QUALITY ASSURANCE OF LIDAR SYSTEMS – MISSION PLANNING

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ABSTRACT

Mission planning is considered a crucial aspect of Airborne Light detection and Ranging (LiDAR) surveys to contribute to total Quality Assurance (QA) experience. Since LiDAR is a relatively new spatial data acquisition practice, one may not find complete documentation on how to get prepared for such a mission. There is abstract information available from a few public and private organizations; however, none of these resources provide fully documented and thorough explanation. Throughout the industry, most airborne LiDAR missions are prepared with the previous expertise of the personnel who have involved in earlier projects. Formal training is not common, and 'learning-on-the-job' has potential complications for the future. Additionally, there are various types of airborne LiDAR surveys that require specific know-how, but expertise carried over may not work for a different type of survey. Field and office managers are advised to assess the project requirements and available resources very carefully prior to mission initiates. There are fundamental requirements, as well as less important actions. Due to the variable nature of airborne surveys, all phases need steady observation to prevent potentially costly changes or mission failures. Various projects experience difficulties in order to complete projects sooner, resulting in overlooked and skipped QA procedures. Careful assessment of the requirements and planning with adequate timing is vital for a successful mission completion. A good mission planning requires careful and extensive consideration of various phases of the project. Hence, author believes that there is a need for detailed airborne LiDAR mission planning documentation that will provide assistance to LiDAR community.

INTRODUCTION

Quality Assurance procedures refer to planned and systematic processes that provide confidence of a product's or service's effectiveness. This applies to all forms of activities; design, development, production, installation, servicing and documentation stages.

QA for airborne LiDAR mission planning refers to forecasting and management activities to ensure that proposed mission is executed and completed with highest possible quality that is available. These activities in general would include good mission planning, accurate system configuration, well documented data processing and complete project delivery. Figure 1 illustrates a general QA model flowchart.

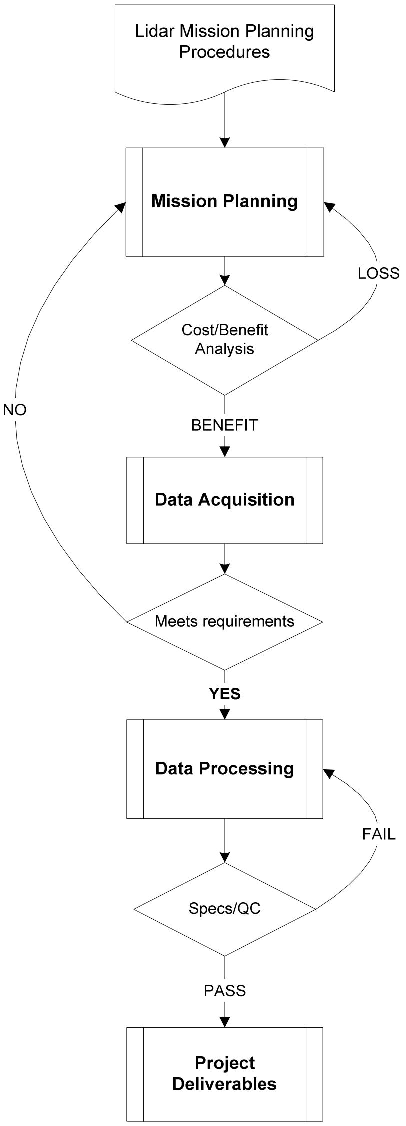


Figure 1. Quality Assurance Model for a LiDAR Mission.

ESSENTIALS OF AIRBORNE MISSION PLANNING

Accurate flight planning for airborne LiDAR survey is essential for a total Quality Assurance experience. Due to the variable and challenging nature of airborne surveys, there are various issues that should be assessed properly. Many people involved at this stage of a LiDAR mission have on-the-job expertise, and do not possess formal training about LiDAR data acquisition basics. Since expenses related to a flight mission are very high, proper mission planning at this stage is very important. Figure 2 illustrates activities towards reaching data acquisition stage.

