Lewis & Clark

LiDAR Campaign (Helena City, Montana) Report of Survey

September, 2012

Eric Spangenberg, on behalf of Lewis & Clark County, contracted with Sanborn to provide LiDAR mapping services for the City of Helena and surrounding areas in the State of Montana. Utilizing multi-return systems, Light Detection and Ranging (LiDAR) data in the form of 3-dimensional positions of a dense set of mass points were collected for approximately 320 square miles between May 8th and May 9th, 2012. All systems consist of geodetic GPS positioning, orientation derived from high-end inertial sensors and high-accurate lasers. The sensor is attached to the aircraft's underside and emits rapid pulses of light that are used to determine distances between the plane and terrain below.

Specifically, the Leica ALS-50 system was used to collect data for the survey campaign. The LiDAR system is calibrated by conducting flight passes over a known ground surface before and after each LiDAR mission. During final data processing, the calibration parameters are inserted into post-processing software.

Two airborne GPS (Global Positioning System) base stations were used in the Lewis& Clark Project. These base stations were provided by Sanborn.

The acquired LiDAR data was processed to all return point data. The last return data was further filtered to yield a LiDAR surface representing the bare earth.

The contents of this report summarize the methods used to establish the base station coordinate check, perform the LiDAR data collection and post-processing as well as the results of these methods.

Contents

1.0   INTRODUCTION

This document contains the technical write-up of the LiDAR campaign, including system calibration techniques, the establishment and processing of base stations, and the collection and post-processing of the LiDAR data.

1.1   Contact Information

Questions regarding the technical aspects of this report should be addressed to:

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1.2   Purpose of the LiDAR Acquisition

As stated in the Statement of Work for Acquisition and Production of High Resolution Elevation data for the Helena City area, this LiDAR operation was designed to create high resolution data sets that will establish an authoritative source for elevation information for the state of Montana.
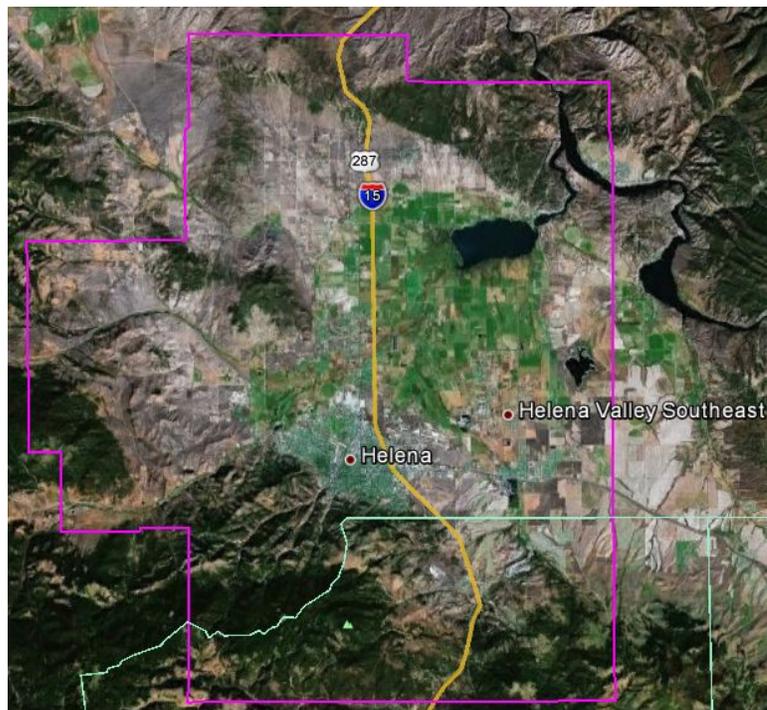
1.3   Project Location

Figure 1: Area of Collection

1.4 Standard Specifications for LiDAR

Acquisition		
Requirement	Description	
Returns per pulse	LiDAR sensor shall be capable of recording up to 3 (or more) returns per pulse, including 1st and last returns	
Scan angle	≤ ±20 degrees	
Swath overlap	Nominal sidelap on adjoining swaths, at 30%	
Design pulse density (nominal)	Pulses/m2 = 1.4	
GPS procedures	At least 2 GPS reference stations in operation during all missions, sampling positions at 1 Hz or higher frequently. Differential GPS baseline lengths shall not exceed 30 km. Differential GPS unit in aircraft shall sample position at 2 Hz or higher. LiDAR data shall only be acquired when GPS PDOP is ≤ 3.5 and at least 6 satellites are in view.	
Coverage	No voids between Swaths or due to cloud cover or instrument failure	

2.0 LIDAR CALIBRATION

2.1 Introduction

LiDAR calibrations are performed to determine and therefore eliminate systematic biases that occur within the hardware of the Leica ALS-50 system. Once the biases are determined they can be modeled out. The systematic biases are corrected for include scale, roll, heading, and pitch.

