

A NEW APPROACH FOR ASSESSING LIDAR DATA ACCURACY FOR CORRIDOR MAPPING APPLICATIONS

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ABSTRACT:

There is a growing demand for high-accuracy elevation data collected by airborne or terrestrial mobile lidar systems in utility corridor surveys. Large-scale projects demand more stringent accuracy of lidar data under strongly variable survey conditions challenging lidar signal detection capability with extremely wide signal dynamic range. While accuracy specifications are provided by the lidar system manufacturers, translating these specifications to real-world achievable accuracy and evaluating it against existing mapping accuracy standards is a challenge left to the end user.

In this paper we present a new cost-effective approach for evaluating lidar data accuracy for linear target detection. The practical application of this approach is demonstrated by assessing accuracy of the lidar data collected in airborne power line surveys. The demonstrated approach could be modified and applied for accuracy analysis of the geo-referenced lidar data collected by either airborne or mobile terrestrial lidar system for various corridor mapping applications.

1. INTRODUCTION

Laser scanning technology has emerged as a preferred operational tool in remote sensing, surveying and mapping, and particularly in utility corridor surveys. It is capable of generating high-density, high-accuracy elevation data collected in corridor surveys either by airborne or terrestrial mobile lidar systems for both commercial mapping industry and academic research. Although recent advances in lidar technology have resulted in a dramatic improvement of lidar data quality, e.g., higher point density and sub-cm accuracy, there are certain misunderstandings about how the lidar instrument's operational capabilities affect the achievable field accuracy of lidar data (Ussyshkin and Smith, 2006). Furthermore, the link between the final accuracy of lidar data and the existing accuracy standards developed for mapping and other more mature technologies is not very well understood (Flood, 2001). Particularly, for large-scale corridor mapping applications, there are no widely accepted standards or well-established guidelines to derive accuracy specifications for the lidar-derived end products. Though manufacturers of airborne lidar systems provide accuracy specifications, translating the specifications to real world achievable accuracy in specific applications and specific survey conditions is a challenge left to the end user.

Considering power transmission lines as one of the most typical examples of the surveyed corridors, the question about the accuracy of the lidar-derived data of the conductor wires would be the most important for the further analytical evaluation of the surveyed transmission line (Piernot and Leahy, 2001; Lu *et al.*, 2006). For a lidar instrument, extremely thin linear targets i.e., transmission wires, suspended very close to the ground represent a demanding challenge to the signal detection components because very weak returns from wires occur alongside very strong returns from the surrounding ground. Such a dynamic range of signal strength means that the

accuracy of the lidar data can vary between the detected linear targets and the underneath ground. Concerns have been raised over the accuracy of lidar data obtained in power line surveys and the subsequent validity of the data for further engineering calculations (Addison *et al.*, 2003).

Most lidar publications related to the corridor surveys are focused on data acquisition rather than on demonstrating achievable data accuracy, which is important for the commercial use of lidar data. There is an evident lack of published methods for assessing lidar data accuracy in power line and other types of corridor surveys, where various types of the linear features are usually surveyed. This is probably due to the difficulty in determining ground-truth references for the linear targets, and particularly, for transmission lines, which may require cost and labour-intensive ground measurements (Addison *et al.*, 2003). Moreover, the accuracy analysis of data collected in any terrestrial or airborne lidar corridor survey may often require complicated 3D object modelling (Melzer and Briese, 2004) and 3D feature extraction algorithms (McLaughlin, 2006).

A new methodology for assessment of the vertical accuracy of lidar data collected during aerial power line surveys has been reported by Network Mapping Limited (NML), Merrett Survey Partnership (MSP) and NetMap (Addison *et al.*, 2003). In order to determine laser point accuracy, ground-truth studies were conducted during each data acquisition project. Then the laser point positions from the aerial survey were compared with the ground survey, and the results were summarized in tables and histograms. According to the results of that study, the position of the key power line points (i.e., attachment points and catenary), was determined with an absolute vertical accuracy ± 1 cm. The ground position, depending upon the terrain type, was determined with the absolute vertical accuracy of ± 0.2 cm for regular uniform terrain, to ± 9 cm for sharply irregular terrain and forest.

We consider the NML and MSP study as an important step forward proper evaluation and documentation of the lidar data accuracy achievable in power line surveys. Being widely adopted the new methodology could provide a basis for further development of the accuracy standards in this area. However, such a time-consuming and labour-intensive methodology is not always affordable, especially if only preliminary evaluation of the lidar data quality is required. In this paper, we present a new simplified approach to evaluate the vertical and horizontal accuracy of the transmission line data, while it could be applied for lidar-detected linear target data in any corridor survey. Using this approach, the achievable field accuracy of a mobile or an airborne lidar system can be evaluated and used for characterizing system performance, particularly in power line surveys and other corridor mapping applications, where linear features are typically surveyed.