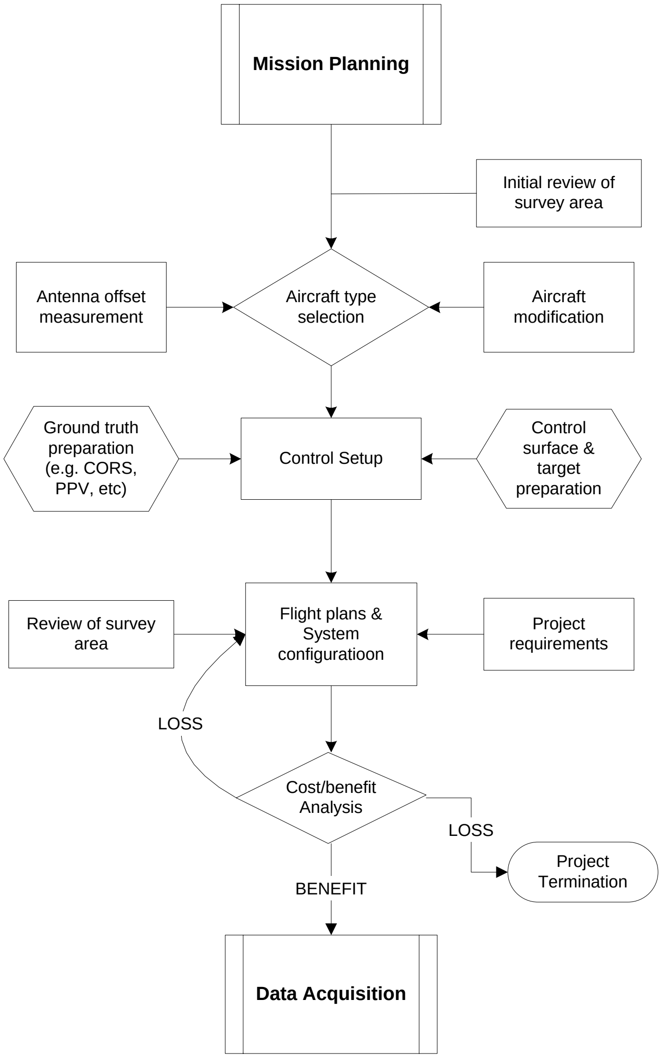


Figure 2. Mission Planning Activities.

Some of the planning essentials and recommendations for airborne LiDAR survey mission are as follows:

1. Initial review of survey area is essential for effective survey planning. Existing imagery or maps may be used for a complete assessment.
   - Local weather patterns, sudden topography changes, existing water basins, and general terrain cover may impact flight planning and should properly be examined prior to flight planning.
   - Large survey areas (>200 km^2) need multiple flight plans (e.g. 4 x 50 km^2) that should accommodate 20-30% overlapping to prevent loss of data in case of a system failure/reset and easier data processing/handling
   - Large survey areas with multiple segments should have flight plans prepared for each survey day and each segment should have sufficient overlapping
   - Borders of a flight plan should exceed the physical borders of the survey area with additional cross strips planned at the end of a survey mission for QC process (system calibration)

   - Multiple flight plans should be prepared to accommodate different flight altitudes; various factors may have an impact on the flight mission such as changing cloud cover, weather turbulence, flight altitude restrictions, and etc.

    - The flight plan parameters should have enough tolerance for variable factors; such as if 1 point is required for each m² per contract; flight plan should accommodate up to 1.1 to 1.5 points per m² (10% to 50% tolerance)
2. Selection of aircraft type; either fixed wing or a helicopter
    - Fixed wing aircrafts are more suitable for large area surveys, while helicopters provide better functionality for corridor survey types, however they are more expensive to operate
3. If project outcome requires Digital Elevation Model (DEM) creation, point density needs to be adjusted accordingly through flight plans. Rule of thumb is to collect data with 1 metre point spacing for each ½ metre contour interval (e.g. 4 metre point spacing is required to create 2 metre contour interval)
4. Selection and planning of base station use for post processing GPS data; a single standalone GPS, Virtual Reference Network (VRS) or Precise Point Positioning (PPP)
    - If a single station scenario is planned for the survey, flight plan borders should not exceed the recommended distance (30 km radius) to maintain good GPS accuracy
    - 2 base stations should be available for a single station scenario for backup purposes, and both should run simultaneously during a mission.
    - Base stations should have capability to collect data with an ellipsoidal height average accuracy of 0.02 metres or better, and have dual-frequency (L1/L2) capability with plenty of internal data storage capacity
    - Position Dilution of Precision (PDOP) values must be checked well in advance and properly examined for survey mission dates. High PDOP values will affect the final product accuracy adversely.
5. All parameters and configuration settings such as GPS antenna offset measurements, communication protocols, computer to LiDAR system connections, and etc should be checked before mission commences to prevent any mission failures or delays.

