AIRBORNE1
LASER TERRAIN MAPPING

LIDAR MAPPING REPORT ADDENDUM

v1.1

OVERVIEW

Airborne1 Corporation performs LiDAR (Light Detection and Ranging) Mapping Surveys across the United States and around the world utilizing the combined technologies of the Global Positioning System (GPS), a Laser Rangefinder, and an Inertial Measurement Unit (IMU) to develop digital terrain models.

THE OPTECH ALTM 2025

Airborne1 Corporation acquired its ALTM 2025 LiDAR system from Optech, Inc. (Toronto, Canada) in May, 2000. The characteristics of this system include: operational altitude to 2000 meters above ground, records first and last laser return, captures the intensity on each return, utilizes high-end Applanix Pos/AV Inertial Navigation System (INS), and dual-frequency NovAtel Millennium GPS receiver.

The system offers several user-configurable parameters that allow the data capture campaign to be tailored to the project. The system and flight parameters include: flying altitude above ground, flying speed, mirror scanning angle, and mirror scanning rate.

LiDAR technology is a recent development in the mapping industry. The system consists of geodetic GPS positioning, orientation derived from high-end inertial sensors, and a powerful laser. LiDAR technology offers fast, real-time collection of three-dimensional points that are employed in the creation of a Digital Elevation Model (DEM).

The light source is generated in the control module and fed in to the sensor head via a fiber-optic cable. A highly engineered reflecting surface (mirror) is mounted in the end of the sensor head. The light is reflected off the mirror as it rotates back and forth through a specified angle. To facilitate the measurement of discreet units, the light is pulsed at a specific rate. The result of these actions is a fan-shaped array of light pulses that are transmitted across the flight path of the aircraft. The swath width of this array is dependant on the flying height of the aircraft and the angle limits to which the mirror rotates.

An optic sensor is co-located with the mirror in the end of the sensor head. Light pulses are reflected from objects on the ground and received by the sensor. The system measures the time difference between the transmission of the pulse and the return of the reflection to calculate the range from the sensor to the reflecting object. The ranges are recorded in the data storage device along with the IMU and GPS data. Additional GPS data is collected simultaneously at know points on the ground. The GPS and IMU data is later post-processed to provide the roll, pitch, and yaw of the aircraft at every measurement event resulting in a very accurate relative vector between the known ground control points and the sensor head. The combination of this data with the observed ranges and known mirror angle provides the 3-dimensional position of points on the ground.

AIRBORNE & FIELD SURVEYS – DATA COLLECTION

Ground Based Geodetic Base Station Occupation

The airborne trajectory is controlled from receivers (base stations) on known control points operated by the client or Airborne1. Preferably a minimum of two base stations are operated simultaneously during the flying operation to guard against a mission failure in the event one of the base receivers failed to collect satellite data during the flight. The two base stations are located so as to maintain a maximum baseline length to the aircraft as it covers the project (preferably not over 16 kilometers). During the field surveys, if two or more base stations are collecting static observations then a static network may be computed to validate the published or record positions of occupied control points.

Dual frequency P-code GPS receivers with antennas mounted on a tripod or fixed height pole are used to collect and store satellite signal data. Data is collected from all satellites above 10° every second. The receiver make and model; antenna model and operators are listed in the report.

Unless otherwise stated, the airborne GPS receiver is a Novatel Model "Millennium DL", Serial #00180388, dual frequency P-code GPS receiver mounted in a Partenavia P68/U (high wing, twin engine) aircraft with a Novatel Model "S12" antenna (specifically designed for use on aircraft) mounted on the roof. The airborne receiver and the Optech ALTM-2025 LiDAR System are operated by Airborne1 Corp.

LiDAR Data Capture

The data capture campaign requires an unobstructed view of the ground from the flying height (i.e. no fog or clouds) and relatively smooth air in which to fly. To accommodate these constraints, some flight operations may be conducted at night.

