PERFORMANCE CHARACTERIZATION OF A MOBILE LIDAR SYSTEM: EXPECTED AND UNEXPECTED VARIABLES

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ABSTRACT

Achieving results that meet the requirements of any survey project requires knowledge and deep understanding of the performance capabilities of the survey equipment. Mobile lidar scanning, which has emerged as the preferred operational tool in remote sensing, surveying and mapping, is demonstrating outstanding capabilities in generating high-accuracy spatial data for a wide range of applications. Although manufacturers of mobile lidar systems provide accuracy specifications and other instrument characteristics in a spec sheet, such specifications are often potentially misleading due to the complexity of new technologies, and the interplay of factors affecting the quality of lidar-derived end products. This paper represents a manufacturer's effort to clarify the issue of characterizing a mobile lidar system's performance. The impacts of the operating parameters, the performance of lidar subsystems such as GPS/INS and the laser scanner on overall system performance, various sources of errors, and data accuracy are investigated. The demonstrated results help to avoid misinterpretations of lidar instrument performance specifications, thereby bridging the manufacturer's approach to characterize mobile lidar performance with the expectations of lidar service providers and lidar data end users.

INTRODUCTION

Mobile lidar is a term widely used for a lidar deployed on any mobile platform such as a van, a boat, or even a 4 × 4 all-terrain vehicle, and often does not imply an airborne lidar. However, both ground-based mobile and airborne lidar are deployed on moving platforms, and both require an INS/GPS system to determine the position and orientation of the sensor. The general principles of operation are always the same for both mobile lidar types and the system design optimized for ground-based operation may or may not be dramatically different from the design of an airborne instrument (depending on the range of intended applications). Moreover, the data processing workflow for both types of instruments is very similar or almost identical since both require position and orientation data to be processed and blended with the laser scanner data. Hence the discussion of performance characterization in a mobile lidar system here includes both ground-based and airborne mobile lidars, though in some particular cases, it may require separate consideration.

When considering the specifications of a system as complex as a mobile laser scanner, it is very important to understand that in many cases the apparently simple numbers do not tell the entire story. Real-world lidar instrument performance capabilities depend not only on the "bare" numbers in a system specification sheet, but also on many other factors and technical details which are often out of the scope of the system performance spec sheets. Achieving results that meet the requirements of any surveying project requires deep knowledge and proper understanding of the mobile survey equipment's real-world performance capabilities. However, due to a lack of generally accepted guidelines for characterizing lidar performance, the manufacturers of surveying equipment may choose different approaches to present and characterize performance capabilities. This is why it is very important for the user of a commercial lidar system to understand the underlying technical details behind the spec sheet numbers, and to make informed decisions based on the project in order to avoid disappointment and misunderstanding. This paper will help lidar system users to better understand the connections between different numbers in lidar spec sheets, and to bridge the "bare" numbers with the expected real-world performance capabilities of a lidar system.

SPEC SHEET VERSUS USER EXPECTATIONS

What specifications do we usually see in a lidar spec sheet? Presented below is a list of what are usually considered to be the most important specifications:

- Operating ranges/altitudes – minimum, maximum
- Laser pulse repetition frequency (PRF)/or maximum laser pulse rate, or effective pulse rate, or data collection rate, or measurement rate. For some scanners the laser PRF and the measurement rate is the same thing, while for others it is not. The laser PRF is, however, considered to be the main factor determining the data collection rate
- Scan FOV (maximum scan angle)
- Scan rate (frequency)
- Data accuracy

Based on these key specifications, the lidar user tries to estimate the system's efficiency: how fast can the data be collected, and what data quality (primarily, accuracy) can be expected? In order to avoid misinterpretation of real-world system capabilities, the numbers in the "most-important" list should always be considered in connection with each other, and with the other specifications, whose impact on overall system performance capabilities may often be underestimated or even ignored. Some of these are:

- Range capture: number of range returns
- Intensity capture: number of intensity returns
- Dynamic range of intensity
- Laser beam divergence
- Position/Orientation system (INS/GPS): brand, model, post-processing software
- Beam deflection/scan pattern

We will show that some lidar system specifications in the second list may have an unexpectedly significant impact on both data collection efficiency and data accuracy. However, due to the complexity of the lidar system and the high variability of real-world operational scenarios, connections between the numbers and the technology behind them are not always clear to the user. Moreover, if we move the focus from the lidar spec sheet, which represents the manufacturer's efforts to present the system's capabilities in the best possible way, to the point of view of the lidar user, the list of performance specs will look different:

- Data collection efficiency:
  - Area coverage rate
  - Point density (point spacing)
- Data accuracy and quality
  - Processed data accuracy: vertical (Z), horizontal (XY), relative, absolute
  - Minimum size of detectable objects
  - Multiple returns
  - Intensity data/image quality
- Efficiency of data processing and lidar-derived-end-product workflow (out of scope of this paper)

These user's performance specifications could be derived from the manufacturer's specifications in the first list. However, since the number of variables in the "equation" of lidar performance is very large, and some of these variables are not independent, the "perfect" solution cannot be found easily. The very basic consideration, "the more the better", does not work here: chasing the biggest numbers in the manufacturer's spec sheet does not guarantee that they will provide the best solution for the user's priorities.

