LiDAR Services International Inc.

R.M. of McKillop No. 220

LiDAR Survey Report

October 2015

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1. SURVEY SUMMARY

LiDAR Services International Inc. (LSI) performed a LiDAR survey for the R.M. of McKillop in October 2015 of a 698 km^2 area located along Last Mountain Lake, across from Regina Beach, SK. LiDAR data was collected and delivered with the following parameters:

- MATRIX LiDAR system installed in a Piper 31 Navajo airplane owned and operated by Can-West Corporate Air Charters of Slave Lake, Alberta.
- LiDAR data was collected in one flight on October 21, 2015 based out of the Regina International Airport (CYQR).
- LiDAR data and imagery along the lakeshore was collected at an average flying height of 910m above ground level and a forward speed of 235 km/h.
- Along the lakeshore, Riegl Q780 laser pulsed at a rate of 400 kHz resulting in a computed average laser ground point spacing equal to 0.48 m with 4.3 points/m^2.
- LiDAR data and imagery away from the lakeshore was collected at an average flying height of 1800m above ground level and a forward speed of 235 km/h.
- Away from the lakeshore, Riegl Q780 laser pulsed at a rate of 400 kHz resulting in a computed average laser ground point spacing equal to 0.68 m with 2.2 points/m^2.
- Horizontal Datum: NAD83(CSRS) in metres.
- Vertical Datum: CGVD2013 orthometric heights in metres using CGG2013 geoid.
- Map Projection: UTM Zone 13 (Central Meridian = 105 degrees west longitude).
- Deliverables included:
    - LiDAR point clouds classified to DTM Key Points, Excess Ground, Low Vegetation (0-1.0m) and High Vegetation (>1m).
    - Bare Earth and Full Feature grids at 1.0 m spacing in XYZ ASCII format.
    - Greyscale hillshades of Bare Earth and Full Feature surfaces at 1.0 m pixel resolution in GeoTIFF format.
    - Ortho-mosaic color digital imagery with 0.10 m (along lakeshore) and 0.20 m (away from lakeshore) pixel resolutions in GeoTIFF, ECW and MrSID formats.
    - Index map in AutoCAD DWG format.

2. MATRIX LIDAR SYSTEM

2.1 MATRIX Installation

The MATRIX LiDAR system was installed in a Piper 31 Navajo (C-GSAZ) airplane, shown in Figure 1, owned and operated by Can-West Corporate Air Charters of Slave Lake, Alberta.

Figure 1: Piper 31 Navajo with MATRIX LiDAR System

The Riegl LMS-Q780 scanning laser, inertial measurement unit, digital camera, computers and data storage devices were mounted to the floor in the rear of the aircraft, as seen in Figures 2 and 3. The GPS antenna was mounted on top of the fuselage, and the operator controlled the MATRIX system with a monitor and keyboard from a rear passenger seat. Transport Canada has approved the installation of the MATRIX LiDAR system into this survey aircraft.

Key sensors utilized in the MATRIX installation for the LiDAR survey included:

- Riegl LMS-Q780 laser scanner and data recorder
- NovAtel SPAN-SE dual-frequency GPS receiver
- IXSEA AIRINS 200 Hz Inertial Measurement Unit (IMU)
- Canon EOS-5DS 50 megapixel digital frame downward camera

