sanborn

www.sanborn.com | 1.866.726.2676

Pima Association of Governments : City of Tucson

LiDAR Campaign for the PAG Tucson Report of Survey

August 2015

EXECUTIVE SUMMARY

Pima Association of Governments contracted with Sanborn to provide LiDAR mapping services in the city of Tucson. 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 2239 square miles covering the City of Tucson in Pima County from February 20th, 2015 through February 26th, 2015. All systems consist of geodetic GPS positioning, orientation derived from high-end inertial sensors and high-accurate lasers. The sensor is mounted on the inside of the aircraft and emits rapid pulses of light through a hole in the floor 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.

Five airborne GPS (Global Positioning System) base stations were used in the PAG Tucson project. These base stations were provided and used 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

LIST OF TABLES

LIST OF FIGURES

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:

Kris Anderson
Project Manager
Sanborn Map Co., Inc.
1935 Jamboree Dr. Suite 100
Colorado Springs Co 80920
719-264-5490
kanderson@sanborn.com

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 collection, this LiDAR operation was designed to create high resolution datasets that will establish an authoritative source for elevation information in the State of Arizona.

1.3 Project Location

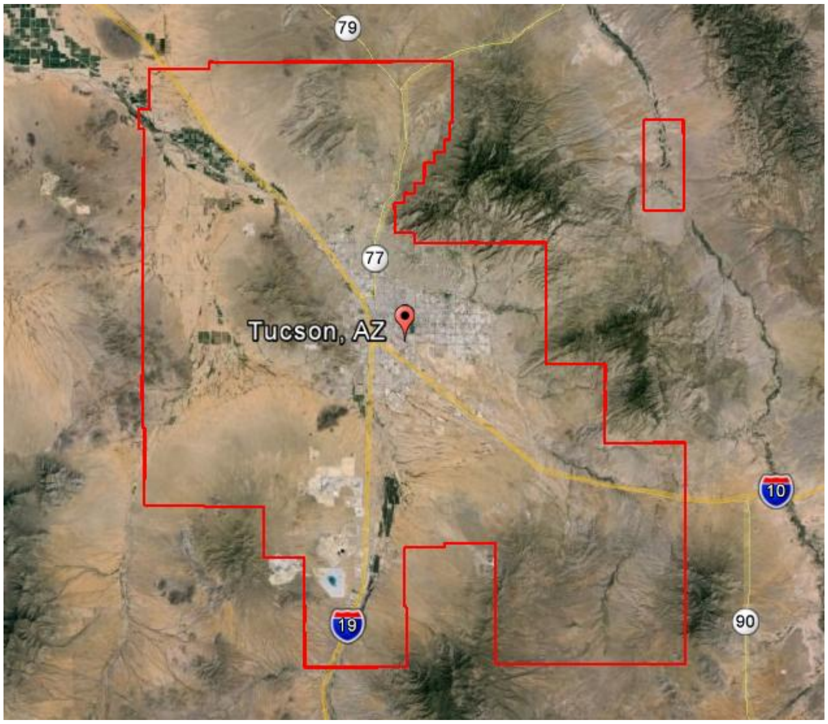

Figure 1: Area of Collection

1.4 Project Specifications for PAG Tucson LiDAR

Data Acquisition Summary	
Requirement	Description
Returns Per Pulse	LiDAR sensor capable of recording 4 returns per pulse, including 1st and last returns
Scan Angle (full)	32°, 40°
Swath overlap	Nominal side lap on adjoining swaths, i.e., survey shall be designed for 30% overlap coverage between flight lines allowing doable pass over every feature on the ground
Points Per Meter²	2
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	Winter 2015
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 PAG Tucson 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 collection.

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	Aero-Commander 500-B, a piston, Twin-Engine fixed-wing aircraft
Average Altitude	2465 Meters AGL (8,087 ft)
Airspeed	~130 Knots (150 mph)
Scan Frequency	35.1 Hertz
Scan Width Half Angle	16°
Pulse Rate	228400 Hertz
Laser Power	100%
Pulse mode	Multi Pulse
NPS	0.7 Meters

2.3 Planned Collection

With the parameters defined above, the LiDAR flight plan was developed and encompasses a total of 319 flight lines for a total of 5069 linear miles flown as shown in Figure 2 below.

