**Farmington, NM LiDAR**

**LiDAR Campaign**

**Processing and**

**QA/QC Report**

November, 2016



EXECUTIVE SUMMARY

The U.S. Bureau of Land Management (BLM) contracted with Sanborn to provide LiDAR mapping services for two AOI’s in northwestern New Mexico encompassing FFO land and surrounding the City of Farmington and portions of the San Juan Basin . 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 1500 square miles between August 29th and September 3rd, 2016. 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-70-HP 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 during each collection in the Farmington 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. Final LiDAR accuracy statistics were then computed, and client deliverables were created per the SOW.

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.

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# 

# 1.0 INTRODUCTION

This document contains the technical write-up of the LiDAR campaign, including system calibration techniques, 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

The purpose of acquisition for the Farmington project pertains to the U.S. Bureau of Land Management sustaining the health, diversity, and productivity of America’s public lands for the use of present and future generations. The BLM is responsible for management of the Farmington Field Office (FFO) land which contains public, private, and tribal properties. This project includes the collection of QL2 LiDAR for 1,500 square miles covering La Plata, San Juan, and McKinley counties in northwestern New Mexico.

## 1.3 Project Location

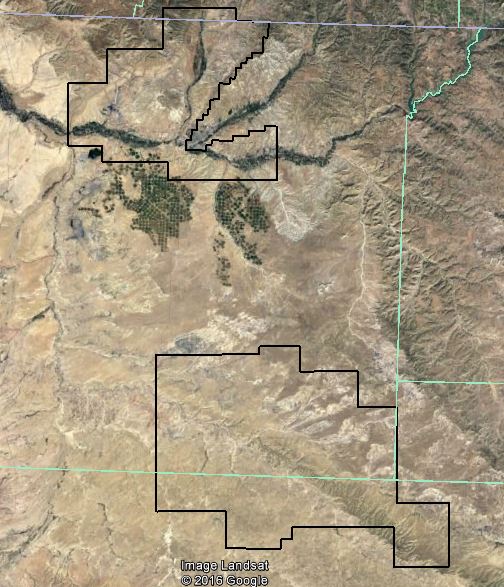


Figure 1: Area of Collection

## 1.4 Project Specifications for BLM LiDAR

|  |  |
| --- | --- |
| Data Acquisition Summary | |
| Requirement | Description |
| Returns per pulse | LiDAR sensor capable of recording 4 or more returns per pulse, including 1st and last returns |
| Scan angle | 20° |
| Swath overlap | 20% |
| Designed point spacing (m) | 0.63 |
| 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. |
| Data Collection Season | Fall 2016. |
| Survey conditions | Leaf-off and no significant snow cover. |
| Coverage | No voids between swaths.  No voids because of cloud cover or instrument failure. |

## 

# 2.0 LiDAR Acquisition

## 2.1 Introduction

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

## 2.2 LiDAR Acquisition Parameters

Based on the requirements in the summary above, Sanborn specifically defined the collection parameters to accomplish the desired Client specifications. These parameters are dependent on the LiDAR sensor and aircraft type used in the LiDAR campaign.

Table 1 shows the planned acquisition parameters for Sanborn’s Leica ALS70 utilized for this specific LiDAR aerial survey operation that was installed in Sanborn’s twin-engine aircraft.

Table 1: LiDAR Acquisition Parameters

|  |  |
| --- | --- |
| **LiDAR Sensor** | ALS70-HP |
| **Aircraft** | Turbine |
| **Average Altitude** | 1900 Meters AGL |
| **Airspeed** | ~155 Knots |
| **Scan Frequency** | 53.4 Hz |
| **Scan Angle** | 20° |
| **Pulse Rate** | 281,400 Hz |
| **Laser Power** | 100% |
| **Pulse mode** | Multi Pulse |
| **NPS** | 0.63 |

## 2.3 Planned Collection

With the parameters defined above, the LiDAR flight plan was developed and encompasses a total of 111 flight lines for a total of 2,676 linear miles. Note: the planned number of flight lines may not reflect actual number of lines delivered.

