Automating Data Alignment from Multiple Collects

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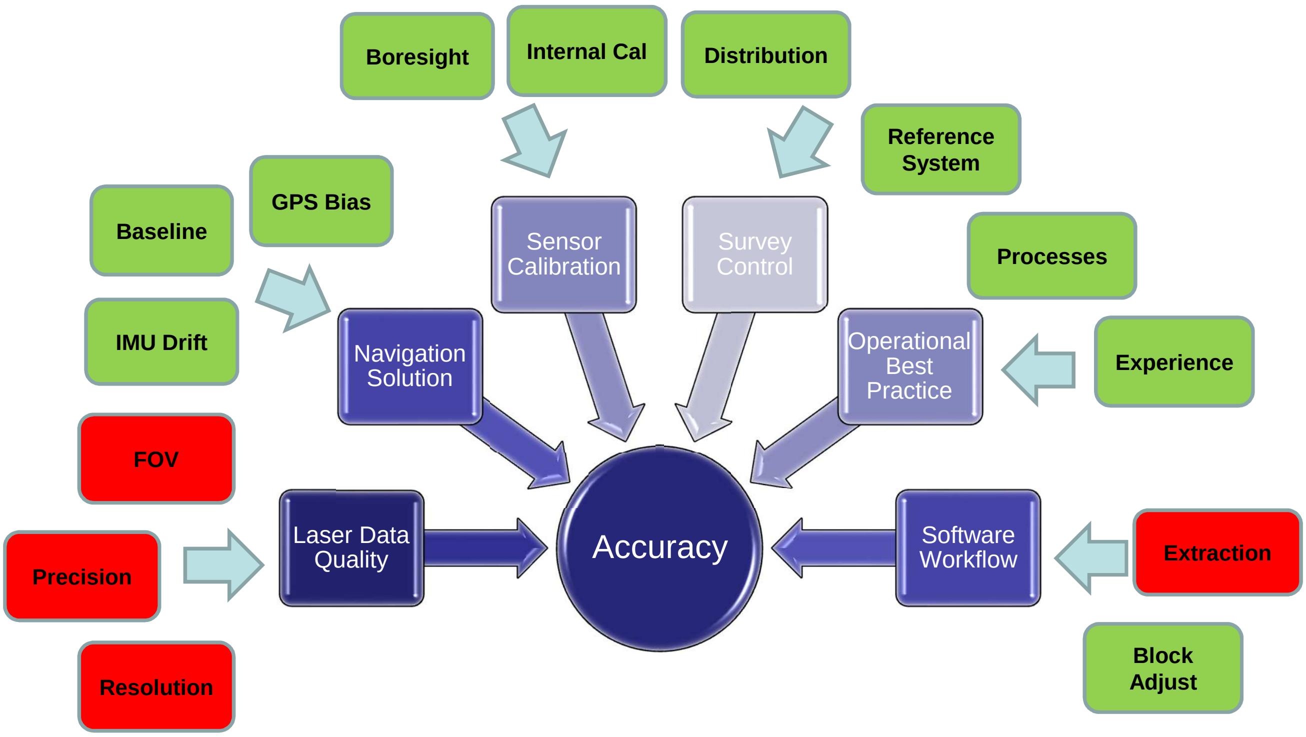
Agenda

- 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

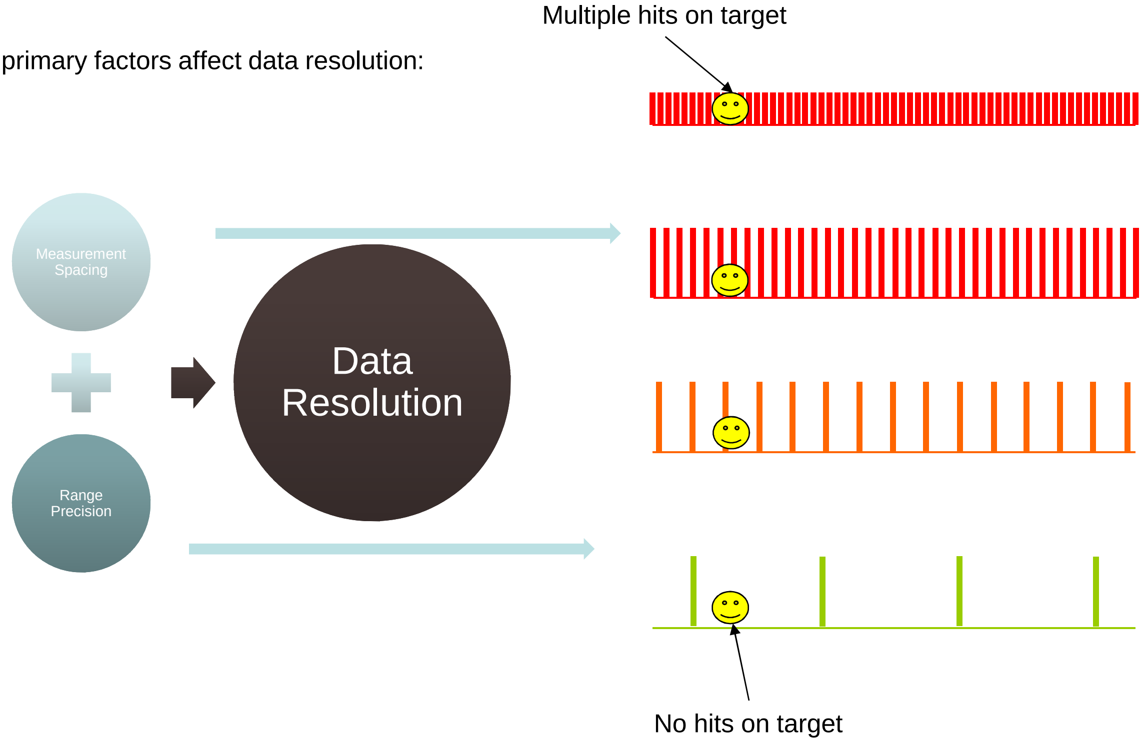
- Survey operations
- Systematic errors
- How 'good' is 'good'?
  - Accuracy verification?
- Data misalignment
  - Internally
  - To control
- Correcting misalignments need effort to fix
  - DASHMap, Terramatch
- Rescan