2. LINEAR TARGET DETECTION

Considering the size and the position of the target with respect to the size and the position of the laser footprint, three types of lidar targets could be defined: 1) an area target, which fills the entire laser footprint; 2) a linear target, which extends through the entire length of the laser footprint, but has the width, which is significantly smaller than the laser footprint diameter; 3) a point target, which area is significantly smaller than the laser footprint area. For the purpose of this discussion, we will consider the first two types of the lidar targets, the area and the linear targets, both located at the same distance R from the lidar receiver.

A typical commercial lidar system, either airborne or terrestrial, is not optimized for the linear target detection. A lidar receiver detects only that portion of the emitted light that is reflected from the interception of the target and the laser footprint. The stress on the receiver electronics is even greater when the laser footprint makes a partial interception of the linear target (Figure 1). Therefore, with the relatively small area of this interception, the return signal is substantially weaker than the signal detected from the full-footprint area target. Moreover, the strength of the signal reflected from the linear target at the range R is inversely proportional to R^3 versus inverse R^2 for the area target (Jelalian, 1992).

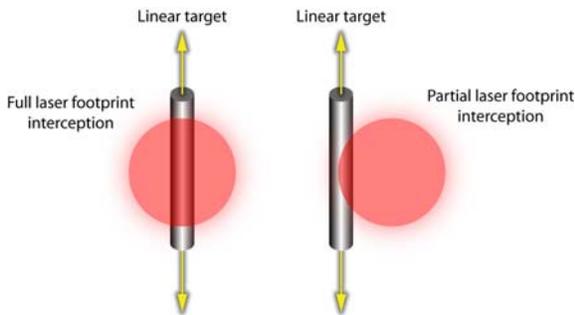


Figure 1: Interception of the linear target and the laser footprint

Assuming Lambertian targets, the following equations for the received signal strength P for the area and linear targets could be derived (Jelalian 1992, Baltasvias 1999):

$$P_{area} \propto \frac{\rho_{area}}{R^2} \quad (1)$$

$$P_{linear} \propto \frac{\rho_{linear}d}{\theta R^3} \quad (2)$$

Here ρ is the target reflectance, θ is the laser beam divergence in radians, and d is the diameter or width of the linear target. These equations indicate that 1) signal strength from the linear target would decrease much more rapidly with the range than that one from the area target; 2) signal strength from the linear target is directly proportional to the diameter of the target and inversely proportional to the laser beam divergence. In other words, the thinner the target, and the larger the laser beam divergence, the weaker the signal return from the linear target should be expected. It means that the signal detection accuracy, which translates to the range accuracy and correlates with the return signal strength, may depend on the size and shape of the linear targets. More detailed consideration on the lidar range accuracy and the return signal strength could be found in Baltasvias (1999) and Jelalian (1992).

It is also important to note that the lidar system manufactures would typically characterize the lidar performance for the area target, i.e., for full footprint signal return. However, it is clear that for the linear target detection the lidar would receive only partial return, and in this case the lidar data accuracy might be compromised.

Thus, the real field conditions of a corridor survey, when thin linear targets (i.e., transmission wires, pipelines, vertical poles, etc.) should be detected alongside with the area targets, an extremely wide dynamic range of the lidar return signal should be expected. If the return signal from the area target is too strong, it could saturate the receiver, and the accuracy of the area target would be compromised. On the other hand, if the return signal from the linear target is too weak, it would not be detected, or the recorded data might be very noisy and consequently might have very poor accuracy. Ideally, the lidar receiver electronics should be able to handle both strong and weak signal levels equally so that the data accuracy would be reasonably consistent for strong and weak signal levels. The challenge of dynamic signal strength fluctuation is even greater, when the slope and reflectivity of the area target beneath or behind the linear target varies significantly. In such cases the lidar receiver electronics should be capable of maintaining the same, or at least a consistent level of accuracy, over a very wide dynamic signal range without any re-adjustments of the receiver electronic parameters.

To the best of our knowledge, there are no well-established or widely accepted procedures for characterization of the lidar data accuracy for linear target detection. Here we present an approach and a case study on the assessment of the lidar data accuracy for the linear targets against the area target accuracy.