A short static occupation takes place at the beginning and end of every flight with all GPS receivers running. Once the GPS has acquired a minimum of four satellites, the IMU switched on. The IMU must be fine-aligned before taxiing begins. The airborne receiver collects continuous data from the time it leaves the airport of operations. The aircraft passes over the base stations to assure that "on-the-fly" integers are correctly fixed during post-processing and then proceeds to fly the project in strips. The strips overlapped each adjacent strip by usually 50% for double coverage as a quality control measure. The aircraft maintains airspeed of 90-140 knots (46-72 meters per second) at a prescribed altitude. In turns, the aircraft bank angle is limited to 15 degree whenever possible to avoid loss of lock on satellites. The laser is set to collect measurements at 25 kHz or less while the laser sweep left and right of the flight line. The IMU provides additional positioning information at 200 Hz while the airborne GPS receiver records positions at 1Hz.

The Optech "ALTM NAV" software is used to plan and navigate the aircraft in real time. The LiDAR system operator uses this comprehensive flight management system to show, among other things, a real-time swath coverage so that any gaps or GPS quality issues can be resolved before landing or leaving the site. A careful record of every flight line, or strip, is taken on the airborne log sheets in a digital form. Start and stop time, system parameters, and system observables represent some of the information recorded in these logs. Following every flight, the LiDAR and GPS data is downloaded and initial post-processing begins immediately.

POST PROCESSING OF DATA

Files created by each receiver contain site information, phase measurements, and ephemeris data. The ground base station receivers are downloaded and files forwarded to Airborne1 on a CD, or by File Transfer Protocol (ftp). The airborne receiver data was recorded on a PCMCIA data storage card and the IMU and laser ranging data were recorded during the survey on an 8mm data tape and are returned to the LA office of Airborne1 for processing. The GPS airborne and ground station data is combined and processed as an "on-the-fly" solution. The results of the processing of the GPS Trajectory Solution are on file at Airborne1. The data is processed on a Pentium-III 1+ GHz PC using Waypoint Consulting Inc. GrafNav post-processing software version 6.02 running in a Windows 2000 Operating System. During the download process, station identification and antenna heights are checked against the field log forms. The baselines are initially processed with a cutoff vertical angle of 15° above the horizon using a broadcast ephemeris and ionospheric model. GPS vectors are converted from the military World Geodetic System of 1984 (WGS84) to NAD83 geodetic coordinates and ellipsoid heights with GrafNav network adjustment software.

The following steps constitute the complete task of post-processing:

1. The base station GPS data is processed in a static mode to verify the published positions identify any problems.

2. The airborne GPS data is post-processed using Waypoints Grafnav software (version 6.03). A fixed-bias carrier phase solution is computed in both the forward and reverse chronological directions to obtain positions for the trajectory.

3. The geoid model is applied to the pseudo-ellipsoid heights of the trajectory to derive orthometric heights.

4. The GPS trajectory is introduced in to the Optech ALTM software to compute the laser point positions. The trajectory is combined with the IMU data and laser range measurements to produce the 3-dimensional coordinates of the mass points.

5. Final mass point coordinates are exported from the Optech software and split into strips that are decimated at a fraction of the actual point interval. This makes the file size manageable and allows the data to be viewed in a CAD package. Any gaps in the data are identified at this time.

6. Classification of data to remove features and vegetation and derive the bald earth ground points.

7. Convert the final coordinates to metric UTM or to the required map projection/units.

8. Perform the QA-QC analysis.

PROJECT DATUMS AND REFERENCE SYSTEMS

Horizontal Datum

The standard operating procedure for Airborne 1 is to base horizontal positions and ellipsoid heights on the North American Datum of 1983 as referenced to the National Geodetic Survey's High Accuracy Reference Network (HARN). HARN surveys established precise positions of stations (including ellipsoid heights) in the NSRS based on NAD83 utilizing GPS measurement techniques. As a matter of information, the HARN adjustment of the NAD83 Datum superceded the 1984.0 Adjustment which supercede the NAD27 Datum. Additionally, as in California, an Epoch of Adjustment may be referenced.