Factors Affecting Accuracy

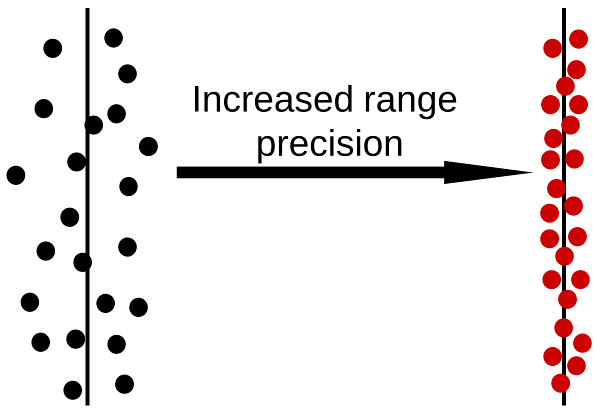


Laser Data Quality - Resoultion

Two primary factors affect data resolution:

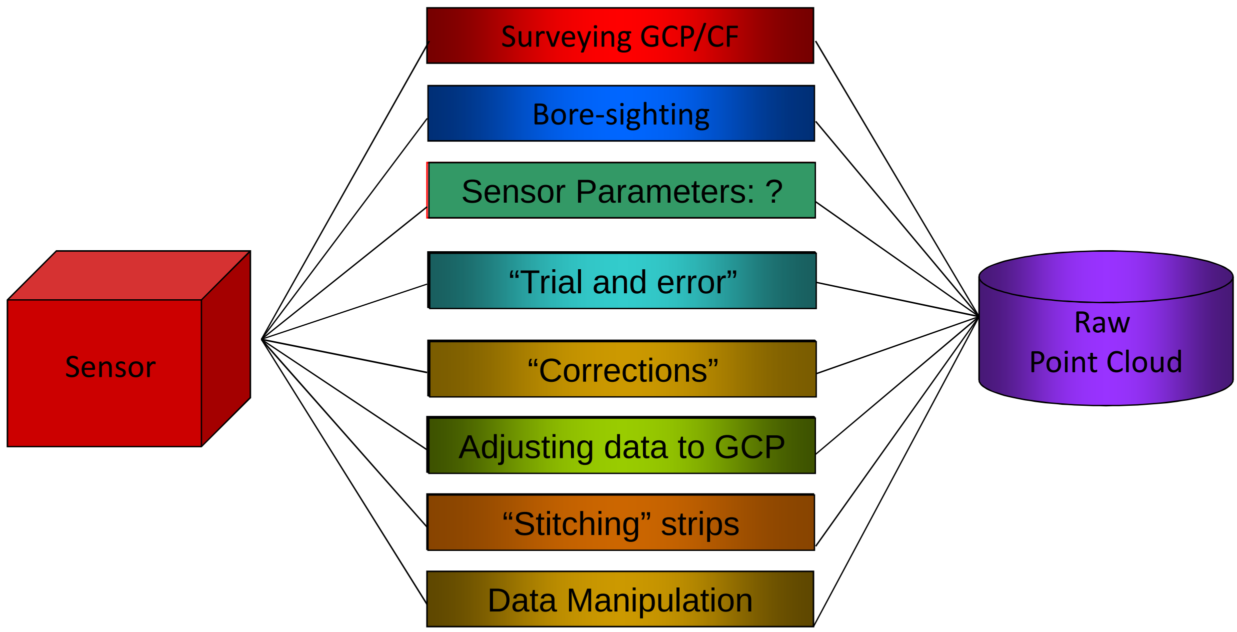


Laser Data Quality - Range Precision



Lynx laser range precision is **8mm**

Traditional Workflow



Multiple software required
Sequential and manual parameter adjustment

Proposed solution

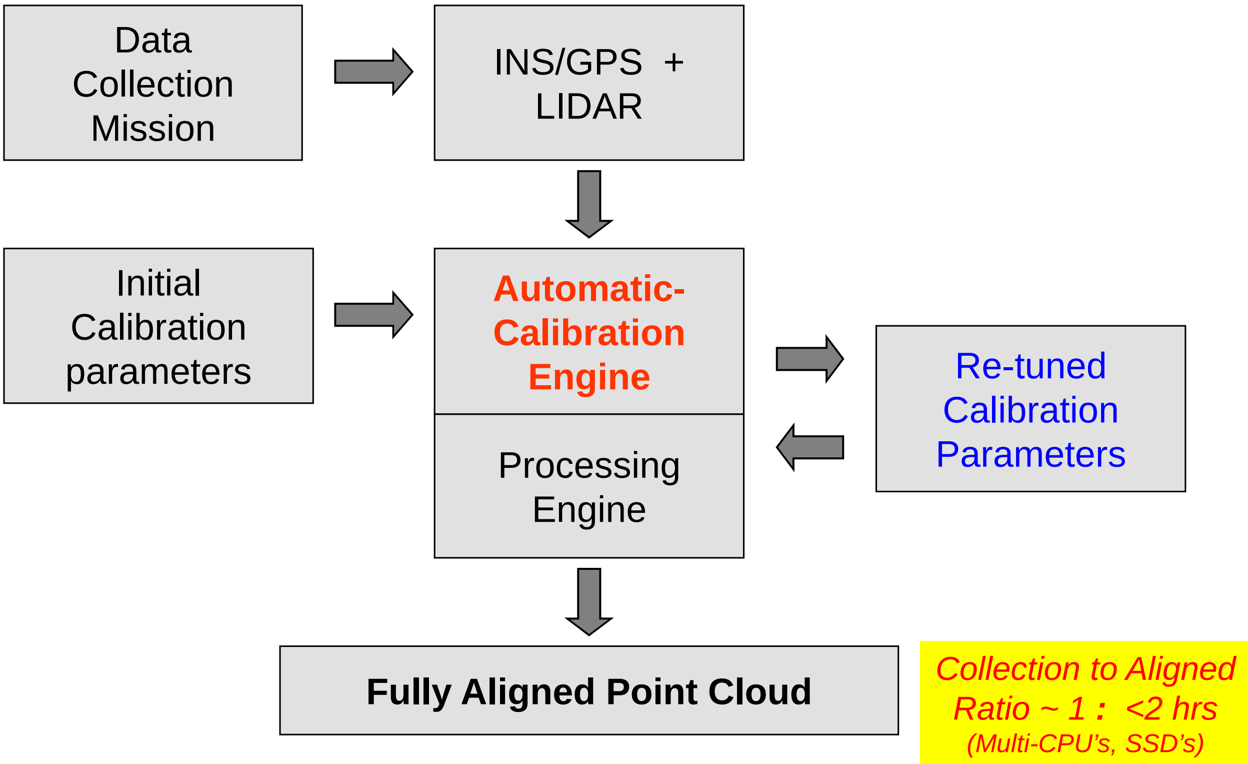
Motivation: A rigorous methodology that provides thorough accuracy control, not just locally for control areas, but the entire project area.