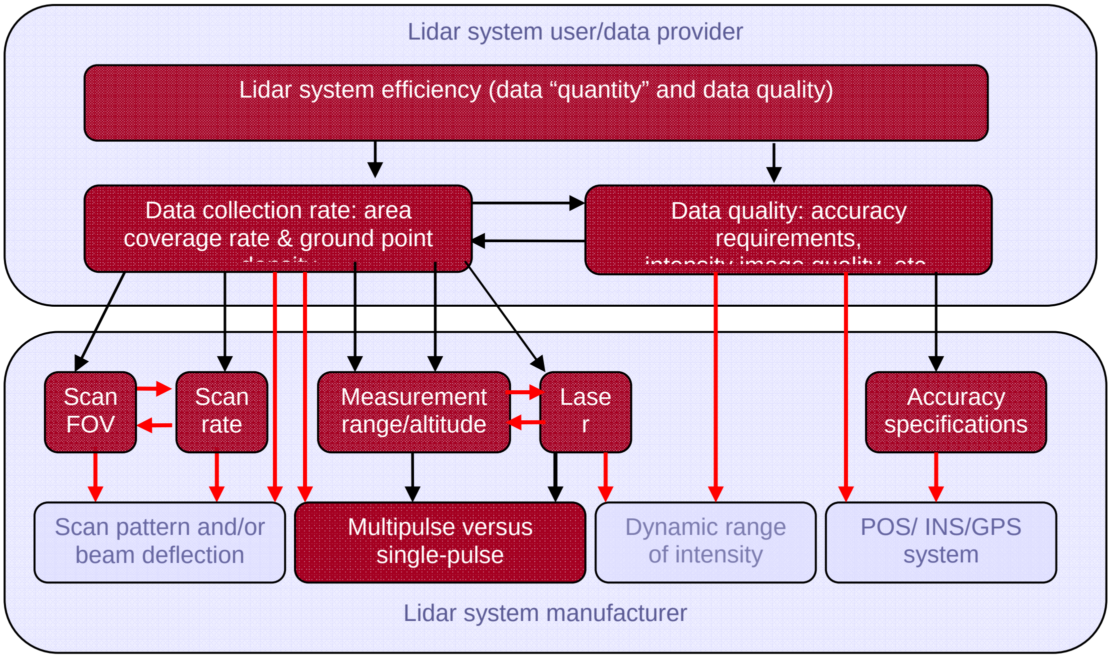

Figure 1. Expected (black arrows) and unexpected (red arrows) connections between lidar system specifications and some unexpected factors (blue boxes), whose impact on lidar performance may be underestimated or ignored.

Figure 1 shows examples of the expected and unexpected variables in the "equation" of lidar system operational efficiency. The color code is used to emphasize those links and factors that impact on the final result and which may easily be underestimated or ignored. In this paper we will explore some of these red links and "shaded" factors:

Data collection efficiency:

- Scan pattern
- Scan rate versus maximum scan FOV and scanner velocity factor

Data accuracy:

- Laser footprint size
- Scan FOV
- GPS/INS system
- Data post-processing and optimization algorithms

DATA COLLECTION EFFICIENCY: POINT DENSITY AND AREA COVERAGE RATE

How fast can the system collect data? How fast can the project be completed? In other words, how cost-efficient is the system? The most basic consideration would be to use the maximum laser PRF, maximum measurement range (or flying altitude), maximum scan FOV, and maximum scan rate. However, the maximum laser PRF and the maximum measurement range are interrelated and limit each other. As well, the maximum scan FOV and the maximum scan rate are interrelated and also limit each other. The first link is very well known and is often emphasized in the lidar spec sheet. But the connection between the maximum scan rate and maximum scan FOV is less obvious, and not always properly explained in the lidar spec sheet. Pushing all these basic operating parameters to their limits is often impossible as there are requirements to maintain a certain point density on the target (ground). The only way to keep high density points *and* the maximum area coverage rate is to fire the laser at the maximum PRF in order to maximize the data collection rate. That is why when cost effectiveness of the survey time is considered, the achievable point density on the target per unit time, i.e., the data collection rate, becomes the parameter of primary importance, and is usually linked solely to the laser PRF, which is often considered to be the major parameter determining the cost efficiency of the survey. As a result, pulse repetition rate has become a prime differentiating factor in the marketing of both sensors and data collection services (Flood, 2001). However, considering PRF as a primary figure of merit without its connection to other parameters might be very misleading. We will show how different mechanisms utilized for laser beam deflection and scan pattern may affect the point density and the area coverage rate even at high laser PRF.