The positions of the mass points are ultimately derived from the airborne GPS trajectory. The GPS trajectory is computed by post-processing the airborne data with the data collected at the receivers located on known monuments. The positions of the monuments are referenced to NAD 83.
In order to realize a local horizontal and vertical datum, the base station positions should be available in NAD83 and NAVD88 as well as the local survey system in order to compute a transformation. A horizontal transformation requires a minimum of three points common to both systems and a horizontal and vertical requires a minimum of four points common to both systems to provide redundancy in the solution.

Vertical Datum

The standard operating procedure for Airborne 1 is to base orthometric heights (elevations) on the North American Vertical Datum of 1988 (NAVD88) published in 1991. As a matter of information, NAVD88 superceded the previous National Geodetic Vertical Datum of 1929 (NGVD29). The estimated shift from NAVD88 to NGVD29 can be estimated using the NGS VertCon software.

If the control points used for the base station receivers do not have published NAVD 88 elevations available, an elevation is either transferred from the nearest benchmarks or the NAD83 ellipsoid height used to estimate an NAVD88 height (accuracy is about 10 centimeters).

The vertical constraints are determined by combining the NAVD88 heights at the base stations with Geoid 99 separations to obtain a pseudo-ellipsoid height. The calculation of LiDAR point positions based on the GPS airborne trajectory will then yield pseudo-ellipsoid heights. It follows that orthometric heights at each laser measured ground point can be derived by removing the geoid separation.

ADJUSTMENTS AND ANALYSIS

The base stations are processed statically. Depending on the number of vectors available from the base station occupations, a network adjustment will be computed to validate existing and new control. A minimally constrained adjustment is performed by fixing one control point at its record horizontal and vertical position and comparing the calculated positions of other points with their record positions to identify problems and confirm control.

The kinematic "on-the-fly" processing determines a trajectory position of the airborne antenna each second from each base station receiver. The observations are processed forward and reverse to obtain the best correlations from each base receiver. The best solution, either forward, reverse, or combined, is selected and compared with data processed from each of the other base receivers. The residuals in the adjusted vectors in latitude, longitude and height are noted. An adjustment is usually made by averaging the positions obtained from multiple bases. These positions are processed with the output of the IMU coupled with the laser ranger for computing ground positions.

The three dimensional position controls the airborne trajectory. By introducing the laser and IMU measurements, coordinates are computed for the ground points. This results in pseudo-ellipsoid heights which are combined with the local geoid separation based on Geoid 99 to obtain estimated orthometric heights (elevations) of the ground points.

SYSTEM CALIBRATION

At regular intervals and whenever the ALTM is placed in an aircraft, a calibration survey is performed. The rooftop of a large, rectangular building is surveyed and used as the calibration target. The aircraft flies several passes over the building with the ALTM system set in both scan and profile (scan angle set to zero degrees) modes. Several passes are also made along and perpendicular to a runway or similar large, flat, hard surface. The purpose of this pass is to identify a systematic bias in the scale or roll of the system. Finally, a pass is made in profile mode across the middle of the building to compensate for any bias in pitch.

New calibration parameters are computed with previous calibration runs. If there is any change, the new values are entered into the LiDAR post-processing software before the final data post-processing is completed.

The Optech ALTM 2025 LiDAR system, consisting of GPS, Laser Rangefinder, and IMU is calibrated on a regular basis at the Van Nuys Airport, Oxnard Airport or a project specific airport to identify system biases and maintain system integrity. The calibration data is incorporated into the processing to refine the accuracy and determine or alleviate the systematic errors within the system. This is accomplished by checking the roll, pitch, and heading of the laser data against a known, accurately surveyed feature on the ground such as an aircraft hangar. The Calibration Reports are on file at Airborne1 Corporation.

CLASSIFICATION

Extraction of bare earth topography from the raw LiDAR data is accomplished by running an iterative morphological classification algorithm that examines the data points and classifies them as “ground” or “non-ground” based on distance and angle of each point from an initial TIN surface. The fidelity of this modeling may vary with terrain relief, vegetation cover, cultural features and the setting of initial seed parameters for the classification algorithm. Reclassification of the raw data with parameters other than those used by Airborne1 Corporation will result in a different bare earth surface and should only be done by a knowledgeable LiDAR analyst.