- 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

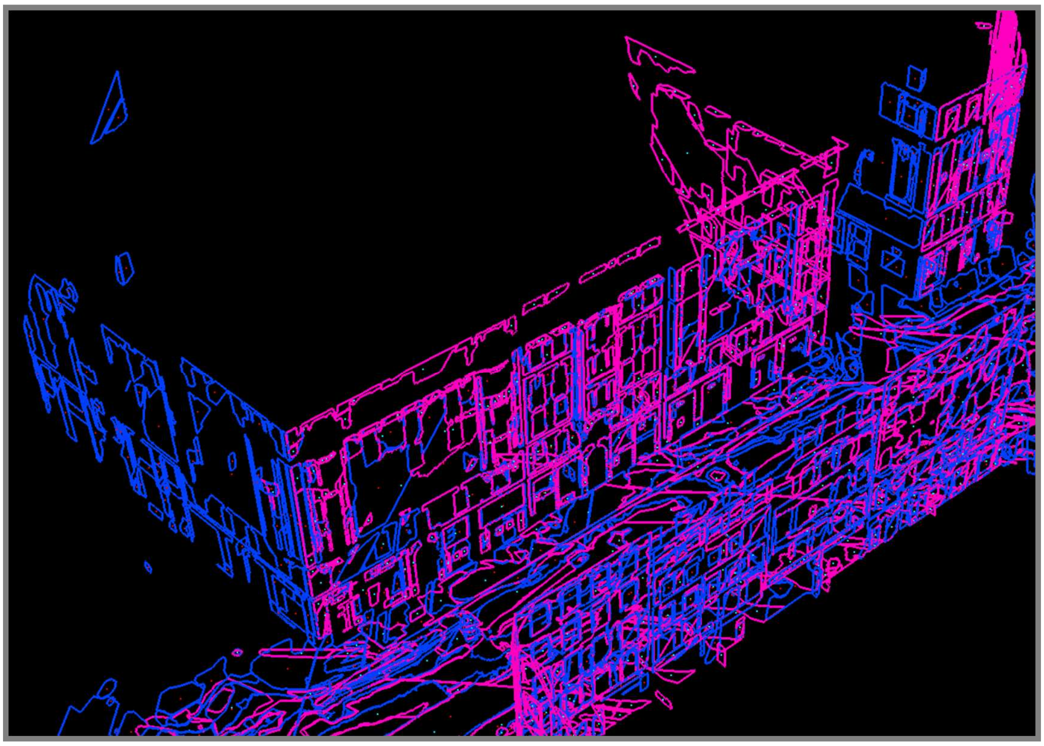


LMS Workflow

Planar Surface Extraction

S1 Blue
S2 Pink

Planes can be exported as ESRI shape files



LMS Workflow

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

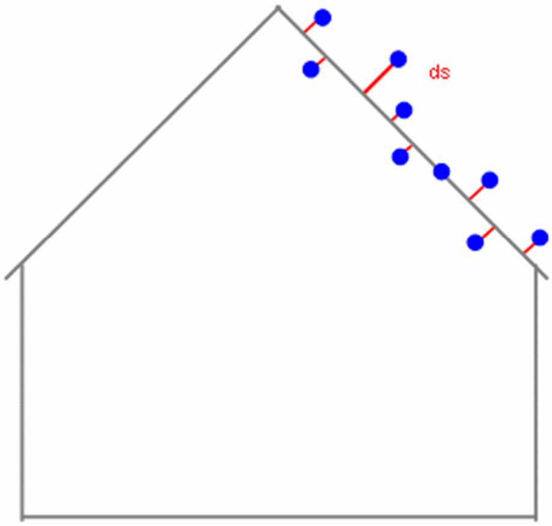
Empirically

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

$$\min ds_j$$
$$\max ds_j$$
$$\overline{ds}_j$$
$$\mathrm{rms}\ ds_j$$

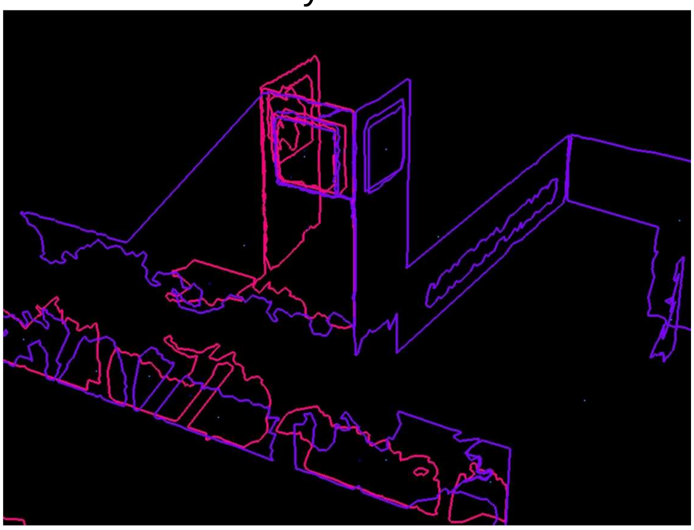
Theoretically

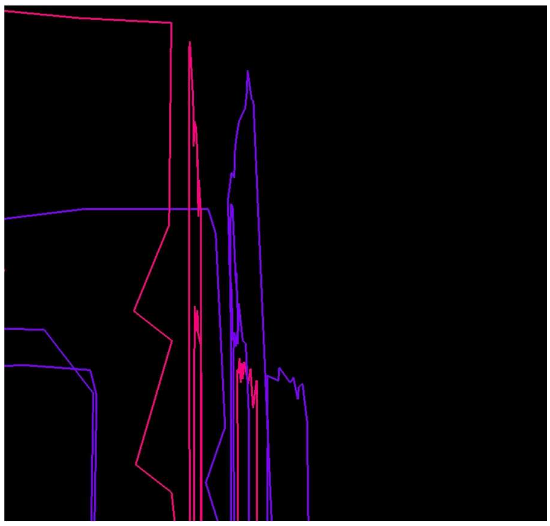
$$\sigma_{ds} = f\left(n_X, n_Y, n_Z, p, \sigma_X, \sigma_Y, \sigma_Z\right)$$