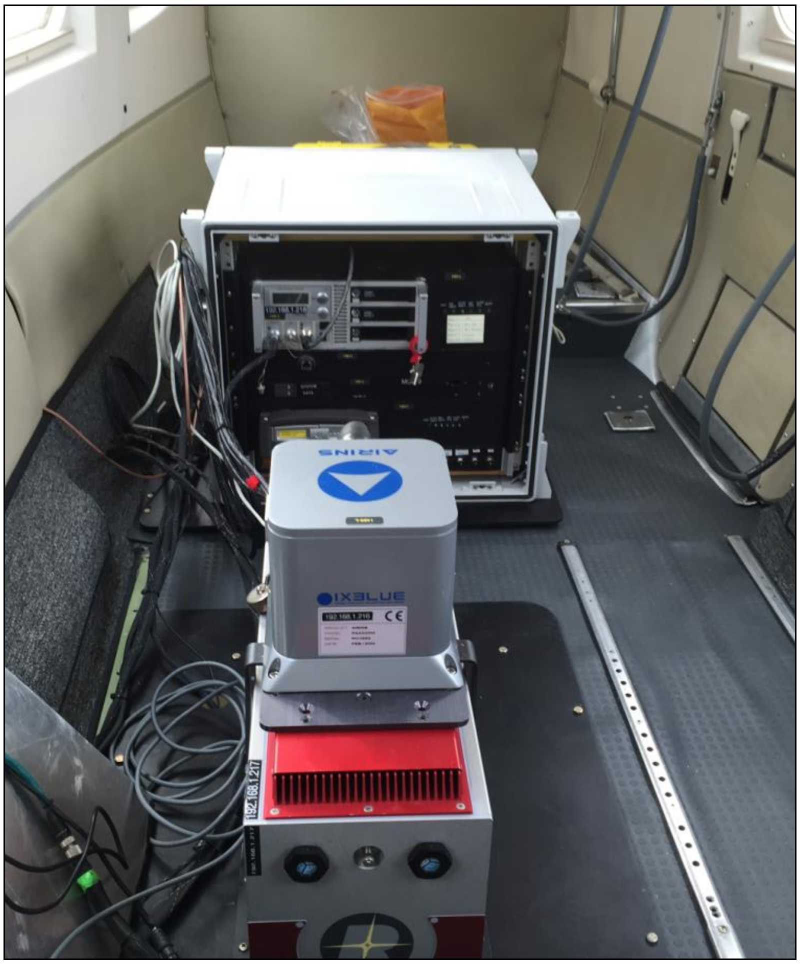

Figure 2 : Q780 Laser, IMU and Computers Mounted in the Piper 31 Navajo

Figure 3 : Camera Mounted on Piper 31 Navajo

2.2 IMU - GPS Antenna Offset Survey

Several parameters unique to each aircraft LiDAR installation must be determined in order to produce accurately positioned LiDAR point clouds. These parameters include the three dimensional vector (lever-arm) between the GPS antenna phase center and the inertial body reference. Using a total station and prisms at several points surrounding the aircraft, redundant distances and angles to the IMU unit and GPS antenna were observed. The observations were then subjected to a least-squares adjustment to compute the final lever arm values. An offset survey was completed prior to mobilization. A portion of a GPS-IMU offset survey on the aircraft is shown in Figure 4 below.

Figure 4: Piper 31 Navajo Lever-arm Survey

2.3 IMU – Laser Misalignment

LiDAR calibration passes were flown over the Craven Jamboree Grounds at the beginning and end of the flight. The calibration passes allow for the determination and verification of the roll, pitch and heading misalignment angles between the IMU measurement axis and the laser sensor. The calibration passes consisted of four flight lines flown at orthogonal and parallel headings at the project flying heights and speed.