Scan Pattern and Data Collection Efficiency

There are several scanning techniques employed in different mobile lidar systems. The most commonly used are: a) constant-velocity rotating polygon mirror, and b) oscillating mirror (Figure 2). The advantage of the rotating polygon mirror is the scan pattern which appears on the target as linear unidirectional and parallel scan lines. Due to the constant scanner velocity there are no acceleration-induced errors at the scan edges. However, the primary disadvantage of this scanner type is that for a certain period of time during each rotation cycle, the range measurement is either not taken or, if taken, should then be discarded. As a result, with this type of scanning mechanism, the laser PRF and the data collection rate are not the same, and in most cases, the manufacturers specify separately the PRF and data measurement rate. This type of scanning mechanism might be employed both in ground-based and airborne lidars.

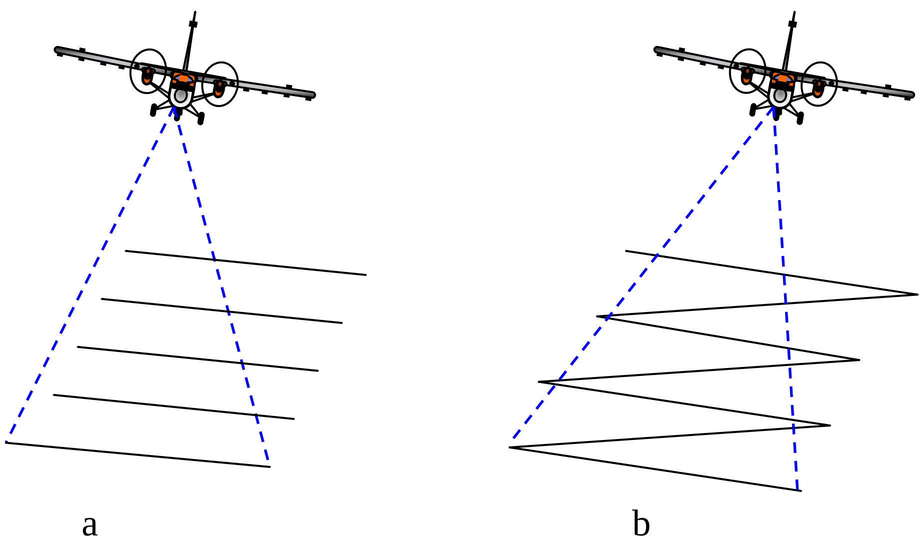

Figure 2. Scan pattern from constant velocity rotating polygon mirror (a), and oscillating mirror (b).

The oscillating mirror scan mechanism seems to be more popular for airborne lidar systems since it has the advantage of compensating for the aircraft motion, particularly, for roll. The mirror is always pointing to the target (the ground), and the laser PRF is equivalent to the data collection rate (for a single laser head and a single oscillating mirror). However, even after taking into consideration the oscillating mirror, the laser PRF is not directly translated to the area coverage rate for a given point spacing due to the differences in the laser point distribution provided by different scan patterns: sawtooth and sinusoidal (Figure 3).

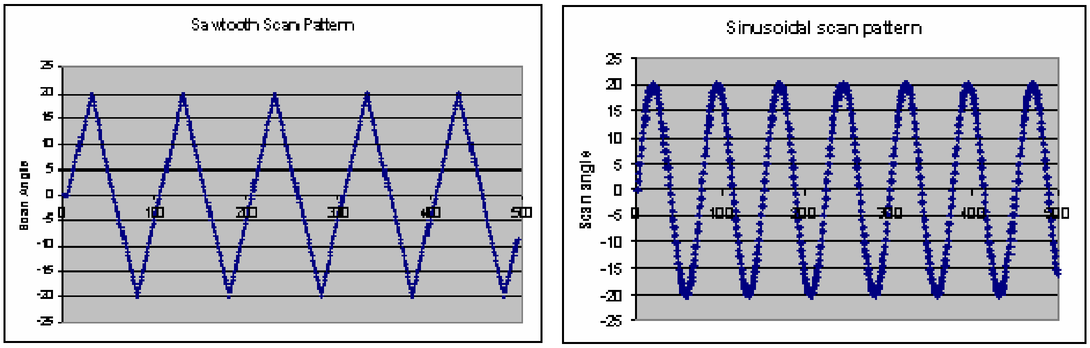

Figure 3. Sawtooth and sinusoidal scan patterns from an oscillating mirror scanner.

In the sawtooth pattern, scanner velocity is kept constant for most of the swath. This gives an almost uniform point distribution across the swath with slightly increasing point spacing towards scan edges. In the sinusoidal scan, the point spacing is minimal at the center of the swath and grows toward the edges of the scan line. The key distinction here is that the sawtooth scan provides a constant speed for most of the swath, while the sinusoidal scan moves fastest in the center of the swath and slow at the edges. That is why a lidar with a sinusoidal scan pattern has to operate at a much higher laser PRF to maintain the same or similar cross-track average point spacing as a lidar with a sawtooth scan pattern.