GPS Antenna Offset Measurement

This procedure is required after a LiDAR system is installed in an aircraft for the first time. There is no need to repeat the procedure on condition that there have been no position changes to GPS antenna, the mounted sensor head, and the aircraft sensor head opening port.

POS (Position and Orientation System) computer needs to register the exact location of GPS antenna phase center relative to the scanner mirror. Therefore, a precise measurement between reference point on the sensor to the phase center of the GPS antenna with using a Total Station and a reflective prism is required. To comply with LiDAR Quality Assurance procedures, this measurement is vital for accuracy of the final product. Precision of such a measurement is expected to be better than 0.02 metres.

Components measured to fore of the point of origin (to nose of the aircraft) has +X polarity, while measurements to aft of the point of origin has the opposite; -X polarity. Components measured to right has +Y, while measurements to left has –Y polarity. Any components measured below the point of origin have + Z and components above are referred with –Z (See above Figure 3).

X, Y, Z offset distance from the scanner mirror to the reference point is always measured at the manufacturer's lab before sensor head housing is sealed. These internal values are provided to the client when a new system is delivered. Each system manufactured may have different values. Values measured with Total Station from the reference point to the phase center of the GPS antenna (as explained above) are added to the internal lab values. The final result illustrates the relative X, Y and Z distances between the scanner mirror and the GPS antenna phase center. These values are entered into Position Orientation system application (e.g. POS/AV Controller) for offset measurement corrections.

Control Surface and Targets Preparation

For any spatial data acquisition system, it is essential to ensure that Quality Assurance procedures are completed and the final product meets the end users' needs and accuracy requirements[1]. Since a typical LiDAR survey includes data acquired in many overlapping strips, a common QA procedure is to correctly establish a control surface that will assist to analyze the coincidence of overlapping laser points collected in opposite directions. The degree of coincidence of points is used to identify the presence of systematic biases in the LiDAR system. Common methods with using control surfaces and distinctive terrain features are explained very briefly in next chapters.

Control Surface – Long & Flat Surface. A ground control surface is required only to determine absolute accuracy. Control points on the surface are measured with a high precision survey instrument (Geodetic level GPS or Total Station) which is tied into local control network with a first order survey monument, horizontally and vertically. It is expected that control surface points would have at least 3 times better accuracy than airborne laser scanner points. Yet, absolute accuracy analysis is only necessary to calibrate the LiDAR system. LiDAR system manufacturers advise to repeat absolute calibration every 6 months or so, even if the system produces good accuracy values.

To create an ideal control surface, a long (1500 to 2000 metres), wide (30 to 50 metres) and a linear surface is required. Control points should be in 5 – 10 metres grid, and possess very little blockage to prevent measurements. Ideally, this would be a municipal airport runway, or a long , straight non-residential stretch of a rural highway. If an airport is preffered, it is advised to check with airport authorities and inquire about flight restrictions in the area. Usually Class D & E airspaces are suitable for such calibration purposes.

A survey grade GPS base station (dual frequency L1/L2 preferred) needs to be established in the close proximity of the calibration site (< 30 kms). GPS base station collects the data that is required for post processing. Ideally, GPS receiver should be capable of data logging at 1 Hz. Additionaly, if possible, a second base station should be running simultaneously for backup purposes. If there are VRS or CORS networks in the area, this should also be considered.

Other Control Features – Buildings, Trees, etc... A ground control feature can be used for both absolute and relative accuracy. Large buildings (80 to 200 metres wide) are preferred since it is difficult to hit the building at an altitude of 1000 metres or more at profile mode (Scanner is set to 0º) to estimate the pitch bias. Also it is important that buildings are higher than 5 metres with no unusual overhangs, ledges and long banks of windows that might catch or reflect laser points. Typically, control points are located at the edge of the corners of the building.

If there are no control features located on the survey location, other terrain features may be used for relative accuracy assessments. These features would be tall trees, smaller buildings, bridges and etc. Investigation of the degree of coincidence of laser points with overlapping laser strips in opposite directions over these features would enable finding of systematic errors present in the LiDAR system.