QUALITY CONTROL & ACCURACY

The end result of the LiDAR data collection process is millions of points defined by their earth-centered, earth fixed cartesian coordinates. These points are converted to grid coordinates and elevations. As stated previously, this process involves the integration of GPS, Laser, and IMU with spatial models.

An empirical process is used to validate the accuracy of the survey by comparing known points on the ground (ground truthing) with the interpolated elevations derived from the LiDAR survey. If due care and diligence is taken in obtaining these ground measurements, then a quantitative assessment can be made of the LiDAR accuracy. This assessment is referred to as a quality-assurance and quality-control or QA-QC Report. The QA-QC data is usually obtained by conducting real time kinematic (RTK) surveys to provide elevations (profiles) along existing roads and on clear level smooth surfaces within the project mapping boundary.

Optimally, two profiles would be measured across the flight lines and equally spaced and one profile would be measured along the flight lines. Often, due to rugged terrain and lack of access, profiles may not be available for all parts of the project. Generally, a large quantity of points well distributed across the project will provide a sound basis for statistically reporting the accuracy of the survey. As a rule, points should be available every ¼ of a square mile or not more than ¼ of a mile apart for corridor surveys. It is preferred to collect several points at any one location. On small projects a minimum of 20 points are necessary.

A suggested survey method is to set up a base on a control point and drive the roads with an antenna mounted on the roof of a vehicle. If the height is properly calibrated and error sources accounted for then the accuracy of this process should be about 0.1ft (3cm). Problems with satellite availability in certain areas (canyons, vegetation, tree canopies, hi-rise urban buildings, etc.) can degrade the results obtained in the field survey and should be noted in a "RTK Field Survey & Procedures Report".

Ground truthing points are processed in Terrascan with a routine to develop comparative elevations. The data is reviewed and outliers larger than the three sigma or the 99.7% confidence level are removed. These points are deemed unqualified by reason that the ground point is not coincidental with the LiDAR point's horizontal position or the profile point is in error. After the removal of outliers, the results of the analysis are listed in the QA-QC Report attached to the LiDAR Mapping Report.

Items of significant in the QA-QC Report are the "Mean" and "Standard Deviation". The Standard Deviation is similar to the Root Mean Square Error (RMSE). The Mean is expected to be at or near zero as it represents the average difference between the LiDAR survey and the ground truthing survey (the sign indicates the shift from the LiDAR elevation to the ground truthing elevation). If the difference is not zero, it may represent a bias or systematic error between the two surveys. A bias may be due to the two surveys not being perfectly related to the same datum or to a timing error in the ALTM system. The latter may be identified and removed by a system calibration. The former is more difficult to identify in source, but is usually the result of one or more of the following problems in the field survey; using reference monuments unrelated to those used to control the airborne trajectory, not calibrating, or otherwise validating the accuracy of the RTK data collection procedures, not taking caution to assure the integers are correctly fixed while collecting RTK data, and publishing results on a different datum or coordinate system.

The Standard Deviation or RMSE is an indication of the relative precision of the data sets and is affected by the altitude of the aircraft, the width of the swath, the length of the vectors from the base stations and the accuracy of the ground truthing survey. The Standard Deviation is the 68% confidence level or one sigma. The results of this survey are reported at the 95% confidence level or two sigma which is 1.96 times the Standard Deviation as defined in the National Standards for Spatial Data Accuracy (NSSDA).

Additional QA-QC is obtained during the flight by overlapping the flight line swaths and flying transverse lines or cross flight lines at the end of each flying session. Validation of the data is obtained by comparing the overlaps. The results of this analysis further substantiates the relative accuracies of this survey by showing agreement usually better than 10 centimeters in the elevations of adjacent flights which are indicative of proper roll and scale parameters.