Table 1 shows area coverage rate and point spacing for two types of oscillating scan patterns, sawtooth and sinusoidal. The sinusoidal scan shows strong non-uniform point spacing,while the nadir point spacing is maximal, and the edge point spacing goes to zero. It is not obvious what number should represent the cross-track point spacing for a sinusoidal scan since the simple average over the swath would be biased towards very small numbers at the scan edges where laser shots are “piling up”. This is why we give three examples showing “effective” PRF for a sinusoidal pattern, which should be used in order to keep the cross-track point spacing equal to the one provided by the sawtooth pattern at a certain scan angle. For example, in order to keep the same point spacing at nadir and the same area coverage rate, the lidar with a sinusoidal scan pattern has to operate at 158 kHz PRF, multipulse mode, while the sawtooth scanner is capable of doing the same thing at 100 kHz.

Table 1. Cross-track point spacing in sawtooth and sinusoidal scan patterns.
The area coverage rate is the same, assuming that point spacing along-track is equal to the simple average of cross-track point spacing in the sawtooth scan.

Specification	Sawtooth	Sinusoidal	Sinusoidal	Sinusoidal
Above Ground Level (AGL)	1,000 m	1,000 m	1,000 m	1,000 m
Laser PRF	100 kHz (single pulse)	100 kHz (single pulse)	132 (single pulse)	158 kHz (multipulse)
Max scan angle	±25º	±25º	±25º	±25º
Scan frequency	30 Hz	30 Hz	30 Hz	30 Hz
Point spacing, nadir	0.52 m	0.82 m	0.62 m	0.52 m
Point spacing, ±10º	0.54 m	0.71 m	0.54 m	0.45 m
Point spacing, ±20º	0.59 m	0.30 m	0.23 m	0.19 m
Point spacing, ±23º	0.63 m	0.13 m	0.09 m	0.04 m
Area coverage rate	121 km^2/h	121 km^2/h	121 km^2/h	121 km^2/h

Thus from the user’s point of view, laser PRF cannot be the only figure of merit for data collection efficiency, as the point distribution in the scan pattern may significantly affect the cross-track point spacing. In a system with a sinusoidal scan pattern the user may have to operate the lidar at a much higher laser PRF to provide point spacing and area coverage rates comparable with the sawtooth scanner capabilities.

Link: Scan Frequency/Scan Angle and Data Collection Efficiency

Maximum scan frequency, as specified in a lidar system spec sheet, is another very important instrument parameter which affects data collection efficiency achievable in the field. Again, comparing "bare" numbers of maximum scan frequency may be quite misleading.

Scan rate for polygon versus oscillating mirror. With a polygon mirror (providing parallel lines on the target), the scan rate is the number of scan lines per second (Figure 2). For example, a 100 Hz scan rate means that the scanner can provide 100 parallel scan lines every second. With the oscillating mirror a scan frequency of 100 Hz means that the mirror completes 100 *full oscillating cycles*, each one consisting of *two* scan lines. In other words, with an oscillating mirror, 100 Hz scan frequency gives 200 scan lines on the target. In this example, the same number, 100 Hz scan frequency, might be interpreted with an "uncertainty" of factor of 2! Many customers using laser scanners with oscillating mirrors misinterpret the maximum scan frequency and apply the presented number to *half* of the oscillating cycle, i.e., to one scan line. Then, calculating the point spacing for the apparently "same" scan frequency may give an error factor of 2 if the beam deflection mechanism is not taken into account.

Scan FOV versus scan rate (frequency). In the case of an oscillating mirror, the operational scan frequency is *always* linked to the maximum scan angle setting. These two parameters—maximum scan frequency and maximum scan angle—are not only interrelated, but are inversely proportional to each other since their product determines the *maximum scanner velocity* a particular type of scanner can practically achieve. The maximum scanner velocity in turn, is proportional to the maximum acceleration and torque exerted on a scanner mirror during oscillation. That is why the maximum scan product (SP), calculated as a number proportional to the product of the maximum scan angle and maximum scan frequency, represents the real physical limitation of an oscillating mirror scanner, and it determines the maximum load allowed for the specific scanner. On the other hand, since the maximum SP determines the maximum achievable scanner velocity, this parameter determines the maximum possible area coverage rate since it provides the highest scan rate *and* the maximum scan FOV at the same time, not separately.

