Exploration of the innovation potential of single-photon LiDAR for Ontario’s eFRI

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Outline

• Single-Photon LiDAR acquisition in Ontario
• Forestry Futures Trust Project - Petawawa Research Forest
  • Elevation testing pilot
  • ABA Plot stratification & Plot methodology
  • ABA modeling approach/results – preliminary
  • SPL Individual Crown Segmentation opportunities Update – AWARE

• What’s next?
• Questions/Discussion
Canadian Wood Fibre Centre (CWFC)

- Created over a decade ago as new research unit of the CFS.
- Partnered with the new “FPInnovations” (consolidation of Feric, Forintek & Paprican).
- Staff located across Canada working on projects with provincial and forest industry.
Scope: Forest Resources Project Area

- Area of the Undertaking – 455,000 sq km
- Southern portion of the Far North project area – 100,000 sq km
Acquisition Schedule 2018
Ontario Forest Resource Inventory Program

2018 Progress

SPL Acquisition

Imagery Acquisition
SPL 100 vs ALS 80

- operates at 6Mhz
- 30 degree FOV at roughly 3800 m or 12,500 feet, and swath width of 2000m.
- Swath width of 400m and FOV of 30 degrees
- SPL efficient for large area capture
  - Uniform conditions
  - Shorter collection periods
  - Prone to atmospheric interference

**photon** is the smallest discrete amount or quantum of electromagnetic radiation.
- It is the basic unit of all light.
- **Photons** are always in motion and, in a vacuum, travel at a constant speed to all observers of $2.998 \times 10^8$ m/s.

<table>
<thead>
<tr>
<th>Flying heights for SPL100</th>
<th>10deg wedge Pt Density* / swath width</th>
<th>15 deg wedge Pt Density* / swath width</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000m</td>
<td>45pt/m / 700m</td>
<td>30 pt/m / 1050m</td>
</tr>
<tr>
<td>3800m</td>
<td>20pt/m / 1350m</td>
<td>13pt/m / 2000m</td>
</tr>
<tr>
<td>5000m**</td>
<td>8pt/m / 1775m</td>
<td>5pt/m / 2700m</td>
</tr>
</tbody>
</table>

*All density estimates are based on single swath at an aircraft speed of 180knots
** At 5000m AGL flying height a pulse rate frequency of 25kHz is used opposed to 50kHz at lower heights
Ontario Forest Resource Inventory Program - SPL Technology

SPL : Single photon LiDAR

- technology for large mapping areas.
- High flying height allows for overlap and maintaining high point densities
- High efficiency LiDAR system for supporting change detection
- Fewer flight lines, reduced data processing

Specification for 25pt/m Data Capture

<table>
<thead>
<tr>
<th></th>
<th>SPL100 (30deg FOV)</th>
<th>ALS80 (30deg FOV)</th>
<th>Leica TerrainMapper (40deg FOV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flying Height (AGL)</td>
<td>3,800m (2000m swath width)</td>
<td>1,200m (640m swath width)</td>
<td>2,100m (1529m swath)</td>
</tr>
<tr>
<td>Aircraft Speed</td>
<td>180kts</td>
<td>110kts</td>
<td>110knts</td>
</tr>
<tr>
<td>Capture rate (single swath)</td>
<td>670sqkm/hr</td>
<td>90sqkm/hr</td>
<td>275sqkm/hr</td>
</tr>
<tr>
<td>Processing time</td>
<td>80x flight time</td>
<td>4x flight time</td>
<td>20x flight time</td>
</tr>
</tbody>
</table>
Single Photon LiDAR

Simplified Single Photon LiDAR

Beam Splitter

Pulse

Beamlets
# LiDAR Density Results for Study Site

<table>
<thead>
<tr>
<th>Category</th>
<th>All Returns</th>
<th>Vegetation (3,4,5) Only Classifications</th>
<th>Ground (2) Only Classifications</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Point Density:</strong></td>
<td>All Returns – 36.7/m²</td>
<td>All Returns – 35.8/m²</td>
<td>All Returns – 4.2/m²</td>
</tr>
<tr>
<td></td>
<td>Last Returns – 34.4/m²</td>
<td>Last Returns – 33.3/m²</td>
<td>Last Returns – 4.2/m²</td>
</tr>
<tr>
<td><strong>Point Spacing:</strong></td>
<td>All - 16cm</td>
<td>All - 17cm</td>
<td>All - 50cm</td>
</tr>
<tr>
<td></td>
<td>Last - 17cm</td>
<td></td>
<td>Last - 50cm</td>
</tr>
</tbody>
</table>
### Linear