LiDAR Specific Control Features. There are applications that require higher accuracy, such as transportation corridor mapping and power lines survey. Building and using well-defined and accurate control targets shall contribute to the success of Quality Assurance procedures and the final product. The objective with building a LiDAR-specific ground target is to provide a highly accurate positioning in both horizontal and vertical directions. Csanyi, N and C. K. Toth (2007)[2] discuss that due to different possible scan directions and different point densities in different directions, the optimal LiDAR target must be rotation invariant, circle-shaped, and elevated from the ground. Also, targets may have specific coating to provide different reflective surface that can be picked up by distinguished intensity values. After LiDAR survey of targets, the coordinates of extracted targets are compared with laser points using a Root Mean Square Error analysis (RSME).

In general, this practice is considered expensive and time consuming[3] since its implementation depends on the accessibility to the survey site. But results indicate that errors larger than 10cm at horizontal and larger than 2-3cm at vertical distances can be detected with this practice. Toth, C. et al (2006)[4] confirm 2-3 cm horizontal and 2 cm vertical accuracy.

GPS Data Quality and PDOP Prediction

Positional Dilution of Precision (PDOP): This is the measure of geometrical strength of GPS satellite configuration. Generally, PDOP < 3 is desired but values less than 4 are acceptable for airborne surveys. PDOP ≈ 1 is the best value achievable theoretically. With the addition of GLONASS satellites, very low PDOP values are attainable. However, most airborne Positioning systems currently on the market utilize only GPS (USA owned) satellites. In near future, with the further use of additional satellites (GLONASS, Galileo, etc), it is expected that Positioning system manufacturers will integrate full GNSS functionality into their products.

System operator may observe unexpected PDOP spikes during a mission. If spike is considerably high, data acquisition process should be suspended until better GPS geometry is achieved. Since GPS is one of the primary sources of positional error source (alongside Inertial Measurement Unit)[5], it is essential to plan ahead for good GPS constellation to comply with QA model. A well-known manufacturer of GPS/Inertial Navigation System specifies 5 to 10 cm for sensor positioning, 0.005º for pitch/roll, and 0.008º for heading error as system tolerance. At a flying altitude of 1000 metre, these orientation errors translate into planimetric errors of 10-15 cm on the ground for each of the three angles[6].

PDOP values for the survey location should be predicted well before the mission by field manager, and flight times should be adjusted accordingly. There are programs available to predict the DOP values for specific dates and locations. For instance, System Effectiveness Model for Windows (WSEM36) is a freeware that is available via Internet[7]. Also, an updated almanac should be downloaded and integrated into WSEM36 before any predictions are completed.

Ground Truthing: Traditional vs. New methods

In the last few years, government agencies and some private organizations began providing post processing GPS data through online services with or without subscription. In Canada; Natural Resources Canada (NRCan) has established continuously operating GPS reference station network referred as Canadian Spatial Reference System (CSRS)[8], while some other provincial governments have also established their own services. For instance; in the Province of British Columbia, Crown Registery and Geographic Base Branch[9] (CRGB) and in the province of New Brunswick, Service New Brunswick (SNB)[10] provides such service to clients. In USA; National Geodetic Survey manages Continuosly Operating Reference Stations (CORS)[11] for various locations throughout the nation. Clients have the opportunity to download data with different logging speeds (1Hz – 30 Hz) and with different formats (raw, RINEX).

In the last few years, Virtual Reference Stations (VRS) have become very popular. A VRS solution uses a network of continuously operating reference stations to compute a set of corrections for a roving receiver located anywhere in the network. If survey location has access to any VRS network, there is no need to establish a ground GPS base station. A manufacturer of airborne positioning systems claims to process up to 50 stations at the same time, where the farthest one can be 400 km away[12].

Addition to Continuously Operating Reference system, there is another alternative for airborne LiDAR surveys without using an independent GPS base station. The availability of precise GPS satellite orbit and clock corrections has enabled the development of a new positioning method – Precise Point Positioning (PPP).

According to GrafNav[13], PPP presents an overall accuracy of 10 to 20 cm. For surveys which do not require very high accuracy levels, these figures are acceptable. For airborne surveys such as corridor mapping which require very long baselines, PPP practice may be an ideal solution.

Important modification with PPP service is to include the replacement of satellite orbits and clock corrections with more precise estimates from an organization such as International GNSS Services (IGS). Rapid satellite position and clock solutions are provided with free of charge from IGS. Data is available usually after 24 hours. IGS stations are well distributed across Canada and USA.

As a Quality Assurance procedure, field manager should ensure the availability, integrity and consistency of ground truth data *before* a LiDAR mission begins. In a nutshell, quality of GPS data collected during a mission (on the ground and on the air) has a direct impact on the quality of final product.