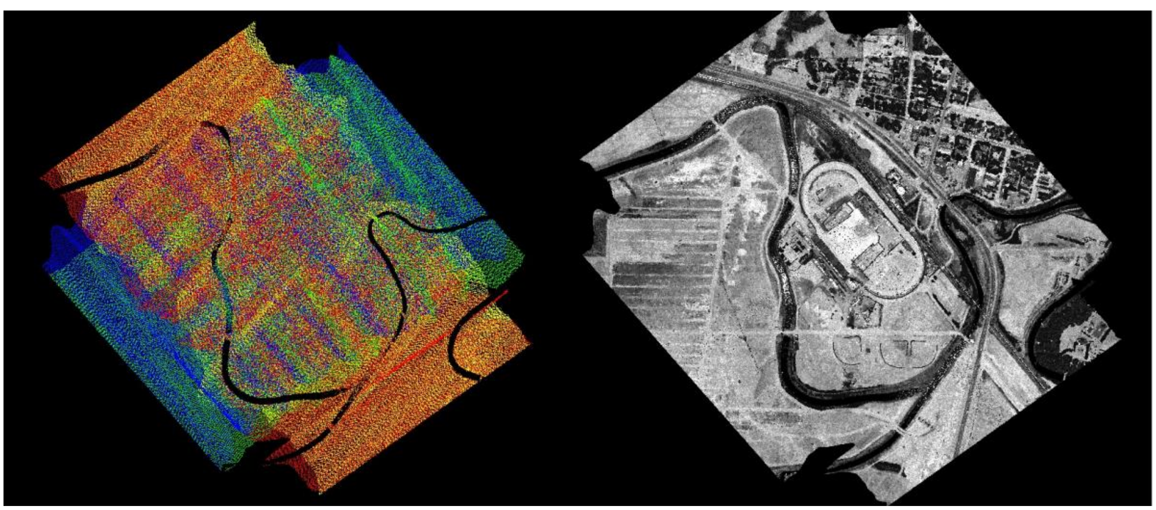

Figure 5: LiDAR Calibration Passes

3. SURVEY CONTROL

High-precision kinematic GPS solutions were obtained for the LIDAR data collection missions using differential GPS (DGPS) survey techniques. DGPS requires a static GPS receiver collecting data at a known ground control point in the vicinity of the airborne (remote) GPS receiver during LiDAR data collection.

For this LiDAR survey, three control points were referenced. *91S125* is a high order control point established by the Geodetic Survey Division (GSD) of Natural Resources Canada. *REGAIR4* and *CRAVEN* are points established by LSI at the Regina Airport and Craven Jamboree Grounds respectively. The *REGAIR4* control point was referenced to high order GSD pillar points *90V107* and *90V108* earlier in 2015 and thus had accurate, known coordinates. The three dimensional coordinates for *CRAVEN* were determined using a least squares network adjustment of the observed GPS baselines, holding the *91S125* and *REGAIR4* control points fixed. The GPS control network and project area is shown below in Figure 6.

Figure 6: Ground Control Points for the LiDAR Survey

The resulting coordinates and elevations of the GPS control points are shown in Tables 1 and 2 as follows:

Table 1: NAD83CSRS LiDAR Control Coordinates (Geographic)

ID	Latitude	Longitude	Ellipsoidal Height (m)
91S125	50 54 22.84513	-104 52 12.31759	533.346
CRAVEN	50 42 05.88759	-104 48 33.54308	471.643
REGAIR4	50 26 03.34588	-104 39 06.13625	553.914

Table 2: NAD83CSRS LiDAR Control Coordinates (UTM Zone 13)

ID	Easting (m)	Northing (m)	Elevation (m)	CGG2013 Geoid Undulation (m)
91S125	509134.195	5639418.317	553.352	-20.006
CRAVEN	513465.738	5616663.816	491.350	-19.707
REGAIR4	524735.728	5586973.795	573.200	-19.286

4. DATA COLLECTION

4.1 Airborne LiDAR Survey

The LiDAR data and imagery was collected in one flight on October 21, 2015 based out of the Regina International Airport. The project consisted of 34 flight lines flown at an average forward speed of 235 km/h.

Along the lakeshore, the average flying height was 910 m above ground level. The Q780 laser pulsed at a rate of 400 kHz and scanned at a rate of 135 Hz, resulting in an average point spacing of 0.48 m or 4.3 points per square meter. The Canon EOS 5DS digital camera took a photo every 3.8 seconds, collecting raw imagery with a pixel size equal to 0.107 m on the ground and 60% forward overlap between consecutive photos.