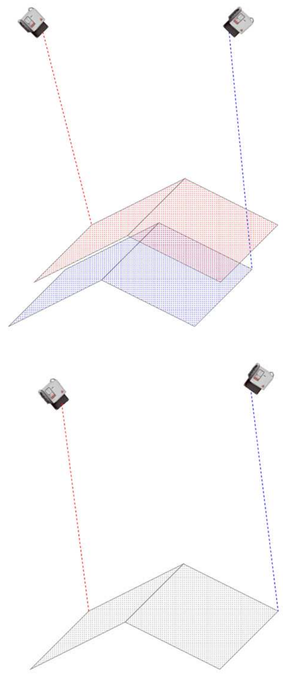
Tie Plane Determination & Selection

- 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

$$\mathbf{g}_{i,j} = n_{x,j}\, x_i + n_{y,j}\, y_i + n_{z,j}\, z_i = 0$$

where

$$\mathbf{x}_i = f\,(obs.,\ cal.\,par., corrections)$$

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

Least squares solution

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

$\Rightarrow$ Applying the correction while reprocessing laser points

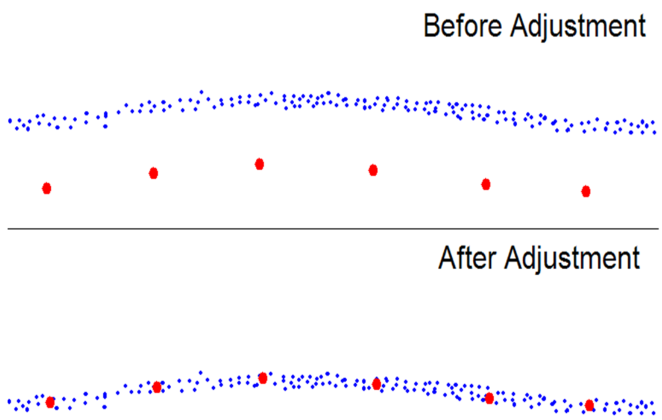
LMS Methodology – Self Calibration

- 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

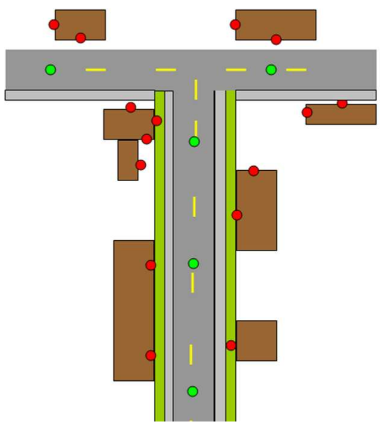
LMS-Pro: Using Control Points



Using Ground Control in LMS is <u>optional</u> but will improve data accuracy

How should GCP's be collected?

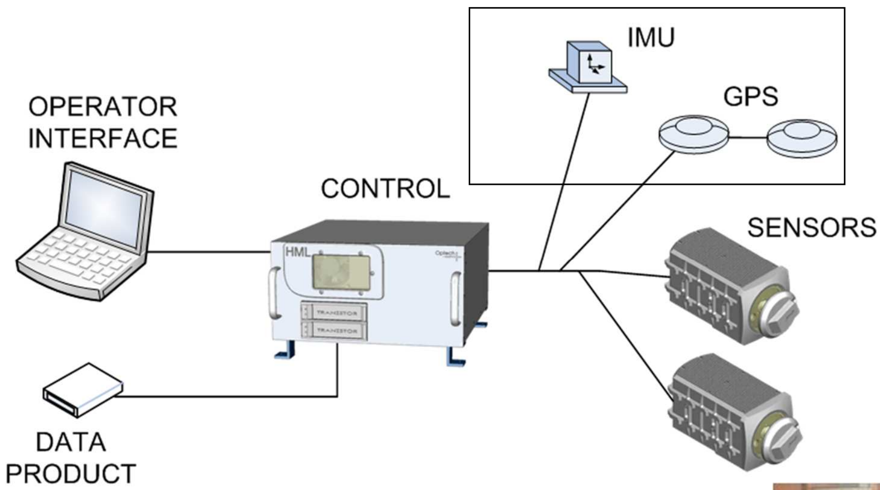
- On flat (planar) surfaces in multiple dimensions



Case Study in Data Alignment

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

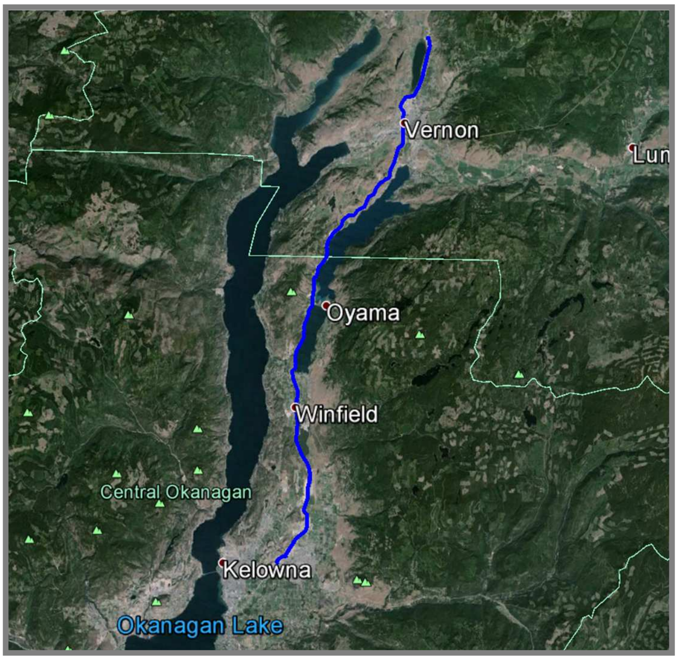
Equipment used



Hardware
•2 LIDAR sensorheads 500 kHz
•4 standard cameras (2-5 MP)
•Ladybug camera fully integrated