A simple mathematical relationship (equation 1) helps to clarify that the maximum available scan frequency, $SF_{max,}$ may have a rather limited practical advantage if the max scan angle, φ_{max} available for this frequency reduces the scanner FOV = $2\varphi_{max}$ to impractical limits.

$$SF_{\max} \sim \frac{SP}{\varphi_{\max}^{k}} \qquad (1)$$

Here, power degree k may or may not equal 1 for different types of scan patterns. Figure 4 shows examples of inverse proportionality between the maximum scan angle and maximum scan frequency for different scan products and scan patterns. For the same type of scanner, a higher scan product means a wider scan FOV available for the maximum scan rate *or* a higher maximum scan rate available for the maximum scan FOV. In other words, with a higher SP, the scanner is capable of operating at higher scanner velocity, therefore gets the job done faster.

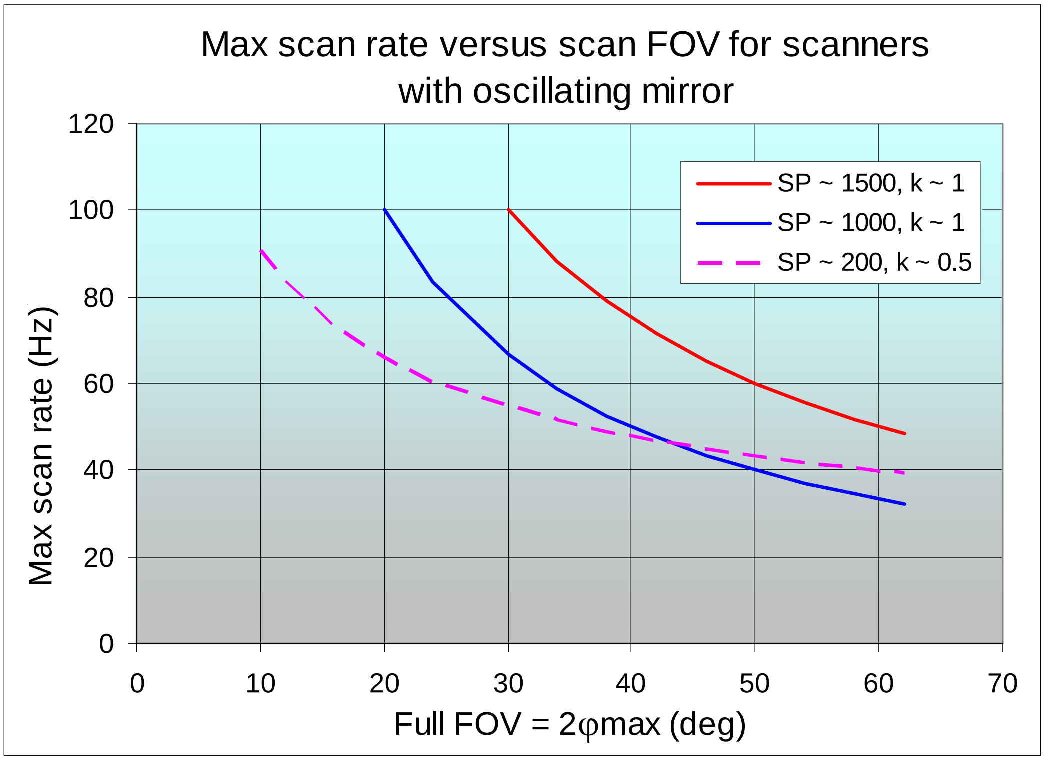

Figure 4. Maximum scan rate (scan frequency) versus maximum scan angle (maximum scan FOV) for oscillating mirror scanners. Dashed line represents sinusoidal scanner; solid lines represent sawtooth scanner with different scan products.

Thus, when considering maximal area coverage rate or data collection efficiency, the maximum scan frequency should always be linked to a maximum scan angle available for this frequency, and the seeming advantage of large numbers in the spec sheet should always be checked thoroughly.

ACCURACY SPECIFICATIONS VERSUS REAL-WORLD ACCURACY

Of particular importance are the spec sheet numbers characterizing lidar data accuracy. These numbers represent one of the most important system specifications. Without considering the context of the reference conditions and deriving methodologies, these numbers can be very misleading. While instrument accuracy specifications are provided by the manufacturers, translating the spec sheet numbers to real world achievable accuracy is a challenge usually left to the end user, and it has long been the subject of different interpretations (Ussyshkin, 2006). Moreover, due to the lack of widely accepted guidelines for deriving accuracy numbers, lidar system manufacturers typically use different methodologies for accuracy specifications.

Due to the nature of lidar data collection, there are many factors that affect the real-world accuracy of lidar data. These factors may be divided into three subcategories related to the lidar system itself:

1. Survey conditions
2. Target properties
3. The data handling process (Airborne 1, 2004).

They include, among others, extreme operational parameters, like very wide scan FOV and very high flying altitudes, strong variations in the target physical properties (size, slope, reflectivity), which may cause receiver saturation, GPS and INS data quality, etc. While some of these factors may be defined and described in the spec sheet, all of them could never be accounted for even in the most detailed document, and that is why the impact of some of these factors on data accuracy is sometimes either ignored or underestimated. However, it is very important for the user to estimate the influence of these factors on expected data accuracy. Here we will give several examples showing connections between unexpected or underestimated factors and their impact on lidar data accuracy.

