LiDAR Product Suite for the Hearst Forest & other R&D activities present and future

Murray Woods
Ontario Ministry of Natural Resources

Doug Pitt
Canadian Wood Fibre Centre
Advanced Forest Resource Inventory Technologies
TEAM AFRIT

Doug Pitt
Dave Nesbitt
Margaret Penner
Forest Analysis Ltd.
Kevin Lim
Lim Geomatics

Paul Treitz
Dave Etheridge
Jeff Dech
Don Leckie
François Gougeon
National CWFC Program

Regional Focus: AFRIT-Hearst
Outline

- LiDAR 101
- LiDAR Derived Inventory
- Current LiDAR Inventory Products
- Other Hearst R&D efforts
- Looking forward
- "Active" remote sensing technology; transmit & receive ~35,000-500,000 pulses of NIR laser light per second
- GPS provides the exact X-Y-Z position of each return
- **Discrete System** - Each pulse can produce multiple returns (3-5)
“Active” remote sensing technology; transmit & receive ~35,000-500,000 pulses of NIR laser light per second

GPS provides the exact X-Y-Z position of each return

**Discrete System** - Each pulse can produce multiple returns (3-5)
LiDAR – Light Detection And Ranging

Full Waveform System

- “Active” remote sensing technology; transmit & receive ~35,000-500,000 pulses of NIR laser light per second
- GPS provides the exact X-Y-Z position of each return
- Discrete System - Each pulse can produce multiple returns (3-5)
- Full Waveform System – not limited to number of returns – but detectible signals

Source: e-education.psu.edu
“Active” remote sensing technology; transmit & receive ~35,000-500,000 pulses of NIR laser light per second

GPS provides the exact X-Y-Z position of each return

Discrete System - Each pulse can produce multiple returns (3-5)

Full Waveform System – not limited to number of returns – but detectible signals

Full Waveform System
(~48 rts/m²)

2012 LiDAR
“Active” remote sensing technology; transmit & receive ~35,000-500,000 pulses of NIR laser light per second

GPS provides the exact X-Y-Z position of each return

**Discrete System**
- Each pulse can produce multiple returns (3-5)

**Full Waveform System**
- Not limited to number of returns but detectible signals

- 2007 LiDAR
- 2012 LiDAR

**LiDAR – Light Detection And Ranging**
LiDAR – Light Detection And Ranging

DSM

DEM

Imagery
LiDAR – Light Detection And Ranging

- DSM
- DEM
- CHM
- Imagery
Historical Reason for Acquiring LiDAR Data

OBM 20m

LiDAR 1m

Classified Ground Returns
Field Sampling

- Cruising generally not occurring in Boreal forests
- Very “light” 1%-2%
- Expensive
- only provides information on sampled sites – extrapolated
- Need to do for the next stand…and the next…
LiDAR Derived Inventory

Field Sampling vs. 100% Enumeration

- 100% enumeration of the landbase with LiDAR measurements of vertical structure
- Scalability
- permits the use of regression estimators to scale PU estimates to groups of PUs, Stand, Block or Forest
LiDAR Derived Forest Inventory - Approach

- 2010 – Field Program
- Established
  446 Calibration – 400m$^2$ plots
  64 Validation plots (2012)
- Sampled 8 Forest Types x Development stages
- All trees measured for DBH and height sample $\geq 10$ cm
- Trees <10 cm – density count by 1 m height classes – avg DBH
- Ecosite description
Additional forest inventory information contained in point cloud data

Focus of AFRIT is “Area” based modeling NOT “Individual Tree”

Prediction Unit = 20m X 20m (400m²)
• Additional forest inventory information contained in point cloud data

• Focus of AFRIT is “Area” based modeling **NOT** “Individual Tree”

• Prediction Unit = 20m X 20m (400m$^2$)
LiDAR Derived Inventory – Pairing with Ground Data

Field Plot Measurement
Enhanced Modeling Approaches - Simplified

Regression

\[ y = b_0 + b_1 x_1 + b_2 x_2 \]

randomForest

Option for hundreds to thousands of trees
Comparison of Basal Area Predictions from RF and SUR

Hearst Forest

Parametric vs. nonparametric LiDAR models for operational forest inventory in boreal Ontario

M. Penner, D.G. Pitt, and M.E. Woods
Enhanced Modeling Approaches

**Regression**
- Requires an existing polygon inventory
- Requires separate forest-type models to statistically be built - specialist
- Can’t adjust to within polygon species variation
- Can extrapolate beyond model building data

