Automating Data Alignment from Multiple Collects

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Agenda

- Introduction & Agenda
- Evolution of mobile LiDAR data processing
  - Factors affecting LiDAR Accuracy
  - Summary of Traditional workflow
- Processing of mobile LiDAR data today
  - Planes, Tie Planes & adjustments
- Case Study – Kelowna & Vernon, British Columbia
  - Urban & Rural scenarios
- Challenges using the technology moving forward
  - Collection Techniques
  - Processing Techniques
- Time for questions
Challenges Present in mobile LiDAR

- Survey operations
- Systematic errors
- How ‘good’ is ‘good’?
  - Accuracy verification?
- Data misalignment
  - Internally
  - To control
- Correcting misalignments need effort to fix
  - DASHMap, Terramatch
- Rescan

Factors Affecting Accuracy

- Boresight
- Internal Cal
- Distribution
- Reference System
- Processes
- Experience
- Extraction
- Block Adjust
- Sensor Calibration
- Survey Control
- Operational Best Practice
- Software Workflow
- Laser Data Quality
- Navigation Solution
- Baseline
- GPS Bias
- IMU Drift
- FOV
- Precision
- Resolution

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Two primary factors affect data resolution:

- Laser Data Quality
- Range Precision

Multiple hits on target

No hits on target

Lynx laser range precision is 8mm
Traditional Workflow

Sensor Parameters: ?

“Trial and error”

“Corrections”

Adjusting data to GCP

“Stitching” strips

Data Manipulation

Raw Point Cloud

Multiple software required
Sequential and manual parameter adjustment

Proposed solution

Motivation: A rigorous methodology that provides thorough accuracy control, not just locally for control areas, but the entire project area.

- Free of blunders & systematic errors
- Accuracy calculated & reported
- Iterative
- Incremental

Requirements: Redundancy!

Lidar Mapping Suite (LMS) originally released for airborne lidar, now enhanced for mobile lidar also.
LMS Workflow

Data Collection Mission ➔ INS/GPS + LIDAR ➔ Automatic Calibration Engine ➔ Fully Aligned Point Cloud

Collection to Aligned Ratio ~ 1 : <2 hrs (Multi-CPU's, SSD's)

Planar Surface Extraction

S1 Blue
S2 Pink

Planes can be exported as ESRI shape files

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Point to plane (ds) analysis - used for assessing quality of the point cloud data.

Empirically

\[ ds_{i,j} = n_{X,j} x_i + n_{Y,j} y_i + n_{Z,j} z_i + p \]

- \( \min ds_j \)
- \( \max ds_j \)
- \( ds_j \)
- \( \text{rms } ds_j \)

Theoretically

\[ \sigma_z = f \left( n_X, n_Y, n_Z, p, \sigma_X, \sigma_Y, \sigma_Z \right) \]

Tie Plane Determination & Selection

- Determines correspondence between lines & selects appropriate tie planes for self calibration
  - Based upon the point to plane analysis
  - Selection criteria includes size, shape, no. points, slope, orientation fitting error
  - Redundancy!
LMS Methodology – Self Calibration

Requirement: Redundant information

Least squares observation equation

\[ g_{i,j} = n_{x,j} x_i + n_{y,j} y_i + n_{z,j} z_i = 0 \]

where

\[ x_i = f (obs., cal. par., corrections) \]

\[ obs. = l_r, \theta, x, y, z, r, p, h \]

Least squares solution

Determine a set of corrections by minimizing the weighted square sum of the observation residuals

⇒ Applying the correction while reprocessing laser points

Sensor parameters

- Optical calibration
- Boresight
  - Roll, pitch, heading
- Position
  - From POS
- Orientation
  - From POS

Keep Fixed
- Free Unknown
- Constrain Unknown

- Per Mission
- Per Surveyed Line

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Using Ground Control in LMS is **optional** but will improve data accuracy

How should GCP’s be collected?

