PRECISE MAPPING: ALTM ORION ESTABLISHES A NEW STANDARD IN AIRBORNE LIDAR PERFORMANCE

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ABSTRACT

Airborne lidar technology has redefined the realm of topographic surveying and mapping. With data collection rates increasing to hundreds of kilohertz, advanced lidar systems deliver unprecedented data collection rates and point density measurements, turning airborne surveying into a quick, efficient and highly productive technology. Along with industry efforts to continuously improve data collection efficiency, resolution and accuracy, there has also been a growing demand for a more compact, robust and light-weight system for low- and mid-altitude airborne surveys in order to maximize the efficiency of data collection missions. This paper presents field study results from a new airborne lidar system developed by Optech Incorporated - the ALTM Orion, the world's most compact complete airborne lidar solution. It will be demonstrated that the ALTM Orion offers the most efficient data collection in the industry, providing a combination of the highest data collection rate, a uniquely advantageous scan pattern, and—owing to its remarkably compact, lightweight and energy-efficient design—unprecedented flexibility with various installation platforms. New advances in Optech's time-of-flight electronics and laser design have facilitated measurement precision that raises the bar for what is commonly expected from raw lidar data quality. The data accuracy and precision demonstrated in the field study surpass the best performance characteristics of any advanced lidar system. The quality of small object detection is characterized by a newly developed approach in quantifying the distribution of 3D point clouds comprising small objects. The field study results on data accuracy and precision are discussed in the context of setting new data quality and accuracy standards in the lidar industry.

INTRODUCTION

Airborne lidar technology has established itself as an efficient way of generating high-accuracy spatial data for a wide range of mapping and surveying applications (Flood, 1999, Renslow, 2005). Over the past several years, new lidar systems have been introduced to the airborne surveying industry on the basis of increasingly competitive specifications. Evolving hardware has mainly focused on gradual technological developments (Toth, 2004) such as increased laser pulse repetition frequency (PRF), laser scanning frequency (SF), the introduction of continuous multi-pulse technology (CMP) and improvements in return signal detection and processing (Ussyshkin, 2006). Concurrent with these hardware developments were software advances in enabling technologies such as position and orientation systems, various post-processing and data visualization tools and others.

The advances made in lidar systems' mechanical and electronic capabilities affected the way new commercial lidar systems could be designed. As a result, a new trend has developed, which points away from flexible, "one-size-fits-all" designs—lidar systems that cover the maximum range of applications—toward new designs that capitalize on certain features geared to specific applications such as utility corridor mapping (Ussyshkin, 2009), UAV platform capability (Hussein, 2009) and ultra-high density systems (Optech, 2009).

Indicative of this trend, Optech Incorporated recently released a new generation Airborne Laser Terrain Mapper (ALTM) that embodies this application-specific design approach. The ALTM Orion-C and Orion-M are two models that were created in response to growing demands in the lidar community. The ALTM Orion models represent a radical departure from previous generations of airborne lidar instruments. First, the physical form factor—size, weight and displacement—has been reduced by a whole order, making the Orion the first ultra-compact complete lidar solution. Second, the lidar data produced from the Orion has established a new benchmark in the industry for accuracy and precision.

This paper presents details of test results from the ALTM Orion-C and Orion-M models. Apart from the advantages of the Orion's new lightweight ultra-compact design, both models offer advanced technology features unavailable in earlier lidar models, features that enable each Orion model to excel in specific applications such as low-altitude corridor mapping for the Orion-C, and mid-altitude, large area mapping for the Orion-M. By capitalizing on advantages that the new technologies offer, the Orion dramatically reduces the cost of data acquisition without compromising data quality. In fact, the resulting data is characterized by unprecedented accuracy and precision. This paper presents an analysis of the Orions' performance, including data collection efficiency, quality and accuracy. Results from field tests on data accuracy and precision are presented and discussed.

ALTM ORION: NEW GENERATION AIRBORNE LIDAR MAPPER

The ALTM Orion contains a lidar transceiver, a position orientation sensor and control electronics all integrated within a 1-cubic foot, 59-pound package (Figure 1). This ultra-compact design is achieved by using the latest laser technology, an advanced optical design, and the most advanced control and data collection architecture. The drastically reduced form factor allows for quick and easy installation into essentially any aircraft, even Unmanned Aerial Vehicles (UAV). One distinct advantage of deploying an airborne lidar in a UAV is economical: pilot fees are obviated and, thanks to the lighter payload, less aircraft fuel is consumed.

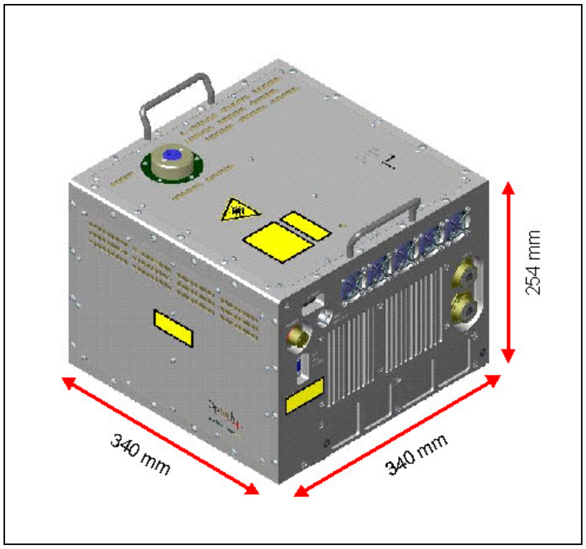


Figure 1. ALTM Orion lidar unit.