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

May 21, 2013 Collect

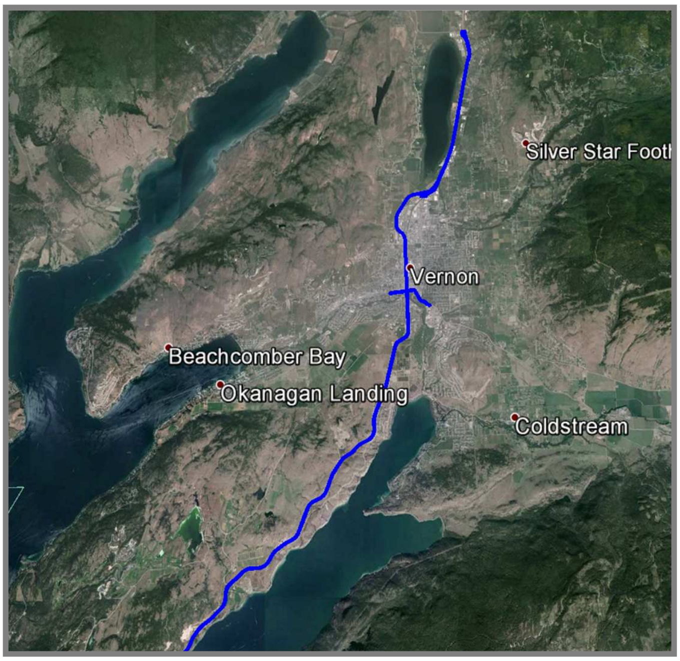


Survey Time: 1h 53min

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

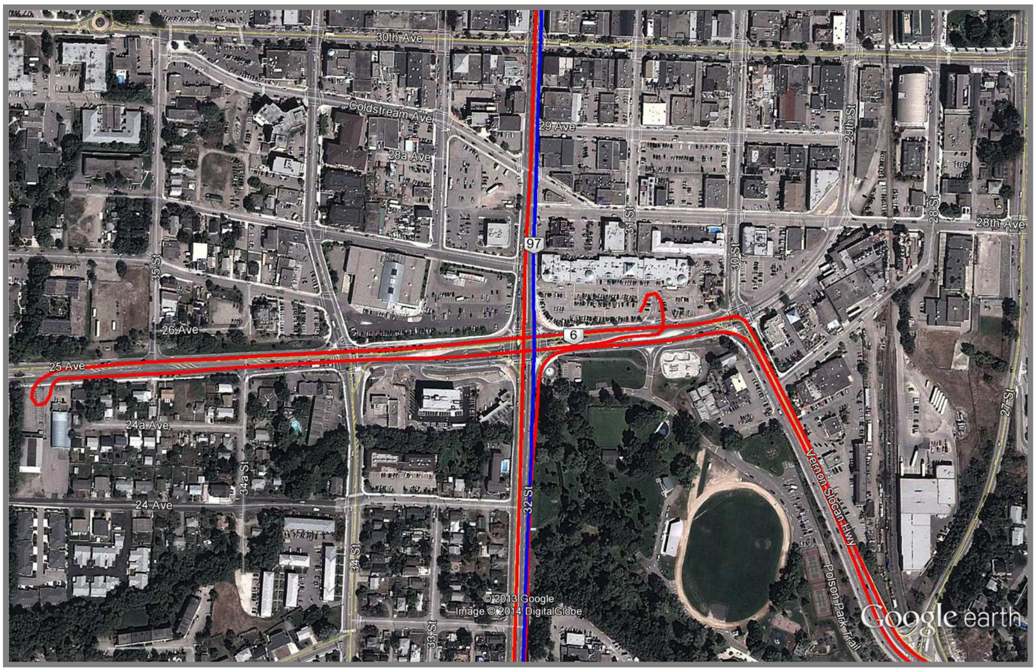
Distance: 46.9 km

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!?

Urban Processing Environment



May 21

May 23

Tie Plane Determination & Selection

Block status: Tie Plane Determination done, Tie Plane Selection done, Determine Self-Calibration Parameters do

- Project Information
- Control Site Quality
- Accuracy Verification - Basic
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes
- Self-Calibration Results
  - Adjustment Information
  - Parameter group assignments
  - Sensor corrections
  - Boresight corrections
  - Position corrections
  - Orientation corrections
- Accuracy Verification - Refined
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes

(3) Accuracy Verification - Basic

(c) At all tie planes - uncorrected laser points

Line	Ch	#Points	Mean-d	RMS-d	Std-d	Ratio
L0001	S1	1212307	-0.001	0.010	0.013	0.765
L0001	S2	865055	0.001	0.009	0.012	0.731
L0004	S1	140320	-0.053	0.057	0.012	4.762
L0004	S2	78781	-0.030	0.046	0.014	3.309
L0005	S1	219169	-0.005	0.018	0.014	1.308
L0005	S2	277167	0.000	0.018	0.012	1.461
L0006	S1	117576	-0.010	0.028	0.012	2.349
L0006	S2	96494	-0.011	0.029	0.013	2.238
L0007	S1	109389	-0.025	0.045	0.012	3.687
L0007	S2	99141	-0.017	0.036	0.013	2.753
L0008	S1	108570	-0.021	0.039	0.012	3.334
L0008	S2	117904	-0.018	0.034	0.015	2.248
L0009	S1	130477	-0.017	0.043	0.013	3.348
L0009	S2	186353	-0.039	0.054	0.011	5.036
L0010	S1	210885	-0.006	0.038	0.012	3.255
L0010	S2	246880	-0.004	0.042	0.013	3.316
L0011	S1	711630	-0.012	0.061	0.011	5.562
L0011	S2	696413	-0.006	0.040	0.013	3.024
L0012	S1	497737	-0.009	0.041	0.011	3.624
L0012	S2	588120	-0.006	0.038	0.013	2.932
L0013	S1	399234	-0.018	0.036	0.013	2.693
L0013	S2	389194	-0.014	0.027	0.012	2.139
L0014	S1	596672	-0.002	0.016	0.013	1.229
L0014	S2	587738	-0.001	0.015	0.012	1.180
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L0015	S2	227574	-0.003	0.020	0.012	1.716
L0016	S1	180510	-0.012	0.032	0.012	2.695
L0016	S2	218214	-0.004	0.017	0.013	1.326
L0017	S1	127206	-0.006	0.022	0.012	1.906
L0017	S2	172173	-0.005	0.021	0.012	1.780

L014 - S1 – **596,627**
L014 – S2 – **587,738**

Tie Plane Determination & Selection

Block status: Tie Plane Determination done, Tie Plane Selection done, Determine Self-Calibration Parameter

- Project Information
- Control Site Quality
- Accuracy Verification - Basic
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes
- Self-Calibration Results
  - Adjustment Information
  - Parameter group assignments
  - Sensor corrections
  - Boresight corrections
  - Position corrections
  - Orientation corrections
- Accuracy Verification - Refined
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes