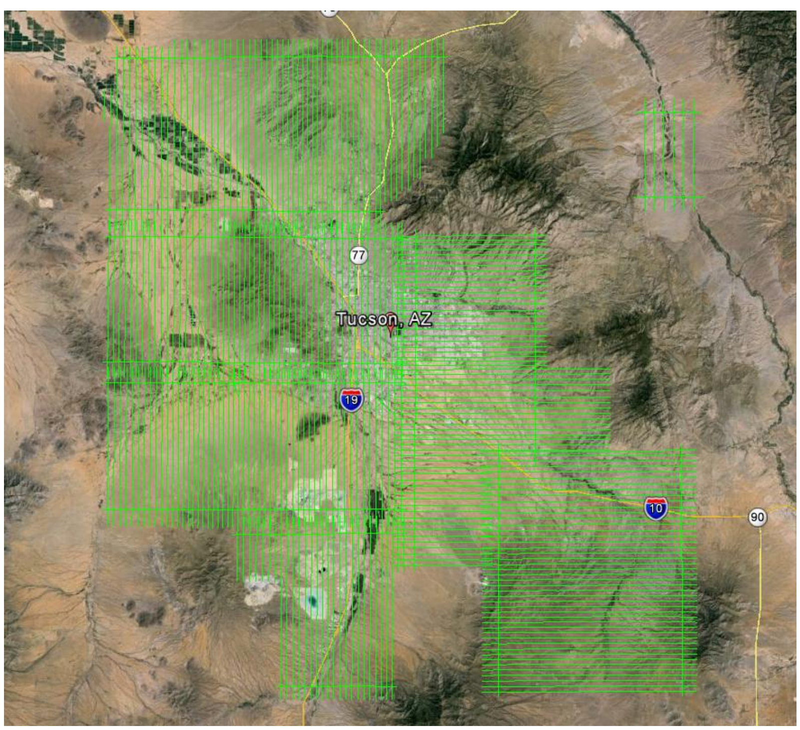

Figure 2: Predetermined Swath Collection

2.4 Sensor INS Calibration

Whenever the ALS70 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 ALS70 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 3 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 4 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.

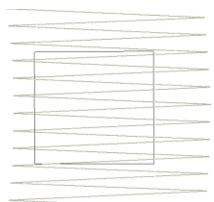

Figure 3: Calibration Pass 1

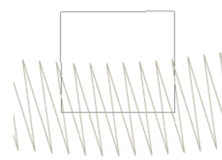

Figure 4: Calibration Pass 2

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 four 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 runway was precisely-surveyed at the Tucson International Airport and Ryan Field using kinematic GPS survey techniques (accuracy: ±3cm at 1σ, along each coordinate axis) to establish an accurate digital terrain model of the runway 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 5 below 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 perpendicular to the runway. 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 system bias is documented and removed from the data. Residuals were then computed and modified calibrated system parameters were used for that specific mission.

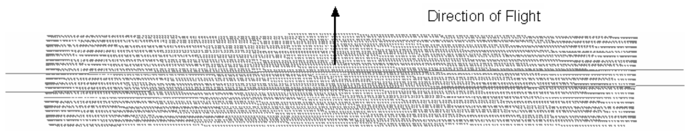

Figure 5: Runway Calibration

The flight missions for PAG Tucson were flown within 1 day resulting in a total of 14 missions and lasted between 2-5hrs 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 acquisition metrics for the PAG Tucson Collection.

Table 2: Collection Dates, Times , Average Per Flight Collection Parameters and PDOP

Mission	Date	Sensor	Start Time	End Time	Altitude (m)	Airspeed (Knots)	Field of view	Scan Rate (Hz)	Pulse Rate (Hz)	PDOP (Mean)
1	20152020a	Leica 70 HP	03:10	08:25	~3200	~130	32˚	35.0	228000	1.20
2	20152020b	Leica 70 HP	04:20	09:07	~3200	~130	32˚	35.0	228000	1.30
3	20152021a	Leica 70 HP	09:45	03:15	~3200	~130	40˚	18.0	92000	1.20
4	20152021b	Leica 70 HP	04:00	09:00	~3200	~130	40˚	18.0	92000	1.20
5	20152021c	Leica 70 HP	10:15	12:30	~3200	~130	40˚	18.0	92000	1.30
6	20152021d	Leica 70 HP	02:30	03:25	~3200	~130	32˚	35.0	228000	1.40
7	20152022a	Leica 70 HP	09:30	02:45	~3200	~130	32˚	35.0	228000	1.20
8	20152025a	Leica 70 HP	10:45	04:05	~3200	~130	40˚	35.0	228000	1.20
9	20152025b	Leica 70 HP	04:35	09.50	~3200	~130	40˚	35.0	228000	1.20
10	20152025c	Leica 70 HP	11:40	03:30	~3200	~130	32˚	35.0	228000	1.30
11	20152026a	Leica 70 HP	04:10	09:25	~3200	~130	32˚	35.0	228000	1.30
12	20152026b	Leica 70 HP	10:05	03:20	~3200	~130	40˚	35.0	288000	1.30
13	20152026c	Leica 70 HP	03:55	09:10	~3200	~130	40˚	35.0	288000	1.20
14	20152026c	Leica 70 HP	10:05	03:30	~3200	~130	32˚	35.0	228000	1.30

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 Inertial Explorer software to create the Smoothed Best Estimated Trajectory (SBET) solutions file. The SBET solution file and refined attitude data were then introduced into Leica's 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 ALSPP in WGS84 UTM with ellipsoidal elevations and later re-projected into the final delivery coordinate system.

The Leica CloudPro 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 ALS70 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 and results 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).

