histograms of interpolated LiDAR intensity

LiDAR intensity from OK against LiDAR intensity from IDW
LiDAR intensity from OK against LiDAR intensity from DT
LiDAR intensity from IDW against LiDAR intensity from DT

y = 0.8768x + 2.9609
$R^2 = 0.2877$

y = 0.4238x + 12.34
$R^2 = 0.1415$

y = 1.0444x - 0.8284
$R^2 = 0.4945$
Characteristics (mean and ±1 SD) of LiDAR intensity and HyMap reflectances for landscape features

*NIR (band 42) HyMap image*

1. stand 4 (Ash dominated);
2. stand 5 (Elm dominated);
3. coniferous forest;
4. coniferous forest;
5. beech;
6. shrub;
7. bare soil;
8. crop and
9. grass.

*First return lidar intensity image (OK)*
Stand analysis of intensity values

<table>
<thead>
<tr>
<th>Stand</th>
<th>Sample Size (N)</th>
<th>DT Equation</th>
<th>Correlation Coefficient ($r^2$)</th>
<th>IDW Equation</th>
<th>Correlation Coefficient ($r^2$)</th>
<th>OK Equation</th>
<th>Correlation Coefficient ($r^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stand 1</td>
<td>1747</td>
<td>$y = 0.0013x + 15.736$; $r^2 = 0.01$</td>
<td></td>
<td>$y = 0.001x + 16.169$; $r^2 = 0.01$</td>
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<td>$y = 0.0013x + 15.064$; $r^2 = 0.03$</td>
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<td>2088</td>
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<td>$y = 0.0004x + 16.963$; $r^2 = 0.002$</td>
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<td>$y = 0.0007x + 15.54$; $r^2 = 0.012$</td>
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<tr>
<td>Stand 3</td>
<td>2010</td>
<td>$y = 0.0005x + 16.424$; $r^2 = 0.003$</td>
<td></td>
<td>$y = 0.003x + 17.729$; $r^2 = 0.002$</td>
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<td>$y = 0.0004x + 17.245$; $r^2 = 0.005$</td>
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<tr>
<td>Stand 4</td>
<td>3131</td>
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<td>$y = 0.0017x + 13.808$; $r^2 = 0.014$</td>
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<td>$y = 0.0017x + 14.003$; $r^2 = 0.032$</td>
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</tr>
<tr>
<td>Stand 5</td>
<td>430</td>
<td>$y = 0.0024x + 9.7862$; $r^2 = 0.09$</td>
<td></td>
<td>$y = 0.002x + 11.483$; $r^2 = 0.08$</td>
<td></td>
<td>$y = 0.0021x + 10.832$; $r^2 = 0.19$</td>
<td></td>
</tr>
</tbody>
</table>

Example plot of Hymap NIR data against lidar intensity data derived using OK at 4m for stand 5.

Per-pixel relationship between interpolated LiDAR intensity and HyMap radiance.
Per parcel analysis of intensity values

Plot of HyMap NIR against LiDAR intensity values (OK) for broadleaved forest (28 compartments).

Average value per compartment

Average value per compartment (separated by flightline)
Preliminary conclusions

- LiDAR intensity values (as binned by Optech) have a low dynamic range compared with HyMap.
- Across the landscape as a whole features with high or low NIR reflectance show corresponding LiDAR intensity.
- But coniferous & deciduous woodland have similar LiDAR intensity values.
- There is as much variation in LiDAR intensity within coniferous & deciduous woodland than between them.
- Far more variation occurs in LiDAR intensity between flightlines than between vegetation types within a single flightline.
- Thus, vegetation bidirectional reflectance characteristics and scan angle are key factors to consider in calibration.

- There is a real need for calibration of intensity data, particularly if flight lines are to be merged and interpolated.