Table 1. Left: ALTM Orion mass and volume figures compared with preceding model, ALTM Gemini. Right: ALTM Orion power consumption figures.

Mass (total)	ALTM Orion	ALTM Gemini
	59 lb.	169 lb.
Volume (total)	1 cubic foot	7.63 cubic foot

State	Input Power
Survey	470 W
Ready (idle)	200 W

Both the Orion-C and Orion-M share the same physical attributes in terms of size, weight and configuration. But the Orion C, which delivers aided eye-safe operation at any operational altitude (NOHD = 7 m), was developed specifically for corridor mapping applications. In order to meet stringent eye-safety standards at such sort ranges, the emitted energy of the laser pulse had to be reduced so that, in combination with other system parameters, it maintains complete compliance with eye-safety standards. Therefore, the Orion C's operational envelope is limited to 1200 m for targets of 20% (or higher) reflectivity (Figure 2). This envelope covers the full range of corridor mapping applications and beyond. At the same time, the relatively low altitude allows for the optional use of a downgraded POS subsystem without compromising data quality yet allowing for a more cost-effective system design.

The Orion-M is equipped with a more powerful laser which enables it to fly at higher altitudes while maintaining increased ranging ability (Figure 2), thus making it especially efficient at large-area surveying and mapping applications.

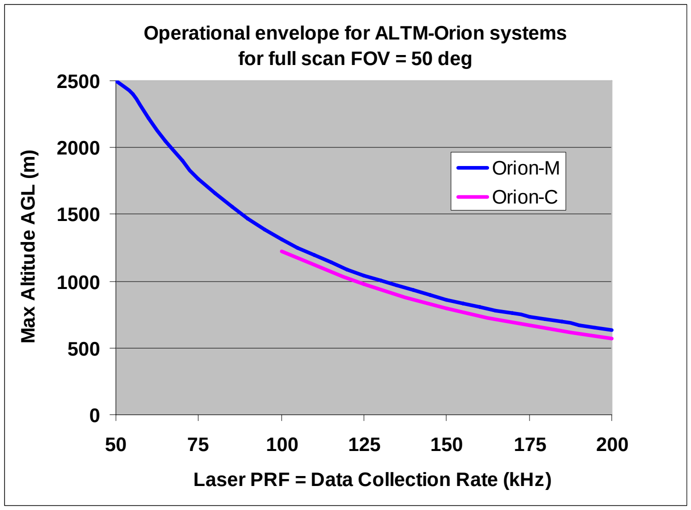


Figure 2. Operational envelopes, ALTM Orion models M and C.

The ALTM Orion-M and C models retain some aspects of the preceding ALTM Gemini model such as efficient scan pattern, but improved on a number of areas that provide more flexibility to the end user. For example, the Orion's scan frequency (SF) has accelerated to a peak rate of 100 Hz (200 scan lines per second). The Orion also uses a new scanning platform that builds on Optech's proven "sawtooth" scan pattern with quasi-uniform cross-track point distribution, a feature that minimizes the reduction of ground point density at nadir (Ussyshkin, 2008c). Figure 3 illustrates the swath coverage resulting from the sawtooth scan pattern. This specific scan pattern was selected for its cross-track quasi-uniform point distribution on the ground as opposed to other patterns, such as sine wave or rotating polygon (Hussein, 2009). Figure 3 shows laser point spacing of 15 cm cross-track and 35 cm along-track, resulting in a ground point density at nadir of 20 ppm^2 at an altitude of 1 km AGL. Such coverage density enables the detailed 3D characterization of corridors, small vehicles and vegetation.

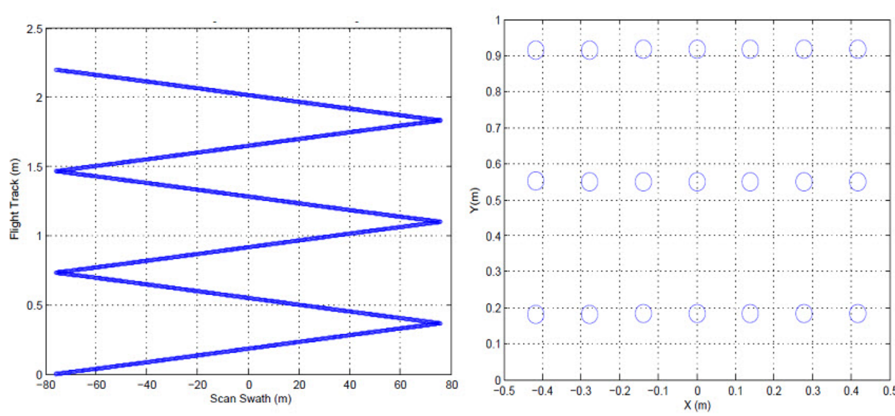


Figure 3. Left: scan pattern from 1 km altitude, PRF = 150 kHz, SF = 70 Hz, FOV = ±14°, aircraft speed 100 knots. Right: Zoom to 1 m^2 box at nadir showing point coverage along flight direction plus swath width.