The following procedures are intended to prevent operational errors in the field and office work, and are designed to detect inconsistencies. The emphasis is not only on the quality control (QC) aspects, but also on the documentation, i.e., on the quality assurance (QA).

2.2 Calibration Procedures

Sanborn performs two types of calibrations on its LiDAR system. The first is a building calibration, and it is done any time the LiDAR system has been moved from one plane to another. New calibration parameters are computed and compared with previous calibration runs. If there is any change, the new values are updated internally or during the LiDAR post-processing. These values are applied to all data collected with the plane and the ALS-50 system configurations.

Once final processing calibration parameters are established from the building data, a

precisely-surveyed surface is observed with the LiDAR system to check for stability in the system. This is done several times during each mission. An average of the systematic biases are applied on a per mission basis.

2.3   Building Calibration

Whenever the ALS-50 system is moved to a new aircraft, a building calibration is performed. The rooftop of a large, flat, rectangular building is surveyed on the ground using conventional survey methods, and used as the LiDAR calibration target. The aircraft flies several specified passes over the building with the ALS-50 system set first in scan mode, then in profile mode, and finally in both scan and profile modes with the scan angle set to zero degrees.

Figure 2 shows a pass over the center of the building. The purpose of this pass is to identify a systematic bias in the scale of the system.

Figure 3 demonstrates a pass along a distinct edge of the building to verify the roll compensation performed by the Inertial Navigation System, INS.

Additionally, a pass is made in profile mode across the middle of the building to compensate for any bias in pitch.
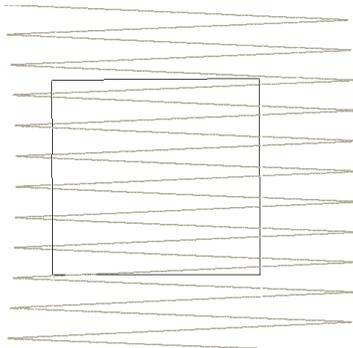

Figure 2: Calibration Pass 1   **Figure 3: Calibration Pass 2**
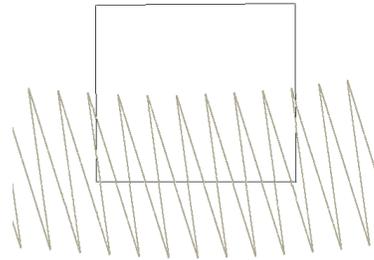
2.4   Runway Calibration, System Performance Validation

An active asphalt runway was precisely-surveyed at the Helena Regional Airport for the LiDAR collection using kinematic GPS survey techniques (accuracy: ±3cm at 1σ, along each coordinate axis) to establish an accurate digital terrain model of the runway surface. The LiDAR system is flown at right angles over the runway several times and residuals are generated from the processed data. Figure 4 shows a typical pass over the runway surface.

Approximately 30,000 LiDAR points are observed with each pass. A Triangulated Irregular Network (TIN) surface is created from these passes. After careful analysis of noise associated with non-runway returns, any system bias is documented and removed from the process.

Direction of Flight

Figure 4: Runway Calibration

3.0 RUNWAY CALIBRATION AND SYSTEM PERFORMANCE VALIDATION
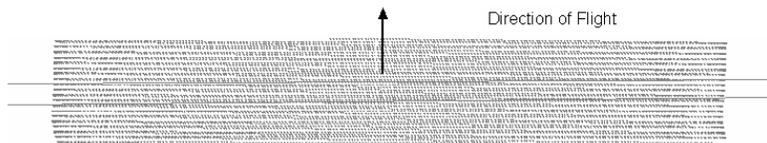
3.1 Calibration Results

The LiDAR data captured over the building is used to determine whether there have been any changes to the alignment of the Inertial Measurement Unit, IMU, with respect to the laser system. The parameters are designed to eliminate systematic biases within certain system parameters.