**RandomForest**
- doesn't rely on an existing polygon inventory
- no separate forest-type models to statistically build
- very quick to implement
- custom application of LiDAR predictions for each 20m x 20m
- Predictions are equivalent to Regression
LiDAR Derived Inventory

LiDAR predictive Models for:

- Height (AVG, Top)
- DBHq (~avgDBH)
- Volume (GTV, GMV)
- Basal area
- Biomass
- Density*
- Sawlog Volume
- Close Utilization Volume
- Dom/Codom Ht
- Mean Tree GMV
- Size Class Distributions

* Derived from DBHq & BA
Hearst Inventory Prediction Rasters (20m X 20m)

- Dominant/Codominant HT: High: 26.7 m, Low: 2.4 m
- Merchantable BA: High: 55 m²/ha, Low: 0.01 m²/ha
- DBHq: High: 31.2 cm, Low: 9.9 cm
- GTV: High: 375 m³/ha, Low: 0.8 m³/ha
- GMV: High: 400 m³/ha, Low: 0.03 m³/ha
- Sawlog Volume: High: 245 m³/ha, Low: 0.03 m³/ha
- Pulp Volume: High: 144 m³/ha, Low: 0.03 m³/ha
- Close Utilization Volume: High: 52.0 m³/ha, Low: 0.0 m³/ha
- Mean Tree Volume
- Stems per Hectare: High: 2200, Low: 99
- Above Ground Biomass

randomForest Solution
November 2012
Gross Merchantable Volume

121.8 m³/ha
Block Summary

a) \(97.5 \text{ m}^3/\text{ha} \times 186 \text{ ha} = 18,135.0 \text{ m}^3\)

b) \(154.5 \text{ m}^3/\text{ha} \times 75 \text{ ha} = 11,587.5 \text{ m}^3\)

113.8 \text{ m}^3/\text{ha} \times 261 \text{ ha} = 29,701.8 \text{ m}^3

Minimum: \(0.75 \text{ m}^3/\text{ha}\)
Maximum: \(365.14 \text{ m}^3/\text{ha}\)
Optimistic Sawlog Volume

Mean Tree Volume

Derived Pulp Volume

Merchantable Basal Area
Hearst LiDAR Derived Size-Class Distributions

Black Spruce Validation Data – by VCI class


Pj Clearcuts: ~within 2-5%
Po Clearcuts: ~ within 5 – 15%
Sb with retention: ~5-25%

- net down for cull
- Retention has to be factored in
**Approach – Volume Comparison**

- LiDAR provides better volume prediction (statistically tested)
  - Yield Curve: 14.5%
  - LIDAR: 5.4%

### Difference from harvested volume (scaled)

<table>
<thead>
<tr>
<th>Yield Curve</th>
<th>LIDAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>BW</strong></td>
</tr>
<tr>
<td>208</td>
<td>12%</td>
</tr>
<tr>
<td>214</td>
<td></td>
</tr>
<tr>
<td>216</td>
<td>-2%</td>
</tr>
<tr>
<td>220</td>
<td>14%</td>
</tr>
<tr>
<td>244</td>
<td>-9%</td>
</tr>
<tr>
<td>245</td>
<td>-2%</td>
</tr>
<tr>
<td>246</td>
<td>-2%</td>
</tr>
<tr>
<td>251</td>
<td>6%</td>
</tr>
<tr>
<td>252</td>
<td>9%</td>
</tr>
<tr>
<td>254</td>
<td>-1%</td>
</tr>
<tr>
<td>256</td>
<td>1%</td>
</tr>
<tr>
<td>257</td>
<td>7%</td>
</tr>
<tr>
<td>259</td>
<td>1%</td>
</tr>
<tr>
<td>275</td>
<td></td>
</tr>
</tbody>
</table>
Hearst Forest ITC – Individual Tree Classification
Hearst Forest ITC – Individual Tree Classification
Hearst Forest ITC – Individual Tree Classification

- ~150,000 ha operationally classified with ITC
- 730 stands – Range of Forest Types – Range of Height Classes
- 2 Certified Forest Interpreters vs. Computer ITC Software

### Leading Species Comparison

<table>
<thead>
<tr>
<th>Misclassification type</th>
<th>Interpreter 1 vs. 2</th>
<th>Interpreter vs. ITC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agreement</td>
<td>59%</td>
<td>39%</td>
</tr>
<tr>
<td>Close (similar species – e.g., Sw, Sb)</td>
<td>71%</td>
<td>51%</td>
</tr>
<tr>
<td>Within hardwood or softwood</td>
<td>91%</td>
<td>81%</td>
</tr>
<tr>
<td>Serious disagreement</td>
<td>9%</td>
<td>19%</td>
</tr>
</tbody>
</table>
## Hearst Forest ITC – Individual Tree Classification