The area of the project away from the lakeshore was flown at an average flying height of 1800 m. Over this area, the Q780 laser pulsed at a rate of 400 kHz and scanned at a rate of 96 Hz, resulting in an average point spacing of 0.61 m or 2.2 points per square meter. The downward digital camera took a photo every 7.5 seconds, collecting raw imagery with a pixel size equal to 0.211 m on the ground and 60% forward overlap between consecutive photos.

Figure 7: LiDAR Flightline Trajectories

4.2 Calibration Check Points

Ground check points were collected at the Craven calibration site to help verify the accuracy of the LiDAR data, including the installation parameters and the GPS-IMU solutions for each flight. The check points were collected on foot with a pole-mounted GPS antenna, as shown in Figure 8, and post-processed in a DGPS solution referenced to the *CRAVEN* control point. A total of 43 check points were collected.

Figure 8: Example of Ground Check Point Collection

The ground points were classified from each individual calibration pass (as described in Section 2.3) and the resulting triangulated surface model was compared to the independently-observed ground check points. The resulting height residuals and statistics are shown in Table 3.

Table 3: Calibration Check Point Residuals

Flight Line	Avg dZ (m)	Min dZ (m)	Max dZ (m)	Avg Mag (m)	RMS (m)	Std Dev (m)
1	0.037	0.010	0.070	0.037	0.039	0.012
2	0.068	0.040	0.090	0.068	0.069	0.011
3	0.018	-0.010	0.050	0.020	0.023	0.016
4	0.051	0.020	0.090	0.051	0.053	0.014
39	0.006	-0.017	0.024	0.009	0.011	0.009
40	0.002	-0.021	0.026	0.007	0.010	0.010
41	-0.035	-0.075	0.005	0.036	0.040	0.020
42	-0.022	-0.041	0.015	0.023	0.024	0.010
All	**0.016**	**-0.075**	**0.090**	**0.031**	**0.034**	**0.013**

5. DATA PROCESSING AND DELIVERABLES

The LiDAR data and imagery for the R.M. of McKillop project were delivered with the following specifications:

- LiDAR point clouds classified to DTM Key Points, Excess Ground, Low Vegetation (0-1m) and High Vegetation (>1m) in LAS v1.2 format.
- Bare Earth and Full Feature grids at 1.0 m spacing in XYZ ASCII format.
- Greyscale hillshades of Bare Earth and Full Feature surfaces at 1.0 m pixel resolution in GeoTIFF format.
- Ortho-mosaic color digital imagery with 0.10 m (along lakeshore) and 0.20 m (away from lakeshore) pixel resolutions in GeoTIFF, compressed ECW and MrSID formats.
- Index map in AutoCAD DWG format.

5.1 LiDAR Point Clouds

5.1.1 LiDAR Tiles

Unclassified point clouds were generated for each individual flight line from the raw laser data, the GPS-IMU post-processed solution and the measured system calibration parameters. The point clouds were then imported into 1km x 1km tiles covering the project area using Terrasolid software. Each tile is numbered according to the UTM coordinates of the south-west corner. For example, the coordinates of the south-west corner of tile 4995647 would be (E: 499000m, N: 5647000m).

The LAS v1.2 point clouds have been classified using the following numbers:

- 2: Excess Ground
- 3: Low Vegetation (less than 1 meter above ground)
- 5: High Vegetation (greater than 1 meter above ground)
- 8: DTM Key Point

Within the provided boundary along the lakeshore, only data from the low altitude flight lines was imported into the tiles. Outside this boundary, data from the high altitude flight lines was used. The tiles that this boundary passes through will therefore contain both the higher and lower resolution LiDAR data.

There are three tiles for which no LiDAR data could be delivered. Only a small part of these tiles are within the project boundary and are also entirely in the lake. LiDAR returns are not generally collected off water surfaces and in these areas, none were received. These tiles were still used for grids, hillshades and imagery.