**Linear Mode**

<table>
<thead>
<tr>
<th>Mode</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tx</strong></td>
<td><img src="image1" alt="Linear Mode Diagram" /></td>
</tr>
<tr>
<td><strong>Rx</strong></td>
<td><img src="image2" alt="Linear Mode Diagram" /></td>
</tr>
</tbody>
</table>

- Digitized Waveform
- Discrete Return Leading-Edge
- First
- Last & Multiple Thresholds

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**2005**

**2012 - FWF**
Current Research

Single Photon LiDAR

- Operates at 6Mhz
- Single laser beam split into 100 beamlets – lower energy per pulse
- Uses the 532 nanometer (green) as opposed to the 1024 portion of the electro-magnetic spectrum
- Receiver can detect and count single photons – multiple returns
- Conical scan pattern (forward and aft looks)
White Pine Uniform Shelterwood
PRF310 – Sb

2005 2012 2018 SPL
LiDAR Point Cloud Classification
Intermediate Returns

Single Returns

Intermediate Returns

Last of Many Returns

LiDAR Point Returns
Lower-Mid-story reduction in returns? – Change in Stand Structure in 6 years?
Single Photon LiDAR Forest Resolution

False Colour Image

Canopy Height Model

Unharvested
U-Shelterwood

LiDAR (Elevation)

Unharvested
U-Shelterwood

Pw Regeneration
Single Photon LiDAR Forest Resolution

Red Pine Plantation

Tolerant Hardwood
Exploring the innovation potential of single photon lidar for Ontario’s eFRI

Project Co-Leads:
- Canadian Institute of Forestry – Science-Extension-Education-knowledge (SEEK) – MacMillan/Collins
- Canadian Forest Service – Joanne White
- Canadian Wood Fibre Centre – Woods/Vekeman/Arbour

Project Partners:
- Canadian Nuclear Laboratories - Morin
- Canada Centre for Mapping and earth Observation – Belanger

Project Team Members:
- Dr Benoît St-Onge – UQAM
- Dr Jili Li – FPInnovations

Project Technical Support:
- MNRF – Forest Resource Inventory Section/Mapping Information Resources Branch /Integrated Monitoring Framework
Exploring the innovation potential of single photon lidar for Ontario’s eFRI

The objectives of this project include:

1. To quantify the comparative performance of SPL in characterizing terrain under varying forest types and canopy densities;

2. To quantify the comparative performance of SPL in an area-based approach to forest inventory attributes

1. To identify and explore any incremental advantages or innovations for the eFRI program resulting from unique SPL data characteristics, particularly data density (e.g. to support individual tree approaches and the improved characterization of canopy vertical structure for applications such as habitat modelling).
Operational Delivery of SPL LiDAR Inventories for the Petawawa Research Forest ~10,000 ha & CNL ~5,000 ha

Operating research forest with a spatial management plan guiding its activities

Forest types include:
- red & white pine, jack pine,
- black and white spruce,
- tolerant & midtolerant hardwoods,
- poplar,
- mixedwoods,
- lowland conifers (Sb/Ce/La)
- plantations

Wall to Wall LiDAR coverage (2005, 2012, 2016, 2018)

Area-based inventory prediction rasters based on a 25m X 25m pixel
Project Timeline – 2 Year Project 2018 – 2019 / 2019 - 2020

Year 1 of 2

- SPL acquired for PRF & CNL - July 1, 2018
- LiDAR data delivered Sept 13, 2018
- Field program to remeasure and establish 249 calibration plots – July 9 – Nov 9, 2018
- Survey transects prepared for RTK elevation validation – Spring 2019
  - Canada Centre for Mapping and earth Observation comparison underway
- Plot summaries produced for modeling
- LiDAR ABA predictor surfaces created
- LiDAR ABA preliminary modeling underway
- LiDAR Individual Crown Segmentation initiated
Year 2 of 2

- Targeted plot establishment – CNL/PRF
- Finalize Models
  - Ht predictions (CHM/Topht/Lorey’s Ht)
  - Basal area & Basal Area by Size Class
  - Dbhq
  - Volume (GTV, GMV)
  - Biomass
  - Etc.
- Validation of inventory prediction
  - Intensive 50m cruising of stands by forest-type
- Technology Transfer of project results – led by CIF
1. To quantify the comparative performance of SPL in characterizing terrain under varying forest types and canopy densities.