Cost/Benefit Analysis of a Mission

Mission planning is not complete without a Cost/Benefit Analysis (CBA). Assessment of total expected costs against the total expected gain is an essential aspect of any project. The truth of the outcome of CBA is dependent on how accurately costs and benefits have been estimated. Since LiDAR projects may have several unexpected expenses, a true assessment of ‘required’ and ‘optional’ costs is strongly advised.

Airborne LiDAR data acquisition expenses may depend on many variable factors. Desired point density and size of survey area may be considered as the principal cause for variable costs. Typically, LiDAR system and aircraft leasing costs, crew and flight expenses, data processing and data delivery related fees count as the largest expenses in a mission. Cost would also vary depending on the terrain type and the proximity of the project location to base office. Typically, an airborne LiDAR mission would include expenditures illustrated with Table 1.

Table 1. Typical LiDAR Mission Expenses

Aircraft Leasing and Flight Charges	Aircraft leasing (covers insurance & maintenance) Fuel charges Airport landing fees Hangar and ground service fees
Personnel Costs	Pilots: Captain and First Officer LiDAR System Operator Ground Control Personnel
Travel & Accommodation Costs	Air or ground travel for personnel Lodging and meals at survey location
Data Processing Costs	Hardware purchase and maintenance Software purchase and licensing Personnel Data Storage & Handling
Miscellaneous Expenses	Ground Truth Surveys/Network Subscription Fees Calibration flight Equipment Shipment charges Other project specific miscellaneous expenses

ACCURATE LiDAR CONFIGURATION

There are various types of airborne LiDAR surveys. Due to diverse nature of airborne surveys, LiDAR systems come equipped with their own mission planning software to configure the laser output. Most surveys require specific parameters depending on the project deliverables. To match the desired 'Point density' requirements, LiDAR systems can be configured in various ways. Below is a list of parameters that may be manipulated either before mission or 'on-the fly' by the System Operator:

- **Scan (speed) frequency (Hz):** Different laser scanners have different scanning mechanisms (oscillating, sinusoidal, fiber scanner, rotating polygon, etc.). Most laser scanners currently on the market have moving scanners, and their motion speed is programmable via user interface. This is usually between 0 – 100 Hz with 0.1 Hz increments.
- **Scan (width) angle (θ):** This applies to swath width and generally referred with half-angle. Typically, half-angle range is between 0 and 30 degrees and can be adjusted with 0.1° increments.
- **System Pulse Repetition Frequency (kHz):** Laser pulse repetition frequency (PRF) defines number of emitted pulses per second. Measured in kHz for solid state lasers. Higher PRF provides denser point distribution on the surface. Current laser scanners on the market have PRF capabilities of up to or exceeding 150 kHz.
- **Beam divergence (mrad):** This mode regulates the width (divergence) of the laser beam. It is measured with milliradian (mrad). Typical narrow beam measures 0.3 mrad, while beam with larger footprint; may measure up to 2 mrad[14]. Narrow beam has a stronger manipulation rate, while wide beam covers larger surfaces.
- **Roll compensation (deg°):** This feature corrects for aircraft roll by biasing the scanner. Scan frequency is sampled and corrections are applied with specific rates (e.g. 5 Hz). Corrections are based on the full scan half-angle of the system. For example, if max half-angle scanning capacity is 30°, and 20° is configured, this feature will compensate to a max of 10° at full swing.
- **Eye safe altitude (metres):** The laser wavelength (λ - nm) and peak power (W) relate to eye safety considerations. Beam divergence (mrad); system PRF (kHz) and flight altitude would also have an influence on eye safety settings.