FOV and Data Accuracy

In order to correctly interpret accuracy numbers in a lidar system spec sheet, the reference set of operational conditions being considered for the system characterization should be specified or indicated. This set should include not only some basic characteristics of the considered or used reference target but also the reference set of the system's operating parameters. Lidar data accuracy—both vertical and horizontal—depends on the scan angle. In general, the wider the operating scanner FOV (or maximum scan angle), the more significant the deterioration of data accuracy around the scan edges. Some manufacturers explicitly specify the considered operating FOV, while others may not. In any case, the question about the accuracy numbers given in the spec sheet remains open: does the spec sheet indicate the scan nadir accuracy (the best), the scan edge accuracy (the worst), or something in between? Over-emphasizing accuracy numbers without indication of the considered scan angle can lead to a misinterpretation of the system's capabilities. The horizontal accuracy analysis presented below will help to quantify the impact of the scan FOV on the expected data accuracy.

Laser Footprint Size and Data Accuracy

Laser footprint size is an additional factor that should be clearly understood while discussing lidar accuracy. There is no direct way to specify the accuracy of a lidar system without taking into account the finite size of the laser footprint (Ussyshkin, 2007). Mathematical modeling applied to analyze lidar accuracies will average a vast range of laser footprint sizes to derive a representative center. Under actual survey conditions however, there is always uncertainty of where the laser spot of a finite size hits the target. That is why consideration of laser footprint size becomes critical for the accuracy of targets producing partial signal return, tilted targets, or sloped terrain, etc. For example, in the case of a building edge, uncertainty in the horizontal position is determined by the laser footprint size, which is typically about 25 cm for 1-km flying height. This factor only brings the horizontal accuracy of the building edge down to the 1/4000 level regardless of other lidar subsystem performance characteristics such as the scanner, rangefinder and GPS/INS system. Therefore, in order to assess horizontal accuracy specifically, the factor accounting for the finite laser footprint size should, in this case, be disregarded.

GPS/INS System and Data Accuracy

It is a well-known fact that GPS/INS data quality is often considered a limiting factor in achieving the best accuracy of lidar data (Ussyshkin *et al*, 2006). In order to quantify the impact of the GPS and INS data quality on the accuracy of a lidar system we have launched a study on attainable horizontal accuracy of an airborne lidar system (Ussyshkin *et al*, 2008). For the theoretical analysis of horizontal accuracy we used the horizontal error budget model developed internally at Optech (Freiss et al, 2006). The horizontal data accuracy was modeled for the following input parameters:

1. 5 cm for the rangefinder error
2. 0.001° for the scanner error
3. POS system performance specs as specified in Table 2
4. All other contributions including finite laser spot size error and calibration errors are zero.

Table 2. Absolute accuracy (RMS) in post-processed Applanix POS™ data

POS/AV Model	Position	Roll and pitch	Heading
510	0.05-0.3 m	0.005°	0.008°
610	0.05-0.3 m	0.0025°*	0.005°

** Requires local gravity model to achieve full accuracy*

The horizontal accuracy was modeled for 1) 0 and 5 cm GPS error; 2) 0°, ±20° and ±25° scan angles.

Figure 5 shows partial results of the horizontal accuracy modeling. These results represent the best theoretically achievable horizontal accuracy under the conditions specified above.