Ontario Base Map

2012 ALS

2018 SPL
1. To quantify the comparative performance of SPL in characterizing terrain under varying forest types and canopy densities.
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50 & 100 m transects cut for RTK level elevation survey
1. Tolerant Hardwood
2. Pine
3. Black Spruce
4. Hardwood Mixedwood
5. Conifer Mixedwood
6. Intolerant Hardwood
7. Conifer Plantations
8. Jack Pine
9. Young Plantations

MNRF Partners – Forest Resource Inventory Section/Mapping Information Resources Branch
2. To quantify the comparative performance of SPL in ABA to forest inventory attributes

- Remeasured 2012 LiDAR project calibration plots originally located using PCA analysis matrix
  - Due to the number of species/forest-types – PCA was used to map different structures to sample
  - Due to short project window – 2012 Structure used as an “on-hand” surrogate for expected 2018 SPL LiDAR measured structure.
  - Species/forest-types were overlaid and additional plots to cover range were established.
Plot Stratification & Plot Methodology

- Remeasured 2012 LiDAR project calibration plots originally located using PCA analysis matrix

  - Circular 14.1m radius calibration Large Tree plot (625 m²)
    - Min threshold 9.1 cm DBH
    - Assessed for Species, Status, Origin, Quality Class, Crown Class,
    - Sub-sampled for heights – or 100% heights if < ~15-20 trees
    - 360° photo
    - Submetre GPS (Topcon Hyper V) – PPP post processing.

  - Circular 3.99m radius calibration Small Tree plot (50 m²) for trees
    - ≥ 2.5cm – 9cm DBH
    - Live stems assessed for Species, DBH, sampled for Ht.
LiDAR Modeling – ABA 101

Basic sampling unit is a forest monitoring plot
• Must be fixed-area
• Must be of suitable size
  • min 400m² in Boreal
  • larger in Great Lakes Forest Types preferred
• Doesn’t have to be permanent plots – but an opportunity to make use of existing array of plot networks (G&Y – NFI – WAM – IFM)
• Does require sub-meter GPS positioning
  • – circular plots preferred – operational advantage
LiDAR Modeling – ABA 101

- Percentiles
- Deciles
- Skewness, kurtosis, AbsDev, Stdev
- Texture, etc.
LiDAR Landscape Predictions

2018 SPL Predictor Surfaces

- Statistical measures of point clouds & CHM raster
- Typically a 20m X 20m cell (prediction unit)
- Derived for Ground Plots and entire gridded inventory area
LiDAR Modeling – ABA 101

LAStools Canopy Metrics Script

```bash
: Lascanopy to calculate tAZ structural attributes - Percentiles
echo off
set PATH=%PATH%;C:\lastools\bin;
set infile=F:\SourceData\LAZ_Norm
set outfile=F:\SourceData\CanopyMetrics\Percentiles
set outmosaic=F:\SourceData\CanopyMetrics\Mosaic
set CORES=8

lascanopy -cpu64
-i %infile%\LAZ_version.az
-crop %CORES%
-mndata -9999
-keep_classification 3 4 5
-step 25 -height_cutoff 1 0 -drop_z_above 49
-p 5 10 20 30 40 50 60 70 80 90 95 99 -epsg 2959
-odir %outfile%\obli

:-----------------------------------------------
: Mosaic the tiles together
:-----------------------------------------------
lasgrid -v -i %outfile%\P05_bil
-merged -step 25 -elevation -highest
-mndata -9999
-odir %outmosaic% -epsg 2959
-odix "_T130cm" -o "PRF_p05.img"
lasgrid -v -i %outfile%\P10_bil
-merged -step 25 -elevation -highest
-mndata -9999
-odir %outmosaic% -epsg 2959
-odix "_T130cm" -o "PRF_p10.img"
lasgrid -v -i %outfile%\P20_bil
-merged -step 25 -elevation -highest
-mndata -9999
-odir %outmosaic% -epsg 2959
-odix "_T130cm" -o "PRF_p20.img"
lasgrid -v -i %outfile%\P30_bil
-merged -step 25 -elevation -highest
-mndata -9999
-odir %outmosaic% -epsg 2959
-odix "_T130cm" -o "PRF_p30.img"
```