### Interpreter 1 vs. Interpreter 2: % Agreement for NE SFU

<table>
<thead>
<tr>
<th>Interpreters</th>
<th>Ab</th>
<th>Bf</th>
<th>Bw</th>
<th>Cw</th>
<th>La</th>
<th>Pb</th>
<th>Pj</th>
<th>Pt</th>
<th>Sb</th>
<th>Sw</th>
<th>agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpreter 1</td>
<td>29</td>
<td>13</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>21</td>
<td>5</td>
<td>6</td>
<td>10%</td>
<td>Not significantly different</td>
</tr>
<tr>
<td>Interpreter 2</td>
<td>1</td>
<td>71</td>
<td>17</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>84%</td>
<td>69%</td>
<td>39%</td>
<td>% agreement</td>
</tr>
</tbody>
</table>

### ITC

<table>
<thead>
<tr>
<th>Interpreters</th>
<th>Ab</th>
<th>Bf</th>
<th>Bw</th>
<th>Cw</th>
<th>La</th>
<th>Pb</th>
<th>Pj</th>
<th>Pt</th>
<th>Sb</th>
<th>Sw</th>
<th>agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpreter 1</td>
<td>29</td>
<td>13</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>21</td>
<td>5</td>
<td>6</td>
<td>10%</td>
<td>Not significantly different</td>
</tr>
<tr>
<td>Interpreter 2</td>
<td>1</td>
<td>71</td>
<td>17</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>84%</td>
<td>69%</td>
<td>39%</td>
<td>% agreement</td>
</tr>
</tbody>
</table>

### Total

<table>
<thead>
<tr>
<th>Interpreters</th>
<th>Ab</th>
<th>Bf</th>
<th>Bw</th>
<th>Cw</th>
<th>La</th>
<th>Pb</th>
<th>Pj</th>
<th>Pt</th>
<th>Sb</th>
<th>Sw</th>
<th>agreement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interpreter 1</td>
<td>65</td>
<td>62</td>
<td>90</td>
<td>47</td>
<td>160</td>
<td>206</td>
<td>31</td>
<td>59%</td>
<td>39%</td>
<td>Not significantly different</td>
<td></td>
</tr>
<tr>
<td>Interpreter 2</td>
<td>224</td>
<td>330</td>
<td>110</td>
<td>30</td>
<td>304</td>
<td>126</td>
<td>134</td>
<td>39%</td>
<td>29%</td>
<td>% agreement</td>
<td></td>
</tr>
</tbody>
</table>

### Visual Elements

- **Color Coding**
  - Ab
  - Bf
  - Bw
  - Cw
  - La
  - Pb
  - Pj
  - Pt
  - Sb
  - Sw

- **Legend**
  - Orange
  - Red
  - Gray
  - Green
  - Pink
  - Yellow
  - Light Green
  - Blue
  - Light Blue
  - Purple
  - Light Purple
  - Shrubs
  - Sw

---

*Note: The table above displays the percentage agreement for each category (Ab, Bf, Bw, Cw, La, Pb, Pj, Pt, Sb, Sw) between Interpreter 1 and Interpreter 2 for the Hearst Forest ITC individual tree classification project. The total agreement is calculated for each interpreter, with Interpreter 1 showing 59% agreement and Interpreter 2 showing 39% agreement.*
Hearst Forest ITC – Individual Tree Classification

Height

* Not significantly different

* Significantly different for a reason
Hearst Forest ITC – Individual Tree Classification

Crown Closure

* Significantly different
### Low Density LiDAR based Species Group Classification

<table>
<thead>
<tr>
<th>Actual</th>
<th>Predicted (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWD</td>
<td>91</td>
</tr>
<tr>
<td>MWC</td>
<td>100</td>
</tr>
<tr>
<td>MWH</td>
<td>9</td>
</tr>
<tr>
<td>CONIFER</td>
<td>4</td>
</tr>
</tbody>
</table>

\[N = 346 \text{ plots}; 86 \text{ used for validation}\]