(3) Accuracy Verification - Basic

(d) At selected tie planes - uncorrected laser

Line	Ch	#Points	Mean-d	RMS-d	Std-d	Ratio
L0001	S1	671296	-0.001	0.011	0.013	0.847
L0001	S2	389044	0.001	0.010	0.011	0.907
L0004	S1	124859	-0.055	0.059	0.012	4.824
L0004	S2	42114	-0.037	0.053	0.013	3.970
L0005	S1	29242	-0.015	0.027	0.012	2.246
L0005	S2	28098	-0.006	0.018	0.012	1.507
L0006	S1	62656	-0.011	0.026	0.011	2.271
L0006	S2	51874	-0.013	0.027	0.014	1.973
L0007	S1	63224	-0.028	0.047	0.012	4.004
L0007	S2	65312	-0.014	0.032	0.014	2.327
L0008	S1	62014	-0.017	0.034	0.012	2.972
L0008	S2	69805	-0.014	0.028	0.015	1.873
L0009	S1	83734	-0.016	0.036	0.013	2.815
L0009	S2	117549	-0.030	0.045	0.011	3.898
L0010	S1	137724	-0.012	0.029	0.012	2.434
L0010	S2	146311	-0.004	0.023	0.013	1.824
L0011	S1	391266	-0.022	0.051	0.011	4.592
L0011	S2	402733	-0.006	0.034	0.013	2.619
L0012	S1	282049	-0.018	0.051	0.011	4.526
L0012	S2	341056	-0.006	0.034	0.012	2.784
L0013	S1	88002	-0.002	0.021	0.012	1.772
L0013	S2	68177	-0.008	0.021	0.012	1.849
L0014	S1	512345	-0.002	0.015	0.013	1.091
L0014	S2	465163	0.002	0.009	0.012	0.728
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L0015	S2	109768	0.000	0.013	0.012	1.125
L0016	S1	115669	-0.003	0.021	0.012	1.769
L0016	S2	116202	-0.001	0.013	0.013	1.047
L0017	S1	69391	-0.008	0.023	0.012	2.031
L0017	S2	97403	-0.001	0.012	0.012	1.000

L014 - S1 – **512,345**
L014 – S2 – **465,163**

S1 – 85% of tie planes determined were selected

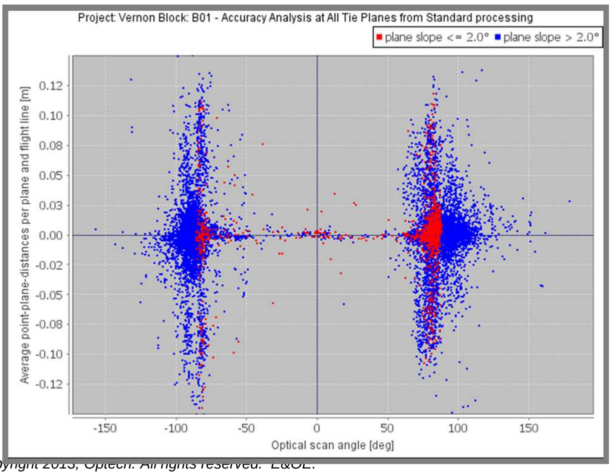
S2 – 79% of tie planes determined were selected

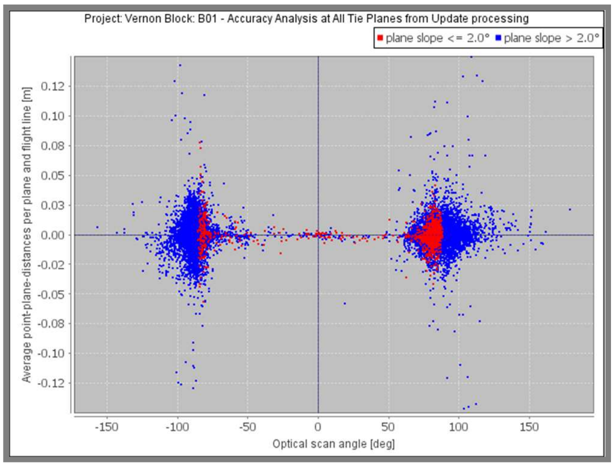
Self Calibration Results

Block status: Tie Plane Determination done, Tie Plane Selection done, Determine Self-Calibration Parameters done

- Project Information
- Control Site Quality
- Accuracy Verification - Basic
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes
- Self-Calibration Results
  - Adjustment Information
  - Parameter group assignments
  - Sensor corrections
  - Boresight corrections
  - Position corrections
  - Orientation corrections
- Accuracy Verification - Refined
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes

```
(4) Self-Calibration Results

  (a) Adjustment Information

  ---------------------------------------
          Parameter name          Value
  ---------------------------------------
  Maximum number of iterations        9
  Number of performed iteration       5
  Convergence test               PASSED
  Standard dev. of unit weight 0.672898
  ---------------------------------------
```





Accuracy Height Report

Standard

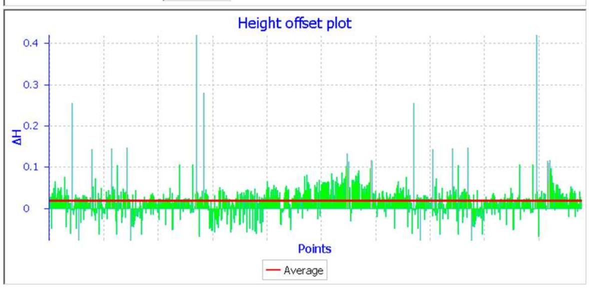
Control Set	ID	Height Difference	Residual
☑ control_Kelowna	36	0.022	0.003
☑ control_Kelowna	37	0.027	0.008
☑ control_Kelowna	38	0.022	0.002
☑ control_Kelowna	39	0.025	0.006
☑ control_Kelowna	40	0.029	0.010
☑ control_Kelowna	41	-0.047	-0.066
☑ control_Kelowna	42	0.036	0.017
☑ control_Kelowna	43	0.035	0.016
☑ control_Kelowna	44	0.021	0.002
☑ control_Kelowna	45	0.050	0.031