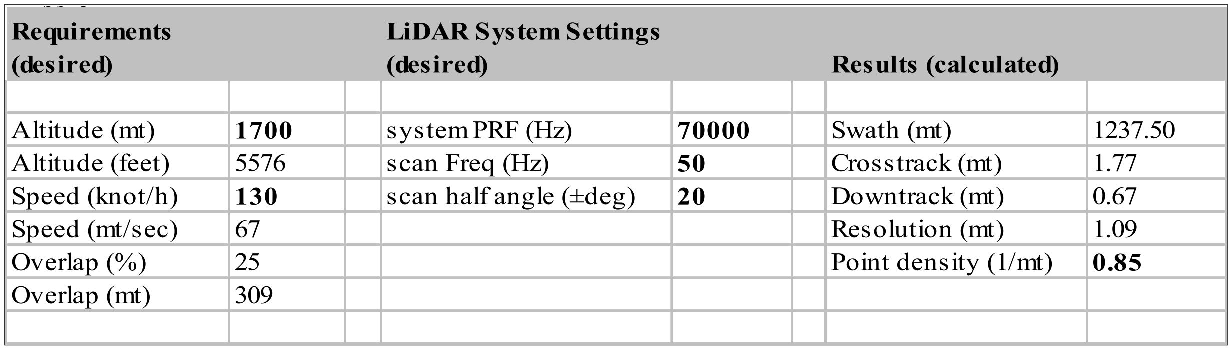
Table 2 configuration parameters affect LiDAR point density directly. These parameters need to be adjusted to produce the desired final product before a mission. Table 3 illustrates basic computation of cross track, down track and average resolution with point density as a final product. Simple formulas used in the Excel worksheet are explained below.

Table 2. Configuration Parameters for Point Density

Parametre	**Typical min & max**	**Surface Point Density**
Scan Frequency (Hz)	0 – 100 Hz	↑ faster, ↑higher
Scan Half-angle (deg°)	0 – 30 º	↑ wider, ↓ lower
System PRF (kHz)	5 – 150 kHz	↑ faster, ↑higher
Operating Altitude (metre)	200 – 4000 m,	↑ higher, ↓ lower
Aircraft speed (knots)	10 – 140 knots	↑ faster, ↓ lower

- Swath width (m) → 2* [Altitude * (TAN (half angle) * PI() / 180)]
- Cross track (m) → (2 * scan Freq * swath) / system PRF
- Down track (m) → (speed / scan freq) / 2
- Resolution (m) → √(cross track * down track)
- Point density (1/x) → 1/ cross track * down track

Table 3. Excel computation for LiDAR point density



Requirements (desired)			**LiDAR System Settings (desired)**			**Results (calculated)**	
Altitude (mt)	**1700**		system PRF (Hz)	**70000**		Swath (mt)	1237.50
Altitude (feet)	5576		scan Freq (Hz)	**50**		Crosstrack (mt)	1.77
Speed (knot/h)	**130**		scan half angle (±deg)	**20**		Downtrack (mt)	0.67
Speed (mt/sec)	67					Resolution (mt)	1.09
Overlap (%)	25					Point density (1/mt)	**0.85**
Overlap (mt)	309						

QA DATA PROCESSING PROCEDURES

LiDAR data processing is a complicated task. Data is large in size and needs powerful hardware and software integration. As to comply with QA procedures, issues need to be addressed and examined for best possible solution prior to any processing practices. Chart 3 illustrates a typical flow of activities for LiDAR data processing.