3. THE METHOD

Any mobile lidar system provides geo-referenced set of horizontal (x , y) and elevation (z) coordinates, which are calculated from the detected ranges to the reflective surfaces (area target) and the smaller objects along the laser path (linear

target). The approach developed in this study is aimed to separate the contribution from systemic and random errors in the linear target and the area target data, and then to compare the root-mean-square (RMS) and the standard deviation of horizontal (x, y) and vertical (z) coordinates for the linear and the area target data.

The RMS and standard deviation for the area target data is normally obtained by comparison of the measured data against an absolute reference. In this study we used a standard algorithm developed at Optech (Lane, 2005). The control reference surface for the ground elevation data was a large open flat terrain, which was surveyed using traditional ground-based methods with sub-cm accuracy. The elevation of the collected data was compared to the elevation of the control differences and the RMS and the standard deviation were calculated. The horizontal accuracy parameters, xy-RMS and xy-standard deviation of ground data, was obtained by comparing the horizontal coordinates of the collected data versus a reference, which was a man-made linear feature densely surveyed by traditional ground-based methods with sub-cm accuracy.

For the assessment of the linear target accuracy parameters a new recently developed method (A. Fidera, *et al*, 2006) was used. Our approach was developed for the case study where accuracy of the power line detection was to be assessed. In the case of the transmission line, the conductors always hang in the vertical plane (Piernot and Leahy, 2001), and it allowed us to reduce a 3D-problem in xyz coordinate system to two 2D-problems in xy- (horizontal) and xz- (vertical) planes.

As a first step, the linear target dataset was manually selected, and the mean of easting, northing and elevation was calculated. Then, the linear target data was translated to a new origin in xy plane. After the translation, a straight line was fitted to the transformed linear target data, and the slope m of the line found in this coordinate system (Figure 2) was used to rotate it so that the linear target would be aligned along the horizontal axis (x) of the newly created coordinate system after the rotation. Then the standard deviation of the ordinate, which characterizes the horizontal accuracy of the linear target, was calculated.

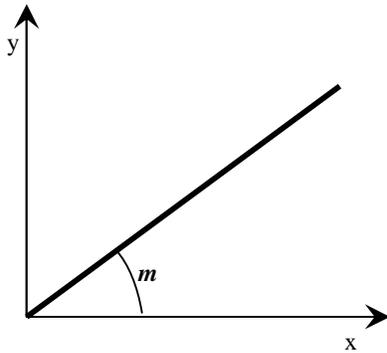


Figure 2: Translated linear target in xy-plane

In order to assess vertical accuracy, xz-coordinate system has been considered. After the coordinate system rotation, the span of the hanging cable in vertical plane can be characterized as a function $z = f(x)$, which can be graphed as a variable x versus the elevation data z of the linear target. Then, the standard deviation of z can be used as characteristic of the detected linear target's elevation accuracy.

The best fit to the data formed by the transmission line is achieved by employing a catenary function, which is known as a solution for the hanging cable problem (Stewart, 1995):

$$z = a + c * \cosh\left(\frac{x-b}{c}\right) \quad (3)$$

Here a, b, and c are generally unknown parameters of the catenary curve schematically presented at Figure 3.

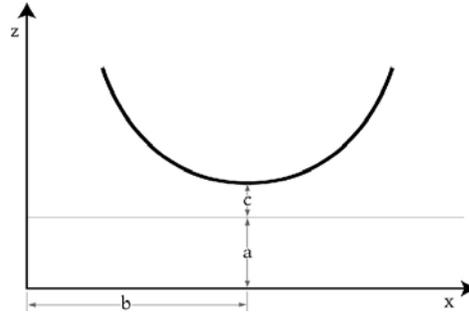


Figure 3: Catenary curve parameters in xz-plane

In order to estimate first approximates for catenary fitting, a second-degree polynomial was fitted into the point cloud. The tangent line to the polynomial curve with zero-slope gives the first approximation for the parameter b, which represents the distance from the origin of the x-axis to the lowest point of the catenary curve. The sum of two other parameters, $a + c$, represents the distance from the origin of the z-axis to the lowest point of the catenary, while c is the catenary curve parameter, characterizing its curvature. From the practical point of view, the value of the parameter c determines the wire sag, which is associated with the tension of the cable and used for further engineering analysis of the transmission line capacity and other practical needs.

In order to find a, b and c for the catenary equation, the least-squares adjustment of the catenary curve was completed by creating a Jacobian matrix and an associated residual vector in 2D vertical plane. The Jacobian matrix was created by taking derivatives of the catenary curve with respect to the three parameters a, b, and c. The solution converges quickly and residual vectors are analyzed using descriptive statistical tools (Stewart, J., 1995). Then, the standard deviation of z coordinate with respect to the best catenary fit could be used as the elevation accuracy of the wire detection. More detailed description of the applied method could be found in our previous publication (A. Fidera, *et al*, 2006).