Woods et al. (in prep)
Ongoing Enhancements

LiDAR Species Classification...from Low to High Density

Error matrix of classification

<table>
<thead>
<tr>
<th>No. Classified trees</th>
<th>At</th>
<th>Ms</th>
<th>Pj</th>
<th>Pw</th>
<th>Total</th>
<th>UA</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. Validation trees</td>
<td>139</td>
<td>8</td>
<td>29</td>
<td>11</td>
<td>187</td>
<td>74.3%</td>
</tr>
<tr>
<td>Ms</td>
<td>10</td>
<td>87</td>
<td>4</td>
<td>13</td>
<td>114</td>
<td>76.3%</td>
</tr>
<tr>
<td>Pj</td>
<td>23</td>
<td>2</td>
<td>120</td>
<td>3</td>
<td>148</td>
<td>81.0%</td>
</tr>
<tr>
<td>Pw</td>
<td>10</td>
<td>8</td>
<td>5</td>
<td>89</td>
<td>112</td>
<td>79.4%</td>
</tr>
<tr>
<td>Total</td>
<td>182</td>
<td>105</td>
<td>158</td>
<td>116</td>
<td>561</td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>77.5%</td>
<td>82.8%</td>
<td>75.9%</td>
<td>76.7%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ka</td>
<td>0.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Baoxin Hu
Dept. of Earth and Space Science and Engineering
York University, Toronto, Canada
Environmental input variables:
- Elevation (10m)
- Slope (%)
- Surface shape (Curvature)
- Mode of deposition (NOEGTS)
- Landcover
- Slope Position from TPI
  - (macro window = 1km)
  - (medium window = 500m)
  - (micro window = 20m)
- Wetness Index

**Soil Texture**
- Contour_dem
- coarse sand
- fine sand
- rock
- clay
- coarse loamy
- organic
- silty

Ongoing Enhancements (Akumu et al. In Prep)
Ongoing Enhancements

Wet Areas Mapping – Site Productivity Linkage - Ecosite

Using the Cartographic Depth-to-Water Index to Locate Small Streams and Associated Wet Areas across Landscapes

Barry White, Jae Ogilvie, David M.H. Campbell, Douglas Hiltz, Brian Gauthier, H. Kyle Chisholm, Hua Kim Wen, Paul N.C. Murphy, and Paul A. Arp
Ongoing Enhancements

WAM Mapping – Site Productivity - Ecosite
Ongoing Enhancements

WAM Mapping – Site Productivity - Ecosite
Ongoing Enhancements

Fibre Analysis – Jeff Dech, Bharat Pokharel, Art Groot

Sampling on AFRIT-Hearst Plot Network
Looking Forward

Semi Global Matching - Pixel Correlation

- Not the same as LiDAR… but similar
- Image based product
- Very detailed DSM
- Lower cost acquisition – produced with each inventory period
Study on the Hearst Forest to:

- Develop process to utilize SGM point cloud like LiDAR
- Compare potential SGM predictions with those derived from LiDAR
- Used the LiDAR derived Hearst DEM to normalize SGM data

A comparison of airborne LiDAR and digital photogrammetric point clouds for the area-based estimation of forest inventory attributes in boreal Ontario

Doug G. Pitt, Murray Woods, and Margaret Penner

(Submitted for review November 2013)
Fig. 4. Observed values are regressed on predicted values for each of the inventory attributes characterizing the average tree in validation plots ($n = 80$). $P$-values are provided for the simultaneous $F$-test of the 1:1 relationship and the regression line is shown (dotted line) when $p < 0.05$. The root mean squares (RMSEs) of the regressions are given. See Table 2 for forest type definitions.

Stem Characteristics

“...image-based point clouds were found produce accuracies that were equivalent to LiDAR, however some losses in precision were evident”

(Pitt et al. 2013 – in review)
For variables such as basal area, gross merchantable volume and sawlog volume, such losses in precision amounted to less than 10% increases in mean absolute errors.

(Pitt et al. 2013 – in review)
SGM Predictions Normalized on OBM 20m DEM

- Increased loss of precision from process using LiDAR DEM
- May still be an enhancement
- **CAUTION** – Study area was relatively flat

*(Pitt et al. 2013 – in review)*
Improving planning decisions by using Enhanced Forest Inventory (EFI)

Sébastien Lacroix, FPInnovations
Murray Woods, OMNR
Chad St-Amand, Tembec
Lino Morandin, Tembec
Pierre Bédard, FPInnovations
Joseph Nader, FPInnovations
Doug Pitt, CWFC
Objectives

• Are LiDAR-enhanced inventories leading to *better* forest management decisions?