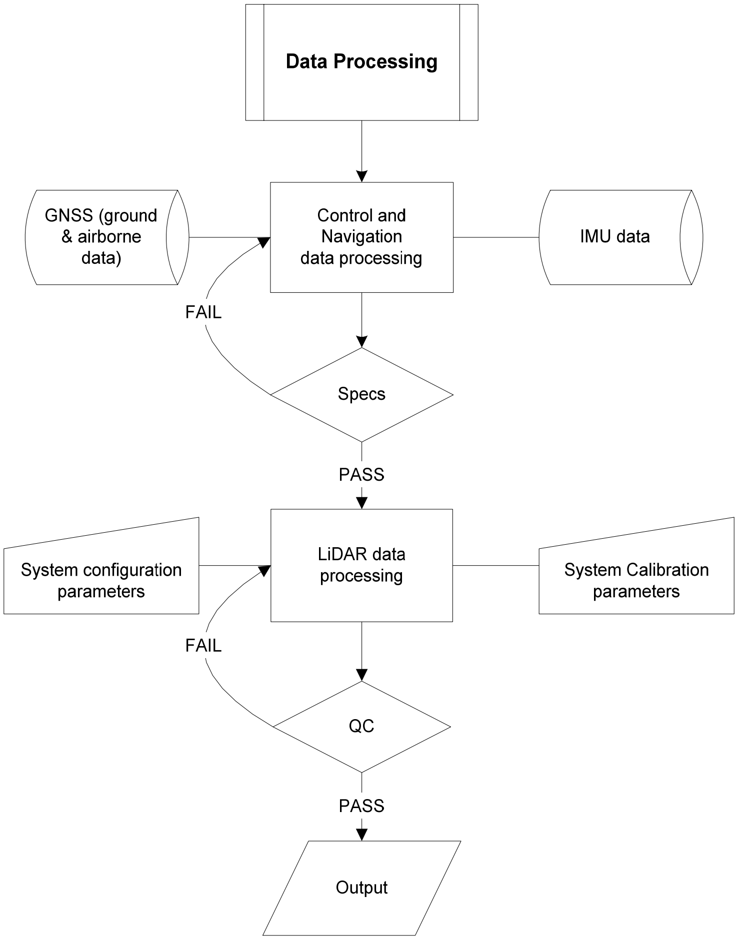


Figure 3. Data Processing Flow.

Data Accuracy Verification

LiDAR data accuracy is influenced by various sources. Calibration of laser scanner instrument, position and orientation determination system (GPS and IMU) and the alignment between these two subsystems affect the data accuracy significantly. Possible human errors in data handling, transformation and processing may also influence final data accuracy.

Table 4 illustrates accuracy parameters for a popular airborne laser scanner as they are published at manufacturer's Web site[15].

Table 4. Data Accuracy Specifications for ALTM 3100EA

Horizontal accuracy	1/5500 x altitude	1– sigma
Vertical accuracy	< 10 cm @ 1000 m < 15 cm @ 2000 m < 20 cm @ 3000 m	1– sigma

American Society for Photogrammetry and Remote Sensing (ASPRS) accuracy standards for Spatial Data are measured with RMSE statistics[16]. Accuracy is reported in ground distances at 95% confidence level. DEM created from LiDAR derived data should have a maximum RMSE of 15 cm, which is roughly equivalent to 30 cm accuracy. Therefore, 15 cm RMSE is often referred to as '30-cm accuracy at 95-Percent confidence level'. According to Federal Emergency Management Agency (FEMA) [16], the RMSE calculated from a sample of test points will not be the RMSE of the DEM. In fact, for each major classification category, a sample of points should be evaluated independently. These points shall be selected carefully from areas of highest PDOP values registered during survey.

Handling and Management Issues

LiDAR data is large due to its nature. This is considered a limitation for LiDAR data handling and processing. A large area survey may produce hundreds of gigabytes of data. However, in the last few years, advances in computing and digital storage hardware enabled much faster and more efficient handling of LiDAR data. Most LiDAR projects make use of large capacity and high speed external hard disks for data handling. Also, accepting LAS (log ASCII) format as an industry standard for data exchange reduced the size of data significantly. 1 sq km of processed data[17] size is compared with Table 5.

Table 5. Comparison of LiDAR data format sizes

Format/ Resolution	1-mt	2-mt	3-mt	4-mt	5-mt
ASCII	30 MB	7.5 MB	3 MB	2 MB	1 MB
Binary (LAS)	4 MB	1 MB	0.4 MB	0.25 MB	0.15 MB

Filtering, Segmentation and Classification Process

Ground elevation data is required in most projects. In order to generate bare earth, all elevated features (e.g. vegetation, buildings, bridges and other structures) should be removed from LiDAR data. Segmentation of laser points is to group the neighbouring laser points that have common characteristics[18]. Elimination of all elevated features above ground may be considered as classification. Main categories of classification are; bare earth and low grass, high grass and crops, brush lands and low trees, forests and urban areas. Various other main or sub-categories may be created depending on the project requirements.

Process, Manipulate and Visualize Data

Currently, vast majority of raw data processing and manipulation is carried out by using proprietary software developed independently by researchers, data providers or sensor manufacturers[19]. Such software is not available as a separate package causing a limited understanding and manipulation process of raw data by end users. However, after raw data processing is completed, LiDAR data may be manipulated in various ways due to its open format nature. Today, there are several software packages on the market with various tools and functionalities (e.g. TerraSolid/Bentley, Z-I Imaging, ESRI ArcGIS, PCI Geomatics, ER Mapper, QT Modeler, etc). Selection of such software depends on the user needs, budgeting and previous expertise.

PROJECT DELIVERABLES

LiDAR System Report

Final system delivery and calibration package should include reports such as data acquisition and processing methods, pre-mission flight plans, final system configuration parameters, accuracy of LiDAR and control data, discovery and treatment of blunders and other supporting documentation.

Errors report: Blunders, systematic and random errors need to be properly examined and documented. A blunder is an error of major proportion, normally identified and removed during editing or QC process. Systematic errors follow some fixed pattern and are introduced by data collection procedures or system errors. They are predictable in theory, and therefore not like random errors where they follow a normal distribution.