The runway over-flights are intended to be a quality check on the calibration and to identify any system irregularities and the overall noise. IMU misalignments and internal system calibration parameters are verified by comparing the collected LiDAR points with the runway surface.

Figure 5 shows the typical results of a runway over-flight analysis. The X-axis represents the position along the runway. The overall statistics from this analysis provides evidence of the overall random noise in the data (typically, 7 cm standard deviation – an unbiased estimator, and 8 cm RMS which includes any biases) and indicates that the system is performing within specifications. As described in later sections of this report, this analysis will identify any peculiarities within the data along with mirror-angle scale errors (identified as a "smile" or "frown" in the data band) or roll biases.

A z bump adjustment was made to the entire data set based on the survey points in the project area and the relative accuracy of the data to itself and in all areas.
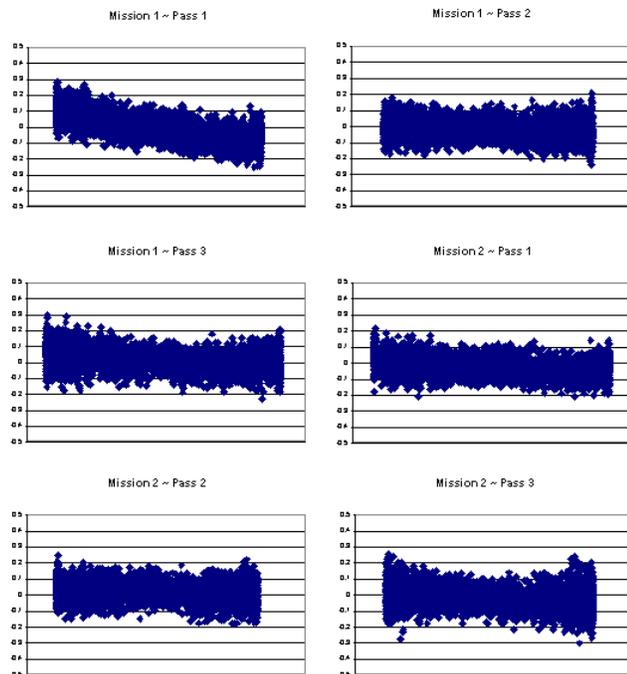

Figure 5: Runway Calibration Results

4.0 LIDAR FLIGHT AND SYSTEM REPORT

4.1 Introduction

This section addresses LiDAR system, flight reporting and data acquisition methodology used during the collection of the Lewis & Clark campaign. Although Sanborn conducts all LiDAR projects with the same rigorous and strict procedures and processes, all collections are unique.

4.2 Field Work Procedures

Pre-flight checks such as cleaning the sensor head glass are performed. A four minute INS initialization is conducted on the ground, with the engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations.

The flight missions were typically four or five hours in duration including runway calibration flights flown at the beginning and the end of each mission. During the data collection, the operator recorded information on log sheets which includes weather conditions, LiDAR operation parameters, and flight line statistics. Near the end of the mission GPS ambiguities are again resolved by flying within ten kilometers of the base stations, to aid in post-processing.

Table 1 shows the planned LiDAR acquisition parameters with a flying height of 2800 meters above ground level (AGL) for the Leica ALS-50 on a mission to mission basis.

Table 1: LiDAR Leica Acquisition Parameters

Average Altitude	2800 Meters AGL
Airspeed	~140 Knots
Scan Frequency	34 Hertz
Scan Width Half Angle	20 Degrees
Pulse Rate	89,200 Hertz

Preliminary data processing was performed in the field immediately following the missions for quality control of GPS data and to ensure sufficient overlap between flight lines. Any problematic data could then be re-flown immediately as required. Final data processing was completed in the Colorado Springs office.

Table 2: Collection Dates, Times (UTC), Average per Flight Collection Parameters and PDOP

Mission	Date	Sensor	Start Time	End Time	Altitude (m)	Airspeed (Knots)	Scan Angle	Scan Rate	Pulse Rate	PDOP (Mean)
1	May 8	Leica-40	11:49	03:26	2800	140	40°	34.0	89,200	1.2
2	May 8	Leica-40	05:59	10:40	2800	140	40°	34.0	89,200	1.4
3	May 9	Leica-40	10:21	11:58	2800	140	40°	34.0	89,200	1.1

4.3   Final LiDAR Processing

Final post-processing of LiDAR data involves several steps. The airborne GPS/IMU data was post-processed using Leica's IPAS TC software to create an *.sol file. The solution file (*.sol) and refined attitude data are then re-introduced into the LEICA ALS post processor for the Leica system to compute the laser point-positions. The trajectory is then combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points.