5.1.2 Ground Points

An initial automatic ground classification was applied to the tiles. The automatic ground macro classified ground points using a sequence of steps that identifies the lowest LiDAR point in an area and then finds neighboring ground points based on user-specified iteration angles and tolerances. After the automatic ground classification, trained technicians inspected each tile and either added or removed points from the *Ground* class that were incorrectly classified by the automatic ground macro. This was done using the Terrasolid suite of LiDAR editing tools in the MicroStation environment.

5.1.3 DTM Key Points

After completion of the manual ground editing, *DTM Key Points* were classified from the *Ground* point class, and all remaining points in the *Ground* class were classified to the *Excess Ground* point class. The automatic *DTM Key Point* classification minimizes the number of ground points needed to create a well-defined ground model. It selects key points from the ground points by maintaining a horizontal point spacing of at least 10 m, and ensuring that no terrain features greater than 10 cm vertically are removed.

The *DTM Key Points* class typically has 40-80% less points than the original *Ground* class, depending on the terrain. Ground points that are not reclassified as *DTM Key Points* are left in the *Excess Ground* class. ***Because the DTM Key Points are taken from the ground points, it is important that the Excess Ground class never be used by itself. Either the DTM Key Point class can be used alone, or the DTM Key Point and Excess Ground classes can be used together.*** The *DTM Key Points* and *Excess Ground* classes together will produce the maximum possible terrain detail with the largest number of points.

5.1.4 Vegetation

The remaining non-ground points were then classified into two classes: *Low Vegetation* (0 to 1 m above ground) and *High Vegetation* (greater than 1 m above ground). The vegetation classes contain all objects and structures above the ground, including buildings, transmission lines, bridges, fences, vehicles and piles of non-earth materials (garbage, wood, etc.).

5.2 Grid Points

Bare earth grid points were created at a 1.0 meter spacing, and delivered in XYZ ASCII format. The bare earth grid point elevations were derived from a Triangulated Irregular Network (TIN) surface model of the combined *DTM Key Point* and *Excess Ground* classes. Since very few LiDAR point returns were captured off the lake, synthetic water points had to be created in order for the grids to triangulate to the edge of the project boundary. These points were placed at the approximate height of the water and were used to generate the bare earth grid files but were not included in the LiDAR tiles.

Full feature grid points were also created at a 1.0 meter spacing, and delivered in XYZ ASCII format. The full feature grid point elevations were derived from the highest point in the *High Vegetation* class within each 1-meter cell. The bare earth grid points were applied for cells having no *High Vegetation* points.

5.3 Hillshades

Georeferenced grayscale raster images with a 1.0 meter pixel size were delivered in GeoTIFF format. The bare earth hillshade images were derived from the bare earth grid points, and the full feature hillshade images were derived from the full feature grid points. The hillshades were created using a 315 degree sun azimuth and 45 degree sun angle.

5.4 Orthoimage Mosaics

Geo-referenced colour digital orthoimage mosaics were delivered in GeoTIFF, ECW and MrSID formats. Mosaics along the lakeshore were delivered at a 0.10 m pixel resolution while the mosaics away from the lakeshore were delivered at a 0.20 m pixel resolution. The mosaics were divided into tiles using the same tile structure as the LiDAR tiles and trimmed to the project boundary. The compressed ECW tiles were created using a 5:1 compression ratio. To keep the file sizes reasonable, the MrSIDs were divided into nine smaller compositions. The boundaries of these are marked in the index file.

Similar to the way LiDAR data was imported into the tiles, only images from the low altitude flight lines were used within the provided boundary along the lakeshore. To ensure 0.10 m pixel resolution mosaics could be produced for this area in its entirety, some tiles along the boundary of the low resolution and high resolution data had to be further subdivided into smaller tiles. These 500m x 500m tiles were subsequently renamed, for example, 5005630_NW, 5005630_NE, etc.

LSI greatly appreciates the opportunity to have performed this survey for the R.M. of McKillop, and is available for any questions or comments regarding the survey or the contents of this report.

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APPENDIX A: CONTROL POINT PHOTOS

91S125

CRAVEN

REGAIR4