4. RESULTS AND DISCUSSION

The data used in this case study was collected by five Optech ALTMs (model 3100EA) over the same segment of power lines. All ALTM systems were flying at the similar altitudes (approximately 1 km) and operating at the same laser pulse repetition frequency (70 kHz) with the full scan angle 20° under different conditions (weather, season, etc.). Each flight contained passes over a control field in order to optimize the

calibration parameters. The results were used for processing the linear target segments of the entire dataset with the same calibration parameters as the area target data. That is why the contribution of GPS and other “external” calibration errors to both linear target and area target data was minimized and assumed to be the same.

For the purpose of this study, the lidar data was classified into two categories: linear target (transmission wires) and area target (ground and buildings) data. Transmission wires are typically positioned at three or four levels: two or three levels of conductors, and the top-level ground wire. One span between two towers was selected as a control site and the top wire was selected for the accuracy analysis. The physical properties of the top wire assembly, typically 3/8” (≈ 1 cm) diameter steel wire in the 795 kcmil family, make it the most difficult wire for an airborne lidar to detect in a transmission line. Since the conductor wire is typically three times thicker than the top wire, taking into account equations (1, 2) one could expect better signal return and better accuracy for the conductor wire data rather than for the top wire data. That’s why for this study we have selected the “worst-case” scenario so that the accuracy of the most-difficult-to-detect top wire data was assessed against accuracy of the ground data.

The top wire data was manually selected and classified. Next, the point cloud was restrained to the points above the area target, and only first-pulse returns were used for the top wire data classification. Additionally, data points from trees were manually removed from the data.

The RMS and standard deviation for the ground data were tabulated alongside, with the standard deviation for the top wire calculated by the method presented in section 3. Table 1 represents the RMS and standard deviation of the z coordinate which characterizes vertical accuracy. Table 2 represents the xy RMS and standard deviation which characterizes horizontal accuracy.

System _flight number	Ground data		Top wire data
	z-RMS (m)	z-st dev (m)	z-st dev (m)
2_00705	0.110	0.088	0.044
4_34305	0.112	0.059	0.070
5_02606	0.117	0.061	0.059
8_27806	0.097	0.037	0.086
9_22906	0.078	0.039	0.065

Table 1. RMS and standard deviation for ground and top wire elevation data

The results presented in Table 1 show that z-standard deviation of the top wire data and the ground data are within 4-9 cm and very consistent for all ALTM systems. It indicates very good fit of the wire elevation data by the modelled catenary function. It is also important to note that the quality of this data demonstrates exceptional capability of ALTM system to detect small-size linear target, 9-mm diameter wire, from the range of about 1 km. Comparing RMS and standard deviation for the ground data, we could estimate the absolute accuracy of the ground data to be within 2-6 cm for all systems. This result could be considered as consistent with the results of the independent

study (Addison, 2003), which showed similar values for the vertical accuracy of ALTM data collected in power line surveys.

System _flight number	Ground data		Top wire data
	xy-RMS (m)	xy-st dev (m)	xy st dev (m)
2_00705	0.103	0.103	0.107
4_34305	0.116	0.116	0.118
5_02606	0.129	0.128	0.121
8_27806	0.107	0.107	0.068
9_22906	0.117	0.116	0.104

Table 2. RMS and standard deviation for ground and top wire elevation data

The xy-accuracy values in Table 2 show that the contribution of the GPS and other external errors to the horizontal accuracy of the area target was almost completely removed: xy-RMS and standard deviation in the area target data are almost identical. This is due to the calibration procedure, which was designed to correlate the results over the controlled calibration target and to remove as many calibration errors as possible. The differences between the xy-standard deviation of the top wire data and the ground data are within 2 cm in four of five ALTM systems. Insignificant variations in standard deviation values for different systems could be explained by variations in flight altitude, atmospheric visibility, some variations in the parameters of the lidar systems, etc., or by combination of any of these factors.

5. CONCLUSIONS

A new method for assessing lidar data accuracy in corridor surveys when linear targets are typically detected has been developed, and its application for power line detection is reported. The presented method can also be used for characterizing lidar system performance in other specific applications, where linear target detection is required. Consistent performance of ALTM system in detecting both strong signals (area targets) and weak signals (linear targets) without readjustment of the system electronics supports the manufacturer accuracy claims and confirms the validity of lidar-derived data for power line engineering calculations.

The presented method can be modified and used to evaluate the lidar data quality for the extracted gas and oil pipelines and other where types of linear features typically detected in various corridor surveys.

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