- On flat (planar) surfaces in multiple dimensions
Case Study in Data Alignment

- May 21 & May 23, 2013
- Kelowna & Vernon, British Columbia on Highway 97.

Equipment used

POS LV System (Position and Orientation System)
- PCS
- IMU
- 2 GPS Antennas
- DMI (Distance Measuring Indicator)

Hardware
- 2 LiDAR sensorheads 500 kHz
- 4 standard cameras (2-5 MP)
- Ladybug camera fully integrated
May 21, 2013 Collect

Survey Time: 1h 53min  
Distance: 77.8 km  
Objective: To survey Highway 97 starting in Kelowna and ending north of Vernon, both directions.

May 23, 2013 Collect

Survey Time: 1h 14min  
Distance: 46.9 km  
Objective: Complete Highway 97 between Vernon & Kelowna. Scan a major intersection within Vernon.
Survey Challenges

- Weather!
  - Rained on May 21, 22 & morning of 23rd
  - Time constraints
- Multiple days of collection leading to misalignments between the two datasets.
  - Factors Affecting Accuracy!
  - How do we make these data sets align!?
### Tie Plane Determination & Selection

#### L014 - S1 – 596,627

<table>
<thead>
<tr>
<th>L014 - S1 – 596,627 L014 – S2 – 587,738</th>
</tr>
</thead>
</table>

S1 – 85% of tie planes determined were selected

S2 – 79% of tie planes determined were selected
Self Calibration Results

Accuracy Height Report

<table>
<thead>
<tr>
<th>Control ID</th>
<th>Height Difference</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.022</td>
<td>0.003</td>
</tr>
<tr>
<td>2</td>
<td>0.022</td>
<td>0.002</td>
</tr>
<tr>
<td>3</td>
<td>0.025</td>
<td>0.008</td>
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<tr>
<td>4</td>
<td>0.029</td>
<td>0.010</td>
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<td>5</td>
<td>0.047</td>
<td>0.006</td>
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<tr>
<td>6</td>
<td>0.036</td>
<td>0.017</td>
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<tr>
<td>7</td>
<td>0.035</td>
<td>0.020</td>
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<tr>
<td>8</td>
<td>0.051</td>
<td>0.033</td>
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</tbody>
</table>

Average height difference: 0.019
Standard deviation: 0.029

Height offset plot

<table>
<thead>
<tr>
<th>Control ID</th>
<th>Height Difference</th>
<th>Residual</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
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<tr>
<td>10</td>
<td>0.005</td>
<td>0.009</td>
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<tr>
<td>11</td>
<td>0.005</td>
<td>0.006</td>
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<td>12</td>
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<td>15</td>
<td>0.029</td>
<td>0.030</td>
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</tbody>
</table>

Average height difference: 0.004
Standard deviation: 0.005

Height offset plot
### Use of GCP’s in processing

#### Accuracy Verification - Basic

(b) At control sites - uncorrected laser points compared to control info

<table>
<thead>
<tr>
<th>Type</th>
<th>Slope [deg]</th>
<th>Points</th>
<th>Min-d</th>
<th>Mean-d</th>
<th>Max-d</th>
<th>RMS-d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td>0 - 5</td>
<td></td>
<td>119</td>
<td>0.001</td>
<td>0.032</td>
<td>0.145</td>
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<tr>
<td>Sloped</td>
<td>5 - 85</td>
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<tr>
<td>Vertical</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td>119</td>
<td>0.001</td>
<td>0.032</td>
<td>0.145</td>
<td>0.044</td>
</tr>
</tbody>
</table>

Mean distance = 0.032m  
RMS = 0.044m

#### Accuracy Verification - Refined

(b) At control sites - corrected laser points compared to control info (without blunders)