• What are the cost savings associated with enhanced decision making?
Approach – Volume Comparison

- LiDAR provides better volume prediction (statistically tested)
  - Yield Curve: **14.5%**
  - LIDAR: **5.4 %**

Difference from harvested volume (scaled)

### Yield Curve

<table>
<thead>
<tr>
<th></th>
<th>BW</th>
<th>SP</th>
<th>PJ</th>
<th>PO</th>
</tr>
</thead>
<tbody>
<tr>
<td>208</td>
<td>12%</td>
<td>10%</td>
<td>0%</td>
<td>-22%</td>
</tr>
<tr>
<td>214</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>216</td>
<td>-2%</td>
<td>33%</td>
<td>3%</td>
<td>-34%</td>
</tr>
<tr>
<td>220</td>
<td>14%</td>
<td>-15%</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>244</td>
<td>-9%</td>
<td>34%</td>
<td>-12%</td>
<td>-14%</td>
</tr>
<tr>
<td>245</td>
<td>-2%</td>
<td>9%</td>
<td>-1%</td>
<td>-6%</td>
</tr>
<tr>
<td>246</td>
<td>-2%</td>
<td>20%</td>
<td>-1%</td>
<td>-17%</td>
</tr>
<tr>
<td>251</td>
<td>6%</td>
<td>33%</td>
<td>6%</td>
<td>-45%</td>
</tr>
<tr>
<td>252</td>
<td>9%</td>
<td>55%</td>
<td>1%</td>
<td>-66%</td>
</tr>
<tr>
<td>254</td>
<td>-1%</td>
<td>4%</td>
<td>10%</td>
<td>-12%</td>
</tr>
<tr>
<td>256</td>
<td>1%</td>
<td>-6%</td>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>257</td>
<td>7%</td>
<td>-17%</td>
<td></td>
<td>9%</td>
</tr>
<tr>
<td>259</td>
<td>1%</td>
<td>0%</td>
<td></td>
<td>-1%</td>
</tr>
<tr>
<td>275</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### LIDAR

<table>
<thead>
<tr>
<th></th>
<th>BW</th>
<th>SP</th>
<th>PJ</th>
<th>PO</th>
</tr>
</thead>
<tbody>
<tr>
<td>208</td>
<td>2%</td>
<td>-6%</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>214</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>216</td>
<td>-16%</td>
<td>6%</td>
<td>1%</td>
<td>8%</td>
</tr>
<tr>
<td>220</td>
<td>0%</td>
<td>-11%</td>
<td>4%</td>
<td>7%</td>
</tr>
<tr>
<td>244</td>
<td>-10%</td>
<td>2%</td>
<td>2%</td>
<td>5%</td>
</tr>
<tr>
<td>245</td>
<td>0%</td>
<td>5%</td>
<td>1%</td>
<td>-6%</td>
</tr>
<tr>
<td>246</td>
<td>0%</td>
<td>5%</td>
<td>1%</td>
<td>-6%</td>
</tr>
<tr>
<td>251</td>
<td>1%</td>
<td>11%</td>
<td>5%</td>
<td>-17%</td>
</tr>
<tr>
<td>252</td>
<td>4%</td>
<td>23%</td>
<td>2%</td>
<td>-29%</td>
</tr>
<tr>
<td>254</td>
<td>1%</td>
<td>-4%</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>256</td>
<td>2%</td>
<td>-1%</td>
<td></td>
<td>-1%</td>
</tr>
<tr>
<td>257</td>
<td>2%</td>
<td>-5%</td>
<td></td>
<td>3%</td>
</tr>
<tr>
<td>259</td>
<td>-3%</td>
<td>-2%</td>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>275</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

10 % & under

greater than 10 %
Comparison of 2 scenarios

1. Actual cut over – ACTUAL
   - Area harvested within approved plan

2. Redesign blocks within proposed plan – LIDAR
   - New harvest planning using LiDAR for area similar to initial plan
   - Validated by Tembec FRM
   - Stay within approved 5 year harvest blocks
Approach – Cost Analysis: Scenarios

Redesign plan, based on full suite of LiDAR data products

Removal of area of less GMV from Scenario
Approach – Cost Analysis Categories

Three groups of cost items:

A. Inventory acquisition and processing – 6 items

B. Forest operations – 20 items

C. Mill - 4 items
Results: Actual vs. LiDAR Scenario

Three groups of cost items:

A. Inventory acquisition and processing - 6 items $ - 0.10 \text{ m}^3$

B. Forest operations – 20 items $ \quad 1.40 \text{ m}^3$

C. Mill - 4 items $ \quad 0.30 \text{ m}^3$

Savings $ \quad 1.60 \text{ m}^3$

\[ X \quad 500,000 \text{ m}^3 / \text{year} = $800,000 / \text{year} \]

Payback $ = 1.3 \text{ years}$

*Tembec’s LiDAR acquisition 50% of what was modeled so payback was achieved in the first year !!!*