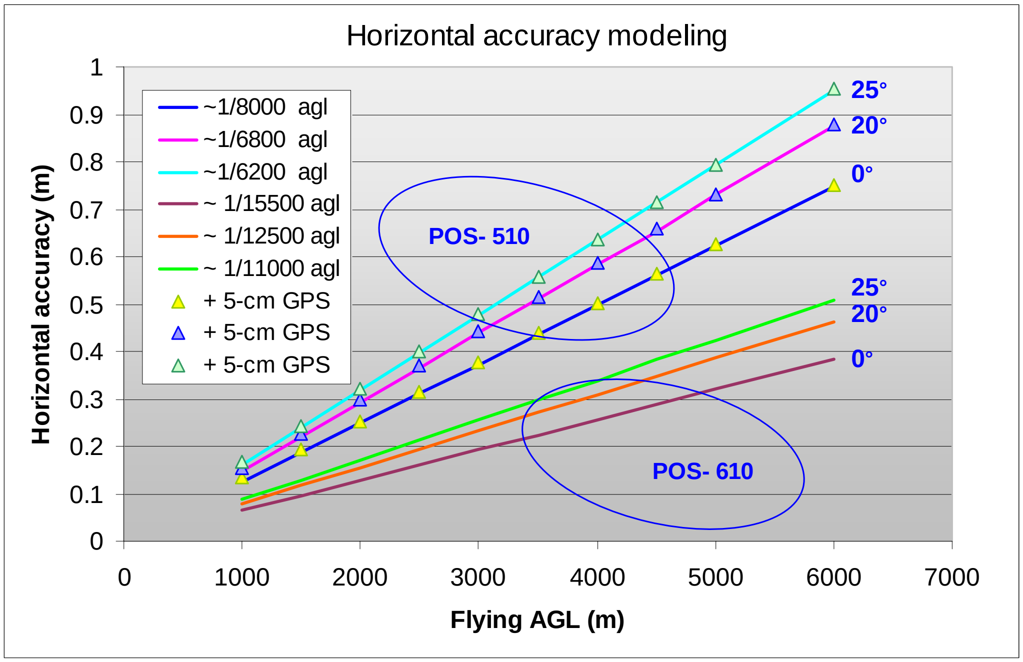

Figure 5. Theoretically achievable horizontal accuracy in an airborne lidar system equipped either with POS-510 or POS-610 (or equivalents) under assumptions specified above. All solid lines represent modeling results for zero GPS error; dotted lines represent the corresponding results, while a 5 cm GPS error was included.

Based on the results of this study, we have derived the following conclusions:

- POS (or any GPS/INS) data accuracy has a dominant impact on attainable horizontal accuracy of airborne lidar data
- Changing the scanner and rangefinder errors within reasonable limits (assuming no gross errors) or even neglecting them does not change the characteristic numbers for horizontal accuracy, which is determined by the POS performance numbers;
- Variations in GPS error within 0-10 cm have minor impact on the horizontal accuracy numbers compared with the impact of POS performance numbers;
- Horizontal accuracy greatly depends on the scan angle (scan FOV), which has considerable impact on horizontal accuracy numbers; increasing the scan angle beyond ±20º or ±25º leads to significant deterioration in horizontal accuracy, which may exceed 1 m error at higher altitudes (assuming POS-510 or equivalent performance) even for the best survey conditions;
- The impact of scan angle on horizontal accuracy is much more significant than the impact of GPS error, and it is somewhat comparable with the impact of POS data accuracy;
- The best theoretically attainable horizontal accuracy is solely determined by the POS system performance and the attainable accuracy of roll, pitch and heading measurements.

In order to compare theory versus practice, we followed the methodology described in detail in our previous study on vertical accuracy (Lane, 2005). The real field data were collected by 20 different ALTM systems equipped with POS/AV-510, in 50 flights over flat uniform terrain at flying altitudes of 800 – 2000 m. The main characteristic of data accuracy, RMSE, was calculated by ACalib, Optech's automated software application, which separates RMSE calculations in vertical and horizontal planes. The horizontal accuracy characteristic, XY-RMSE, was obtained by calculating horizontal coordinates X and Y from a reference target, a man-made linear feature (building edges) thoroughly surveyed by traditional methods with sub-centimeter accuracy for the ground control absolute reference.

It is very important to note that ACalib calculates RMSE by using imported flight data and imported control reference data with respect to the real points, while no spatial interpolation or smoothing or any other data optimization algorithms are applied to the data. (The ACalib algorithm does include a procedure for eliminating the contribution from the finite-size laser footprint factor to the overall XY error). Thus, the accuracy numbers derived in this study, as well as the lidar data accuracy numbers in the ALTM spec sheet, represents the basic "raw" accuracy of the lidar data points while no interpolation, smoothing or optimization by third-party software are applied to the XYZ-data.

Figure 6 represents the horizontal accuracy numbers converted to 1/x fraction of AGL (Altitude above Ground Level). The GPS data quality was variable, although for most flights it was 1 (the best). The demonstrated field results indicate agreement with the theoretical analysis, which showed ~ 1/6,000 AGL as the best theoretically achievable data accuracy at scan angles close to ±25º for a lidar equipped with POS/AV-510 or equivalent.