LiDAR predictive Models for:

- Height (DC, Topht, Lorey)
- DBHq
- Volume (GTV, GMV)
- Basal area
- VBAR (Poles, Sawlogs)
- Biomass/Carbon
- Density
- Mean Tree GMV
- Size Class Distributions
- Canopy Height
- Crown Closure
- Vertical Structure

No species – age information used in modeling
Validation of 17 Stands

- Basal Area
- Gross Total Volume
- Gross Merchantable Volume
- DBHq

Predicted vs Observed comparisons for each metric.
RandomForest Predictions of PRF “Heights” with SPL Data

**RF_toph_OOB**

- **RMSD:** 2.14
- **Pearson’s Cor:** 0.96
- **Spearman’s Cor:** 0.94
- **Obs:** 1.02(pred) + 0.43

**RF_HL_merch_OOB**

- **RMSD:** 1.74
- **Pearson’s Cor:** 0.97
- **Spearman’s Cor:** 0.97
- **Obs:** 1.01(pred) + 0.24
RandomForest Prediction

Total Basal Area (m²/ha)
RandomForest Prediction

Merchantable Basal Area (m$^2$/ha)
RandomForest Predictions of PRF VBARs with SPL Data
RandomForest Predictions of PRF DBHq with SPL Data
RandomForest Prediction of GMV ($m^3$/ha)
PRF Validation

Intensively Cruised in 2015

Or₄₂ Pw₂₄ Mr₁₁ Bf₁₀ Pr₄ Sw₄

<table>
<thead>
<tr>
<th></th>
<th>PRF575</th>
<th>2015 Cruise Summary</th>
<th>2018 SPL LiDAR Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merch BA m²/ha</td>
<td>26.1</td>
<td>26.4</td>
<td></td>
</tr>
<tr>
<td>GMV m³/ha</td>
<td>152.0</td>
<td>155.7</td>
<td></td>
</tr>
<tr>
<td>Dbhq cm</td>
<td>20.9</td>
<td>20.6</td>
<td></td>
</tr>
</tbody>
</table>

Mh₁₈ Be₁₇ Pw₁₃ PT₇ By₄ Bw₄ Pl₃ Bd₃ Sw₂

<table>
<thead>
<tr>
<th></th>
<th>PRF463</th>
<th>2015 Cruise Summary</th>
<th>2018 SPL LiDAR Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merch BA m²/ha</td>
<td>28.9</td>
<td>28.3</td>
<td></td>
</tr>
<tr>
<td>GMV m³/ha</td>
<td>215.3</td>
<td>214.6</td>
<td></td>
</tr>
<tr>
<td>Dbhq cm</td>
<td>23.6</td>
<td>24.9</td>
<td></td>
</tr>
</tbody>
</table>

17.0 ha – 71 plots

14.3 ha – 59 plots
PRF Validation

Intensively Cruised in 2015

13.0 ha – 51 plots

<table>
<thead>
<tr>
<th>PRF589</th>
<th>2015 Cruise Summary</th>
<th>2018 SPL LiDAR Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Merch BA m²/ha</td>
<td>26.6</td>
<td>26.8</td>
</tr>
<tr>
<td>GMV m³/ha</td>
<td>220.8</td>
<td>214.6</td>
</tr>
<tr>
<td>Dbhq cm</td>
<td>21.7</td>
<td>24.4</td>
</tr>
</tbody>
</table>

GMV

PRF Validation
Basal Area Prediction - PRF 10,000 ha Forest

No Polygon information required

<30 seconds for 25m raster predictions on laptop

2.3 seconds to calculate mean BA for all interpreted polygons
Cavities filled, by B. St-Onge  SEGMA 3.0
Mobile LiDAR – Next Game Changer?

11 minute walk around a 1/10ha (18m radius plot)
Mobile LiDAR – Next Game Changer?

Pilot Study Results
Questions/Discussion

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