## 2.4 Sensor INS Calibration

Whenever the ALS-70 system is moved to a new aircraft, a building calibration is performed. The rooftop of a large, flat, rectangular building near Sanborn’s base airport is surveyed on the ground using conventional survey methods and also used in the LiDAR calibration process. The aircraft flies several specified passes over the building with the ALS-70 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.

|  |  |
| --- | --- |
| **middle**  Figure 2: Calibration Pass 1 | **edge**  Figure 3: Calibration Pass 2 |

## 2.5 Field Work Procedures

Sanborn’s standard procedure, before every mission, is to perform pre-flight checks to ensure correct operation of the systems sensor/AGPS/IMU/Aircraft. All cables were checked and the sensor head glass was cleaned. A five minute INS initialization was conducted on the ground with the engines running prior to flight take-off to establish fine-alignment of the IMU and to resolve the GPS ambiguities of the aircraft’s GPS unit.

During the collection of the LiDAR project, an active asphalt taxiway was precisely-surveyed using kinematic GPS survey techniques (accuracy: ±3cm at 1σ, along each coordinate axis) to establish an accurate digital terrain model of the taxiway surface.

Before the project collection occurred, just after take-off, the aircraft collected one (1) perpendicular and one (1) parallel swath over the runway for each mission flown which would later be used in the Pre-Calibration process. Figure 4 shows a typical pass over the runway surface. Approximately 2 million LiDAR points were collected with each pass. The aircraft then mobilized to the project area for collection of actual project within the specified AOI. Once each mission was completed, two (2) more calibration swaths are collected parallel to the runway in opposing directions before the aircraft landed. A Triangulated Irregular Network (TIN) surface was created from these passes over the airport’s runway. After careful analysis of noise associated with non-runway returns, any systematic bias is documented and removed from the data. Residuals were then computed and modified calibrated system parameters were then used for that specific mission.

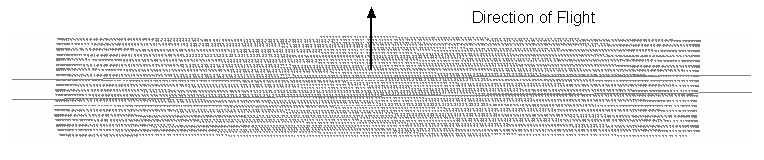


Figure 4: Runway Calibration

The flight missions for Farmington were flown within six days resulting in a total of six missions and lasted between 2-4hrs and includes 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, flight line statistics and PDOP. Near the end of each mission, GPS ambiguities are again resolved by flying within ten kilometers of the base stations to aid in post-processing.

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. The table below shows the flight acquisition metrics for the entire collection.

Table 2: Collection Dates, Times (Local), and PDOP

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Mission** | **Date** | **Sensor** | **Start Time** | **End Time** | **PDOP**  **(Ave.)** |
| **1** | 20160829 | 70-HP | 03:56 | 07:20 | 1.2 |
| **2** | 20160830 | 70-HP | 07:57 | 12:36 | 1.3 |
| **3** | 20160831 | 70-HP | 08:04 | 12:52 | 1.2 |
| **4** | 20160901 | 70-HP | 07:52 | 12:50 | 1.3 |
| **5** | 20160902 | 70-HP | 07:56 | 12:48 | 1.3 |
| **6** | 20160903 | 70-HP | 07:01 | 11:42 | 1.3 |

# 3.0 LiDAR Processing

## 3.1 Introduction

Final post-processing of the LiDAR data involves several steps. The airborne GPS/IMU data was post-processed using Leica’s CloudProsoftware to create the Smoothed Best Estimated Trajectory (SBET) solutions file. The SBET solution file and refined attitude data were then introduced into the Leica CloudPro software to compute the actual laser point-positions creating trajectory files. The trajectory is then combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates resulting in an accurate set of Raw Point Cloud (RPC) mass points. These raw swath LAS files are output from CloudPro in WGS84 UTM with ellipsoidal elevations and later re-projected into the final delivery coordinate system.