All return values are produced within ALS Post processing software for the Leica system. The multi-return information is processed to obtain the "Bare Earth Dataset" as a deliverable. All LiDAR data is processed using the binary LAS format 1.2 or 1.3 file format.

LiDAR filtering was accomplished using GeoCue, TerraSolid, TerraScan LiDAR processing and modeling software. The filtering process reclassifies all the data into classes with in the LAS formatted file based scheme set using the LAS format 1.3 specifications or by the client. Once the data is classified, the entire data set is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract guidelines, whichever apply.

The coordinate and datum transformations are then applied to the data set to reflect the required deliverable projection, coordinate and datum systems as provided in the contract.

The client required deliverables are then generated. At this time, a final QC process is undertaken to validate all deliverables for the project. Prior to release of data for delivery, Sanborn's Quality control/quality assurance department reviews the data and then releases it for delivery.

Table 3: Processing Accuracies and Requirements

Accuracy of LiDAR Data (H)	0.5m RMSE
Accuracy of LiDAR data in bare areas (Z)	15cm RMSE

5.0 ACCURACY ASSESSMENT

5.1 Final LiDAR Verification

The LiDAR data was evaluated using a collection of 22 GPS surveyed checkpoints which were collected by Sanborn. These checkpoints were evaluated against the LiDAR resulting in a lower RMSE and standard deviation than the project required. Table 4 shows the results for the LiDAR data set.

Table 4: LiDAR Accuracy Assessment based on the Checkpoint Report (Sanborn, Meters)

Name	Vegetation Class	Easting	Northing	Known Z	Laser Z	Dz
H04	Bare Earth	391812.319	261862.002	1357.931	1358.12	0.189
E100	Bare Earth	408629.414	256699.438	1410.968	1411.15	0.182
H01	Bare Earth	399512.416	285834.965	1415.547	1415.72	0.173
H04A	Bare Earth	391785.505	262136.464	1357.535	1357.67	0.135
RX0014	Bare Earth	404253.764	265468.78	1196.317	1196.43	0.113
E113	Bare Earth	399201.797	267877.958	1255.814	1255.91	0.096
E120	Bare Earth	402544.727	277388.37	1221.635	1221.73	0.095
H05	Bare Earth	399179.508	253317.512	1564.673	1564.74	0.067
H01PID	Bare Earth	399495.497	285823.955	1415.355	1415.41	0.055
H03	Bare Earth	391161.68	275454.501	1619.363	1619.41	0.047
E116Ros	Bare Earth	410539.145	267182.028	1138.806	1138.84	0.034
E123RA	Bare Earth	410387.325	280285.27	1241.927	1241.96	0.033
H06	Bare Earth	419251.956	252627.866	1583.512	1583.5	-0.012
H03PID	Bare Earth	391189.862	275436.168	1617.838	1617.82	-0.018
H02	Bare Earth	419601.478	279374.378	1152.787	1152.76	-0.027
E123R	Bare Earth	410387.306	280263.226	1241.793	1241.76	-0.033
E114R	Bare Earth	420019.182	265754.345	1201.87	1201.78	-0.09
E114Ros	Bare Earth	420022.312	265790.508	1198.927	1198.82	-0.107
E116R	Bare Earth	410540.966	267167.375	1139.469	1139.35	-0.119
H05A	Bare Earth	398853.04	253418.671	1566.83	1566.63	-0.2
H06A	Bare Earth	419266.895	252695.473	1587.827	1587.61	-0.217
H02A	Bare Earth	420118.433	279177.083	1159.816	1159.45	-0.366

Average dz	+0.001	
Minimum dz	-0.366	
Maximum dz	+0.189	
Average Magnitude	0.109	
Root Mean Square	**0.138**	
Std deviation	0.141	

6.0   COORDINATES AND DATUM

6.1   Introduction

The final adjustment was constrained to the published NAD83 (HARN) coordinates (ϕ, λ) and NAVD88 elevations.

6.2   Horizontal Datum

The final horizontal coordinates are provided in Montana State Plane HARN on the North American Datum with units of Meters.

6.3   Vertical Datum

The final orthometric elevations were determined for all points in the network using Geoid09 model and are provided on the NAVD88 in units of meters.