<table>
<thead>
<tr>
<th>Type</th>
<th>Slope [deg]</th>
<th>Points</th>
<th>Min-d</th>
<th>Mean-d</th>
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<th>RMS-d</th>
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<tbody>
<tr>
<td>Horizontal</td>
<td>0 - 5</td>
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<td>0.091</td>
<td>0.021</td>
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<tr>
<td>Sloped</td>
<td>5 - 85</td>
<td>0</td>
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<td></td>
<td>111</td>
<td>0.000</td>
<td>0.014</td>
<td>0.091</td>
<td>0.021</td>
</tr>
</tbody>
</table>

Mean distance = 0.014m  
RMS = 0.021m

### Rural Processing Environment

May 21  
May 23
Rural Processing Environment

Tie Plane Determination & Selection

| Line | Ch | Points Mean/Std Mean/
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>L001</td>
<td>S1</td>
<td>1340123.000 0.008 0.010 0.471</td>
</tr>
<tr>
<td>L002</td>
<td>S1</td>
<td>1795345.000 0.008 0.010 0.477</td>
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<tr>
<td>L003</td>
<td>S1</td>
<td>8243578.000 0.008 0.010 0.468</td>
</tr>
<tr>
<td>L004</td>
<td>S1</td>
<td>4323678.000 0.008 0.010 0.463</td>
</tr>
<tr>
<td>L005</td>
<td>S1</td>
<td>2135634.000 0.008 0.010 1.200</td>
</tr>
<tr>
<td>L006</td>
<td>S1</td>
<td>4323678.000 0.008 0.010 1.163</td>
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<tr>
<td>L007</td>
<td>S1</td>
<td>8243578.000 0.008 0.010 1.281</td>
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</table>

Accuracy Verification - Basic

<table>
<thead>
<tr>
<th>Line</th>
<th>Points Mean</th>
<th>Std Mean</th>
<th>Std Dev</th>
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<tbody>
<tr>
<td>L001</td>
<td>1340123.000</td>
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<td>0.010</td>
</tr>
<tr>
<td>L002</td>
<td>1795345.000</td>
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<td>0.010</td>
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<tr>
<td>L003</td>
<td>8243578.000</td>
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<tr>
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<td>4323678.000</td>
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<tr>
<td>L007</td>
<td>8243578.000</td>
<td>0.008</td>
<td>0.010</td>
</tr>
</tbody>
</table>

L008 - S1 – 257,243
L008 – S2 – 137,992
Tie Plane Determination & Selection

L008 - S1 – 93,466
L008 – S2 – 45,346

S1 – 36% of planes extracted were selected
S2 – 32% of planes extracted were selected

Self Calibration Results
### Accuracy Height Report

#### Standard

<table>
<thead>
<tr>
<th>Control Set</th>
<th></th>
<th>Height Difference</th>
<th>Residual</th>
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</thead>
<tbody>
<tr>
<td>Vernon 18</td>
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<td>0.063</td>
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<td>Vernon 19</td>
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<td>-0.053</td>
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<td>Vernon 20</td>
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<td>0.088</td>
<td>-0.118</td>
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<tr>
<td>Vernon 24</td>
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<td>0.094</td>
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<tr>
<td>Vernon 28</td>
<td></td>
<td>0.021</td>
<td>-0.036</td>
</tr>
</tbody>
</table>

#### Affixed

<table>
<thead>
<tr>
<th>Control Set</th>
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<th>Residual</th>
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<tbody>
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<td>Vernon 18</td>
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<tr>
<td>Vernon 19</td>
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<td>0.032</td>
<td>0.030</td>
</tr>
<tr>
<td>Vernon 20</td>
<td></td>
<td>0.063</td>
<td>0.037</td>
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<tr>
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<tr>
<td>Vernon 28</td>
<td></td>
<td>0.024</td>
<td>-0.052</td>
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</tbody>
</table>

#### Challenges moving forward

- **Vertical plane availability & orientation**
  - *POS Accuracy*
- **Collection techniques**
  - GCP’s on planes (~ centre)
- **Processing techniques**
  - GCP’s post collection, after planar extraction