The CloudPro Post processing software created raw swath files with all return values. This multi-return information was processed and classified to obtain the “Bare Earth Dataset” as a deliverable. All LiDAR data is processed using the binary LAS format 1.2 file format.

LiDAR calibrations are performed to determine and therefore eliminate systematic biases that occur within the hardware of the Leica ALS-70 system. Once the biases are determined they can be modeled out. The systematic biases are corrected for include Dz, scale, roll, heading, and pitch.

## 3.2 Pre-Calibration Results

The LiDAR data captured over the airport and buildings 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 the system and are calculated in an automated calibration software.

The runway flights are intended to be an internal quality check on the calibration biases and to identify any system irregularities. The IMU misalignments and internal system calibration parameters are verified by comparing the collected LiDAR points with the taxiway surface. Sanborn’s Pre-Calibration process is designed to eliminate and correct most systematic biases before the Project Calibration process. Both the LiDAR point cloud and the surveyed taxiway are in the WGS84 datum for this process.

The Pre-Calibration process analyzes one lift’s calibration lines as collected from the sensor used. TerraMatch was used to find and apply corrections for Roll, Pitch, and Heading. Once the shift is applied to the calibration lines and verified, the ‘Z-bump’, roll, pitch, and heading adjustments are also applied to all swaths collected with that specific sensor (all lifts).

## 3.3 Project Calibration Process

When Sanborn completes the Pre-Calibration process, the raw point cloud data is calibrated yet again using TerraSolid GeoCue software; inlcuding TerraScan and TerraMatch. Utilizing these tools, Sanborn is able to correct each raw data swath to precisely match the two overlapping swaths. In return, the RMSE of the enitre project is substantually lower- resulting in a more accurate dataset- both against the checkpoints and swath-to-swath relative accuracies. TerraMatch samples the data perpenicular to the flight pattern to assess and correct for Dz, scale, roll, pitch, and heading errors. Before this process takes place, the raw point cloud is transformed into the final delivery datum and coordinate system using GeoCue.

Throughout the Farmington LiDAR project, flight direction consisted of an east-west flight pattern. Rows of custom sample tiles were created and placed perpendicular to the raw swaths, and populated with the raw point cloud data as seen in Figure 5 below. Once the population of the data is complete, a filter is applied to each sample tile. The filter classifies bare earth and building rooftops per flight line in order for TerraMatch to recognize the individual swaths and their features, allowing the software to find corrections for Dz, scale, roll, pitch, and heading throughout the project. Once the adjustments are calculated, the corrections are applied to the entire dataset. During this process, twenty (20) control points were used to evaluate the vertical accuracy of the calibration. These points were dispersed throughout the project area and were intended for internal departmental QC only.

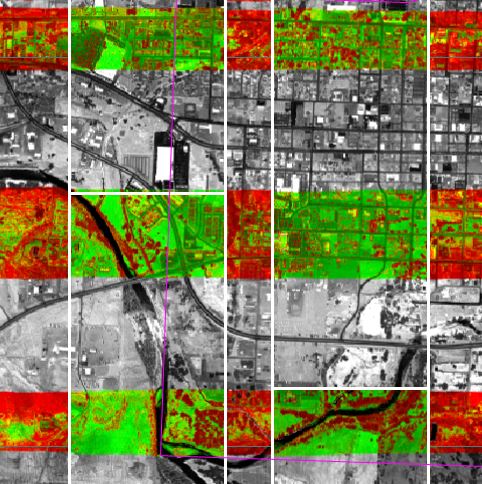


Figure 5: TerraMatch Tiling

## 3.4 Final LiDAR Processing

LiDAR filtering was accomplished using GeoCue and TerraSolid 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 1.2 specifications. Once the data is classified, the entire dataset is reviewed and manually edited for anomalies that are outside the required guidelines of the product specification or contract guidelines. This can include, but not limited to, removing bridges, structures, filling culverts, and manually analyzing the Bare Earth surface by classifying features that belong in non-erroneous classification codes.