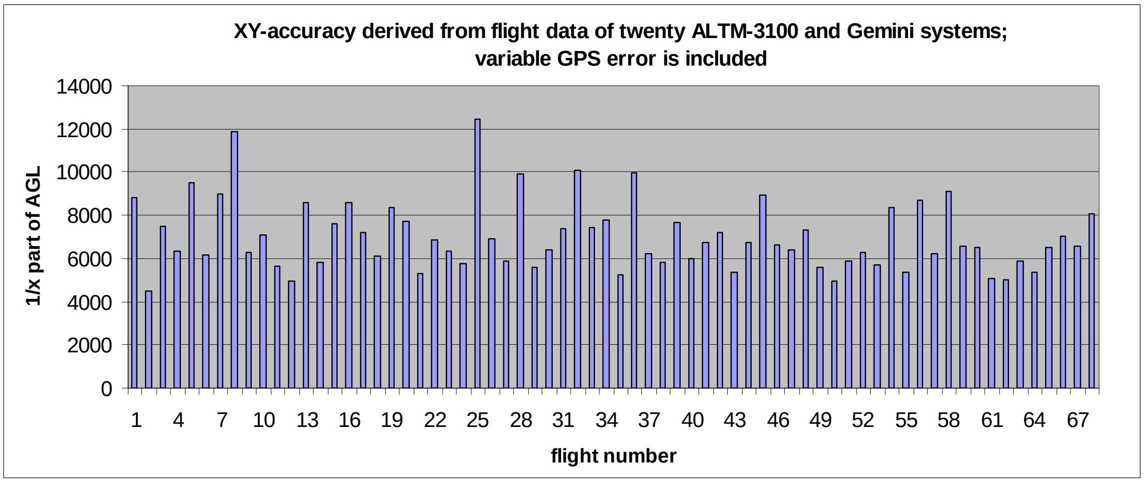

Figure 6. XY accuracy derived from the flight data of twenty ALTM 3100 systems at different flying altitudes, variable GPS error included.

Thus, the horizontal accuracy numbers in the specification sheets of two airborne lidar systems equipped with the same or equivalent GPS/INS systems must be identical, if these numbers are derived under the same assumptions, by the same methodology, and the same or similar reference set of operating conditions has been considered.

These conclusions are applicable for an airborne lidar, where operating ranges are so large that the error contribution from roll, pitch and heading measurements has absolutely dominant impact on data accuracy. For a short-range mobile lidar the situation is different, and the contribution from roll, pitch and heading measurements might be quantitatively comparable with the errors from the other subsystems. Then the overall data accuracy of a short-range mobile lidar may have different dominant players, but this consideration is out of the scope of this paper.

Post-Processing and Data Accuracy

Even after thorough consideration, which would include a reference set of operating parameters, a reference target and a reference set of data collection conditions, there is another factor which may have crucial impact on the accuracy numbers in the system spec sheet. The data processing procedure and the various processing algorithms applied to the raw lidar data may introduce or reduce errors so that the *final* accuracy numbers may look very different, depending on the applied processing procedures. Moreover, the data set might be further adjusted, optimized or smoothed by using third-party software, and additional data optimization algorithms could be applied after the data have been processed and calibrated by the proprietary manufacture's software. Since every manufacturer of commercial lidar systems uses their own proprietary procedures in order to determine the final accuracy numbers, there is always a "gray" area around the accuracy numbers in the lidar system spec sheet.

Based on the results of the recent study on the impact of the data processing procedure on the lidar accuracy numbers (Pokorny, 2008), we have concluded that the optimization algorithms applied to the processed lidar data may significantly improve the derived accuracy numbers. Moreover, since the overall lidar data accuracy strongly depends on the accuracy of the position and orientation data, the post-processing software tools available in the advanced GPS/INS systems may also have significant impact on the final data accuracy. A prime example is the new POSPac 5 processing package offered by Applanix/Trimble, which has proved to be even more robust than the POSPac 4.4 currently used with ALTM/Gemini and is capable of handling steeper banking angles without compromising the determined accuracy (Applanix). In tests performed at Optech (Boba, 2007), the POS data processed using POSPac 5 has consistently shown improved positional accuracy which in turn, improved the overall accuracy of ALTM/Gemini data.

Thus the data accuracy derived right after data processing may look quite different from the numbers derived after additional optimization algorithms have been applied to the data. Moreover, the methodology the data processing workflow used to derive the accuracy numbers may vary from manufacturer to manufacturer, and it is not obvious that the results of different methodologies would be valid for sensible comparison.

CONCLUSIONS

When comparing mobile and airborne lidar systems from different manufacturers, look carefully not only at the numbers in the spec sheet, but also at the underlying connections between these numbers. Many of the numbers characterizing system capabilities for extreme settings of operational parameters are not available at the same time. Some of the highest and best numbers may be strongly affected by other lidar capabilities whose impact on data collection efficiency and accuracy may often be unexpected, ignored or underestimated.

Position and orientation data accuracy have the most significant impact on the accuracy of mobile lidar data and particularly, it has dominant impact on the horizontal accuracy of an airborne lidar system. Two different airborne lidars equipped with equivalent GPS/INS systems should have identical horizontal accuracy specs, if these numbers were derived under the same assumptions, by the same methodology, and the same or similar reference set of operating conditions. Dramatic improvement of routinely achievable horizontal accuracy in an airborne lidar is possible only if a next-generation GPS/INS system is used for position and orientation data collection and processing.

Data accuracy numbers derived right after data processing may look quite different from numbers derived after additional optimization algorithms have been applied to the data. A knowledgeable user should always look into the technology behind the numbers, and understand the impact of the technological solutions utilized in a particular lidar system on the numbers presented in the spec sheet.

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