95th Percentile Error: For supplemental and consolidated accuracy tests, this method shall be employed to determine accuracy. The 95th percentile indicates that 95 percent of errors in the dataset will have absolute values of equal or lesser value while 5 percent of values will be of larger value[20].

A thorough analysis of errors in the data should be provided with the final report. Any large errors evident in the data should not be deleted before any relevant investigations for the cause is addressed. Every major and minor error found and investigated in the dataset should be documented for inclusion in the QA model.

Flight Report

A detailed flight log should be prepared for every flight mission by LiDAR Operator. Any information relevant to data collection with start/stop time, configuration parameters, flight altitude, heading, PDOP and flight plan used should be documented. This information is necessary to understand the characteristics of laser strips during data processing and QC process. A typical flight log is illustrated with Table 6.

Table 6. Flight Log Information

Date	31 January 2010	**Julian Date**	31
Project Number	711-2010-3	**Mission**	3rd segment – 2nd try
Aircraft	C-GAWS	**Operator name**	Jack S.
Pilot name	Steve R.	**Co-Pilot Name**	David T.
Airport Up	CYYJ	**Airport Down**	CYYJ
Wheels Up	14:50	**Wheels Down**	17:10
Aircraft HOBBS start	2345	**Aircrafts HOBBS end**	2347
Ground Temperature	+15 C	**Visibility**	Clear
Cloud cover	12,000 ft – broken	**Precipitation**	None
Wind direction	250º - SW	**Wind speed**	22 knots
Atmospheric Pressure	29.96 mbar	**Other notes**	

Ground Control Report

All information related to ground control network, every control points used and GPS base station monument information should be included in the report. Additional information such as local/provincial network that is used to tie control points, GPS base station monument metadata (e.g. survey date, accuracy, Datum) and any other facts considered to assist post-mission activities should supplement the report.

Calibration Report

Contractor should provide an initial calibration report that is delivered with system acceptance. Also, contractor must submit evidence and final calibration parameters prior to project initiation for the purposes of identifying and correcting systematic biases[21]. Initial and final calibration parameters comparison, all adjustments and iteration parameters used during calibration should be made available in the final report.

Delivery of LiDAR Data

All raw datasets and processed LiDAR data (ASCII or LAS) should be supplied. Each processed point should have GPS time, orthometric height, intensity value and positional information (x, y, and z). Break lines must be produced and break line information must be identified with proper flagging and information relevant to their source and accuracy.

DEM data should be delivered with USGS DEM or ASCII XYZ format unless project requires another specific format. The contractor must submit raw datasets in tiles or as a separate file for each data strip. Due to the current limitations with LiDAR data processing software and hardware, each file size is not advised to exceed 1 gigabyte.

All project deliverables must conform to pre-mission specified contract requirements. Datum, projection and coordinate system employed must be documented. Data may be delivered in various forms according to project requirements. Since most organizations have secure and fast broadband connections, online delivery of large amounts of data is becoming more popular than ever. Data delivery with an external hard drive is also commonly used and accepted. If project deliverables require data copied on media (CD or DVD), this practice should conform to ISO 6990 standards.

CONCLUSION AND RECOMMENDATIONS

Quality Assurance goes a long way with LiDAR mission planning. As noted throughout this paper, this is rather a *systematic* approach with guidelines than a *practical* experience with no documentation. There are basic fundamentals as practised daily and in variable nature, and there are project requirements that are addressed very specifically. Some QA procedures are practiced with former expertise of personnel, with no established documentation and standards. As expected, many required practices are overlooked or even forgotten with the urgency of mission completion, leading to project deadline delays, additional expenses and yet mission failures.

This paper presents essential guidelines of QA practices for LiDAR mission planning as the author recommends. Practising any of these guidelines is up to sole decision of the contractor, but highly advised for possible successful mission accomplishment. Author believes that recommendations presented throughout this paper are in general perspective and may be customized with minor modifications to fit specific project requirements. Since many aspects of QA procedures need each other for conclusion, it is necessary not to disregard any steps. Due to the nature or airborne LiDAR surveys, procedures that may appear to be insignificant or unnecessary could result in disappointing final results.

As a final statement, author believes that it is a good practice to remind the LiDAR community with the importance of QA procedures to comply with “Do it right, the first time’.

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