The collected breaklines; such as the water bodies and river shapes, are then used to classify points to the designated water and breakline buffer classes.

The final LiDAR dataset consisted of 1,905 All Return LAS files and were finalized in LAS version 1.2 in units of meters.

## 3.5 Accuracy Assessment - Final LiDAR Verification

Table 3: Processing Accuracies and Requirements

|  |  |
| --- | --- |
| **Horizontal Accuracy of LiDAR Data** | ≤50cm RMSEh |
| **Vertical Accuracy of LiDAR data**  **NVA<= 19.6 ACCz, 95%**  **VVA<= 29.4cm 95th Percentile** | ≤10cm RMSEz |

The final LiDAR data was evaluated using a total of 121 GPS surveyed checkpoints. The 54 required VVA class checkpoints were collected in areas of low and high grass/vegetation and/or surrounding trees of substantial height. 67 NVA checkpoints were evaluated against the raw LiDAR swaths and DEM. The end result provided an RMSE that fell within project specifications. Please see Appendix A1 and the project Metadata for an in-depth accuracy assessment. Table 4 shows high level statistics and mean errors for the area processed by Sanborn.

Table 4: Farmington 2016 RMSEz Statistics (Meters)

|  |  |  |  |
| --- | --- | --- | --- |
| Report  Type | NVA  RPC | NVA  DEM | VVA  DEM |
| RMSEz | 0.082 | 0.077 | 0.073 |
| 95% ACCz | 0.161 | 0.151 | - |
| 95th Percentile | - | - | 0.136 |

## 3.6 Product Generation

Once the final LiDAR surface was finalized and Manually QC’ed for anomalies, the required deliverables were then generated and organized. The following products, along with the All Returns LiDAR, were generated using the final coordinate system as defined in the contract, and provided in section 4.0 of this report.

**Raw Point Cloud**

After the NVA checkpoint report is generated, the data is filtered to Unprocessed (Class 0); and delivered in LAS format v1.2. These files contain all returns.

**Classified Point Cloud**

The Classified Point Cloud, containing all returns, is delivered in LAS v1.2 format and meets USGS v1.2 LiDAR specifications (where applicable). The Classified Point Cloud contains file names referencing the US National Grid naming conventions as specified in the SOW.

**Bare Earth Flattened DEM**

Digital Elevation Models (or DEMs) were created on a tile-by-tile bases conforming to the clients specifications. The DEMs consist of using interpolated ground points in floating point 32 Bit IMAGINE Image format with a cell size of 2 feet and hydro-flattened using the collected hydro-flattened breaklines. Pyramids were then created using the resampling of Nearest Neighbor.

**Breaklines**

The breaklines were digitized using LP360- an advanced LiDAR processing and modeling software extension of ArcGIS. 3D polygons were digitized for all standing water bodies as to hydro-flattening contract specifications. Each water body and river was collected based upon surface conditions at the time of acquisition. Delivery format consisted of geodatabase (.gdb).

**Metadata**

The project, product, and tile-level metadata files were created using XML format and follows FGDC requirements. All metadata must passes the USGS metadata parser without errors.

**Other Deliverables**

* Classified LiDAR Tile Extents
* Raw Point Cloud Swath Extents
* Bare Earth DEM Tile Extents
* Control/Checkpoint shape files
* Accuracy assessment

A final QC process was 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.

# 

# 4.0 Coordinates and Datum

# 

## 4.1 Introduction

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

## 4.2 Horizontal Datum

The final horizontal coordinates are provided in UTM 13 North on the North American Datum of 1983 (NA2011) with units of Meters.

## 4.3 Vertical Datum

The final orthometric elevations were determined for all points in the network using the Geoid12b model and are provided on the NAVD88 in units of Meters.