☑ Show matched points only

Number of selected control points: 957

Average height difference: 0.019

Standard deviation: 0.029



Apply

Refined

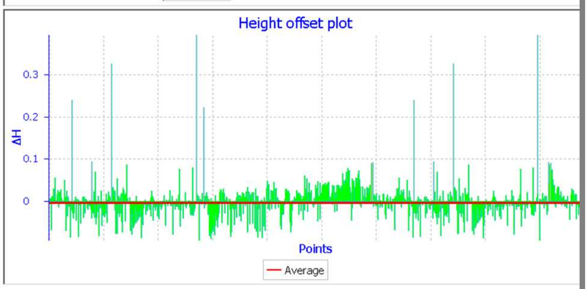
Control Set	ID	Height Difference	Residual
☑ control_Kelowna	36	-0.001	0.003
☑ control_Kelowna	37	0.005	0.009
☑ control_Kelowna	38	-0.004	0.000
☑ control_Kelowna	39	0.005	0.009
☑ control_Kelowna	40	0.007	0.011
☑ control_Kelowna	41	-0.069	-0.065
☑ control_Kelowna	42	0.012	0.016
☑ control_Kelowna	43	0.010	0.014
☑ control_Kelowna	44	-0.004	0.000
☑ control_Kelowna	45	0.029	0.033

☑ Show matched points only

Number of selected control points: 967

Average height difference: -0.004

Standard deviation: 0.031



Apply

Use of GCP's in processing

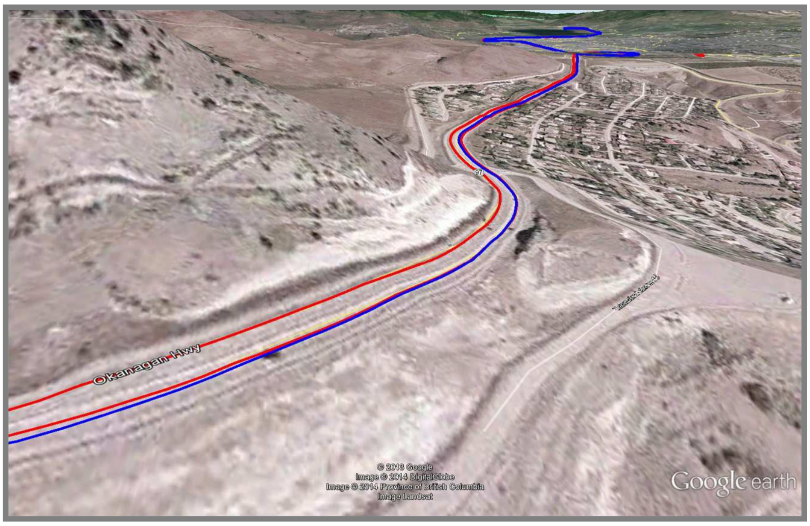
```
(3) Accuracy Verification - Basic

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

    ------------------------------------------------------
       Type     Slope [deg] #Points Min-d Mean-d Max-d RMS-d
    ------------------------------------------------------
    Horizontal 0  - 5          119 0.001  0.032 0.145 0.044
    Sloped     5  - 85           0
    Vertical   85 - 90           0

    Total                      119 0.001  0.032 0.145 0.044
```

Mean distance = 0.032m
RMS = 0.044m

```
(5) Accuracy Verification - Refined

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

    ------------------------------------------------------
       Type     Slope [deg] #Points Min-d Mean-d Max-d RMS-d
    ------------------------------------------------------
    Horizontal 0  - 5          111 0.000  0.014 0.091 0.021
    Sloped     5  - 85           0
    Vertical   85 - 90           0
    ------------------------------------------------------
    Total                      111 0.000  0.014 0.091 0.021

    Control sites - Blunders
    -------------------------------------
      Control Site  Point ID  Separation
    -------------------------------------
    control_Kelowna 254            0.116
    control_Kelowna 928            0.116
    control_Kelowna 200            0.040
    control_Kelowna 874            0.040
    control_Kelowna 675            0.095
    control_Kelowna 1004           0.095
    control_Kelowna 677            0.096
    control_Kelowna 1000           0.096
    -------------------------------------
    Total           8        Mean: 0.087
```

Mean distance = 0.014m
RMS = 0.021m

Rural Processing Environment



May 21

May 23

Rural Processing Environment

Tie Plane Determination & Selection

Block status: Tie Plane Determination done, Tie Plane Selection done, Determine Self-Calibration Parameters done, Retrieve Self-Calibration Parameters done

- Project Information
- Control Site Quality
- Accuracy Verification - Basic
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes
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  - Position corrections
  - Orientation corrections
- Accuracy Verification - Refined
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes

(3) Accuracy Verification - Basic

(c) At all tie planes - uncorrected laser points compared to uncorrected planes

Line	Ch	#Points	Mean-d	RMS-d	Std-d	Ratio
L0001	s1	1311713	-0.002	0.008	0.012	0.671
L0001	s2	1272061	0.002	0.008	0.010	0.804
L0002	s1	1738375	-0.002	0.008	0.011	0.677
L0002	s2	1604429	0.002	0.011	0.010	1.063
L0003	s1	342065	-0.001	0.009	0.012	0.764
L0003	s2	310638	0.004	0.017	0.010	1.739
L0004	s1	12779	0.002	0.015	0.010	1.452
L0004	s2	9041	-0.003	0.016	0.014	1.120
L0005	s1	35641	-0.007	0.016	0.011	1.401
L0005	s2	28712	-0.009	0.022	0.011	2.022
L0006	s1	112127	0.002	0.016	0.011	1.415
L0006	s2	160762	0.001	0.014	0.012	1.160
L0007	s1	179603	0.003	0.016	0.012	1.281
L0007	s2	98125	0.003	0.015	0.011	1.427
L0008	s1	257243	0.002	0.018	0.013	[illegible]
L0008	s2	137992	0.005	0.018	0.009	[illegible]
L0009	s1	440330	-0.002	0.015	0.012	1.246
L0009	s2	410643	0.001	0.010	0.010	1.036
L0010	s1	571767	-0.002	0.010	0.012	0.850
L0010	s2	609829	0.003	0.009	0.010	0.925
L0011	s1	419514	-0.002	0.011	0.012	0.879
L0011	s2	317571	0.001	0.012	0.011	1.111
L0012	s1	631601	-0.001	0.011	0.012	0.960
L0012	s2	622333	0.001	0.013	0.010	1.274
L0013	s1	1128983	-0.001	0.008	0.011	0.700
L0013	s2	980177	0.001	0.010	0.010	1.078
L0014	s1	337470	0.001	0.011	0.012	0.942
L0014	s2	232058	-0.001	0.011	0.009	1.233
L0015	s1	197436	-0.001	0.014	0.011	1.334
L0015	s2	151501	0.003	0.012	0.011	1.015
L0016	s1	853209	-0.001	0.009	0.011	0.804
L0016	s2	778886	0.002	0.009	0.011	0.806
L0017	s1	132103	0.002	0.018	0.011	1.560
L0017	s2	103403	0.004	0.017	0.012	1.465
L0018	s1	511257	-0.000	0.012	0.012	1.005
L0018	s2	248691	0.003	0.011	0.010	1.074
L0019	s1	233186	-0.002	0.014	0.012	1.201
L0019	s2	216457	0.000	0.014	0.011	1.281
L0020	s1	620816	-0.002	0.008	0.011	0.743
L0020	s2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