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 runway 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 the first lifts' calibration lines as collected from each sensor used. TerraMatch was used to find and apply corrections for Roll, Pitch, and Heading before a vertical adjustment was applied to closer match the surveyed runway. A mission from February 20th 2014 was chosen to analyze. The four (4) calibrated lines from the sensor collected on this day was compared against the sensor's surveyed runway. The Average Dz was then used to determine the amount of vertical shift needed to accurately match the runway. 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 in the AOI.

3.3 Project Calibration

When Sanborn completes the Pre-Calibration process, the raw point cloud data is calibrated yet again using TerraSolid products; inlcuding TerraScan and TerraMatch. Utilizing these two 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. TerraMatch samples the data perpenicular to the flight pattern to assess and correct for scale, roll, pitch, and heading errors.

Throughout the PAG Tucson LiDAR project, flight direction consisted of an northwest to southeast flight pattern. Rows of custom sample tiles were placed perpendicular to the raw swaths, and populated with the raw point cloud data as seen in Figure 6. 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 scale, roll, pitch, and heading throughout the project. Once the adjustments are calculated, the settings are applied to the entire dataset.

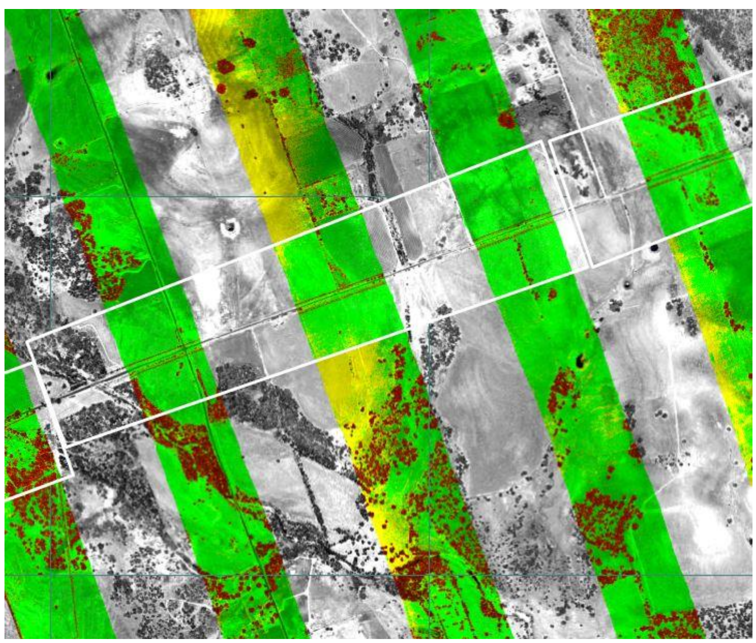

Figure 6: TerraMatch Calibration

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 or by the client. 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, culverts, structures, and manually analyzing the Bare Earth surface by classifying features that belong in non-erroneous classification codes.

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

The final LiDAR dataset consisted of 2642 tiles and were finalized in LAS version 1.4 in units of Intl Feet.

3.5 Internal Accuracy Assessment – Control Point Verification

The LiDAR data was evaluated using a collection of 32 GPS surveyed control points, and two (2) base stations which were used during the Project Calibration process. These 32 calibration control points were used for internal quality checks only and compared to the all return point cloud before classification. Please see Appendix A1 for the list of control points and their difference in Z (Dz) values. Table 3 shows high level statistics and mean errors for the area processed by Sanborn.

Table 3: PAG Tucson Control Point RMSE Statistics (Feet)

RMSE	Average Dz	Min. Dz	Max.	Average Magnitude	Std. Deviation
0.179	-0.010	-0.484	+0.308	0.138	0.181

3.6 Product Generation

Once the final LiDAR surface was finalized and Manually QC'ed for anomalies, the required deliverables were then generated. 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 LAS

After the calibration point report is generated, the data is filtered to Unprocessed (Class 0); and delivered in LAS format. These files contain all returns and conform to LAS 1.4 specifications.

Classified Point Cloud LAS
Delivered in an index created by Sanborn:
Class 1: unclassified points, Class 2: ground points, Class 7: low point, Class 9: water points, Class 10: ignored ground (breakline proximity), Class 17: bridges, Class 18: high noise. These files contain all returns and conform to LAS 1.4 specifications

Breaklines
The breaklines were created and output in Shape file format (.shp) and were digitized using ArcGIS 10.1.

Bare Earth DEM
Digital Elevation Models (or DEMs) were created on a tile-by-tile basis conforming to the clients specifications. The DEMs consist of using interpolated ground points in Imagine Image format with a cell size of 2ft (QL2) and 5ft (QL3).

Metadata
The project, product, and tile-level metadata file was created using XML format and follows FGDC requirements. All metadata must pass the USGS metadata parser without any errors.

Other Deliverables
- Final Report
- Project tiling scheme/Boundary

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 2011 coordinates (ϕ, λ) and NAVD88 elevations.

4.2 Horizontal Datum

The final horizontal coordinates are provided in Arizona State Plane Central on the North American Datum of 1983 2011 in units of Intl Feet.

4.3 Vertical Datum

The final orthometric elevations were determined for all points in the network using the newest geoid model, Geoid12a, and are provided on the NAVD88 in units of Intl Feet.