L008 - S1 – **257,243**
L008 – S2 – **137,992**

Optech

Tie Plane Determination & Selection

Block status: Tie Plane Determination done, Tie Plane Selection done, Determine Self-Calibration Parameters done, Retrieve Self-Calibration Parameters done

- Project Information
- Control Site Quality
- Accuracy Verification - Basic
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes
- Self-Calibration Results
  - Adjustment Information
  - Parameter group assignments
  - Sensor corrections
  - Boresight corrections
  - Position corrections
  - Orientation corrections
- Accuracy Verification - Refined
  - Roof line analysis
  - Control sites
  - All tie planes
  - Selected tie planes

(3) Accuracy Verification - Basic

(d) At selected tie planes - uncorrected laser points compared to uncorrected planes

Line	Ch	#Points	Mean-d	RMS-d	Std-d	Ratio
L0001	S1	727012	-0.002	0.008	0.012	0.709
L0001	S2	763265	0.002	0.009	0.010	0.866
L0002	S1	627022	-0.002	0.008	0.011	0.728
L0002	S2	593148	0.002	0.012	0.010	1.244
L0003	S1	138405	0.001	0.008	0.012	0.704
L0003	S2	130402	0.007	0.018	0.010	1.877
L0004	S1	9473	0.003	0.011	0.010	1.128
L0004	S2	7068	-0.005	0.014	0.015	0.923
L0005	S1	26743	-0.007	0.016	0.011	1.439
L0005	S2	19092	-0.012	0.025	0.012	2.089
L0006	S1	86447	-0.001	0.013	0.011	1.198
L0006	S2	139591	0.001	0.013	0.012	1.071
L0007	S1	119534	0.003	0.015	0.012	1.212
L0007	S2	87818	0.003	0.014	0.011	1.374
L0008	S1	93466	0.006	0.026	0.013	2.035
L0008	S2	45346	0.012	0.028	0.009	3.167
L0009	S1	248836	-0.001	0.018	0.012	1.528
L0009	S2	201651	0.001	0.012	0.010	1.239
L0010	S1	345067	-0.002	0.011	0.011	0.926
L0010	S2	456135	0.002	0.009	0.010	0.937
L0011	S1	354451	-0.002	0.011	0.012	0.908
L0011	S2	278379	0.001	0.012	0.010	1.161
L0012	S1	593053	-0.001	0.011	0.012	0.926
L0012	S2	585755	0.001	0.012	0.010	1.249
L0013	S1	1097415	-0.001	0.008	0.011	0.673
L0013	S2	931542	0.001	0.010	0.010	1.080
L0014	S1	287893	0.001	0.011	0.012	0.982
L0014	S2	200980	-0.002	0.011	0.009	1.209
L0015	S1	98878	-0.001	0.017	0.010	1.667
L0015	S2	47380	0.005	0.015	0.014	1.122

L008 - S1 – **93,466**
L008 – S2 – **45,346**

S1 – 36% of planes extracted were selected

S2 – 32% of planes extracted were selected

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Self Calibration Results

- Project Information
- Control Site Quality
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  - Sensor corrections
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- Accuracy Verification - Refined
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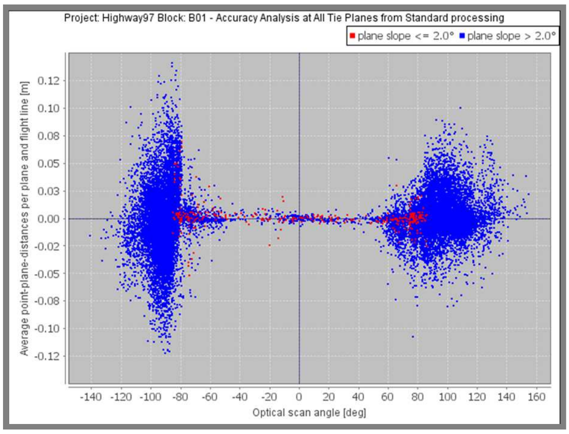
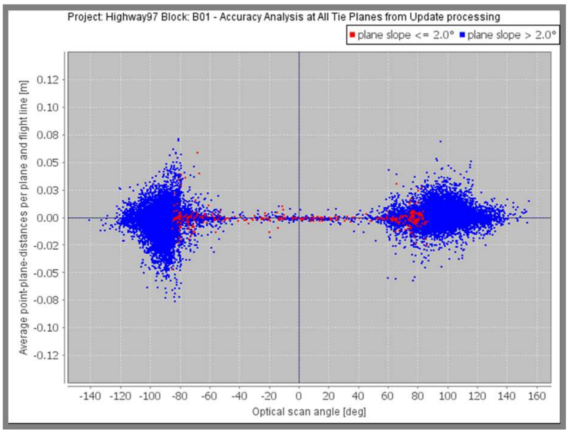
  - Control sites
  - All tie planes
  - Selected tie planes

(4) Self-Calibration Results

(a) Adjustment Information

Parameter name	Value
Maximum number of iterations	9
Number of performed iteration	6
Convergence test	PASSED
Standard dev. of unit weight	0.536356





Accuracy Height Report

Standard

Control Set	ID	Height Difference	Residual
☑ Vernon	15	0.101	0.045
☑ Vernon	18	0.119	0.063
☑ Vernon	19	-0.053	-0.109
☑ Vernon	20	0.038	-0.018
☑ Vernon	24	0.110	0.054
☑ Vernon	28	0.021	-0.035

☑ Show matched points only

Number of selected control points: 6

Average height difference: 0.056

Standard deviation: 0.067

Apply

Refined

Control Set	ID	Height Difference	Residual
☑ Vernon	15	0.014	-0.012
☑ Vernon	18	0.031	0.004
☑ Vernon	19	-0.012	-0.039
☑ Vernon	20	0.063	0.037
☑ Vernon	24	0.040	0.013
☑ Vernon	28	0.024	-0.002

☑ Show matched points only

Number of selected control points: 6

Average height difference: 0.027

Standard deviation: 0.025

Apply

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