Another dramatic improvement achieved in both Orion-M and C models, is the high data collection rate, or laser pulse repetition frequency (PRF): up to 200 kHz. In combination with the highest SF available at the maximal scan FOV, the ALTM Orion provides the highest area coverage rate of any airborne lidar system operating in single-pulse mode while also maintaining quasi-uniform cross-track point distribution. Figure 4 shows examples of ground point density (at nadir) from the Orion-C in parallel with the achievable area coverage rate while using the same operational parameters.

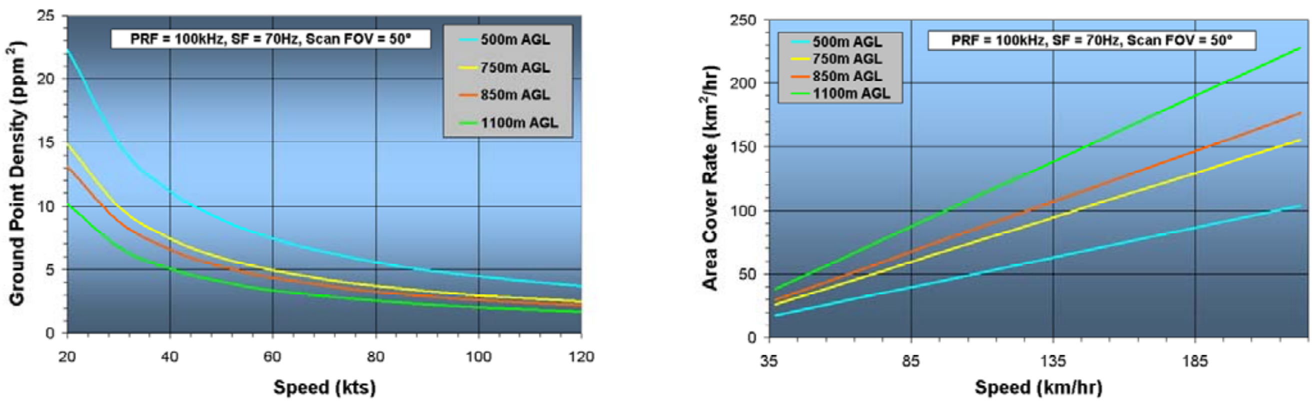


Figure 4. Left: An example of ALTM Orion-C ground point density. Right: ALTM Orion-C area coverage rate.

Thus, Optech's new ALTM Orion series represent a new level of achievable data collection efficiency for any airborne lidar system of similar class. Its ultra-compact design affords a dramatic reduction in data acquisition costs. Moreover, as will be shown below, the highest data collection efficiency is attained without compromising data quality, accuracy and precision. The results of the field study supporting these claims are presented below.

DATA QUALITY, ACCURACY, PRECISION

Ground data accuracy is the key performance specification claimed by lidar system manufacturers and lidar data providers, but it has always been subject to different interpretations among the end users of lidar data (Ussyshkin, 2006). The lack of clearly defined and widely accepted industry guidelines on the characterization of lidar data accuracy has given instrument manufacturers the latitude to claim either best-case scenarios, or averaged numbers, or theoretical/expected accuracy or lab-qualified numbers derived from specific test setup configurations, or the numbers derived after adjustments using a third party software tools (Ussyshkin, 2008a,b).

Optech's accuracy specifications listed in lidar system data sheets have always been derived from flight-qualified test results, and always include significant safety margins so that the user can expect to acquire data that will meet or exceed the accuracy specs. This paper reports on the study on field-qualified evaluation of the accuracy of Orion-M and Orion-C data in comparison with the accuracy specifications presented in the data sheet of both systems.

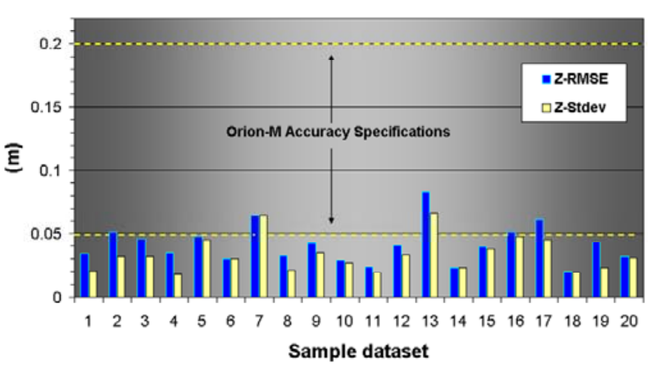
Airborne lidar system accuracy is typically characterized in terms of vertical (elevation) accuracy (Z), and horizontal (planimetric) accuracy (X, Y). Both vertical and horizontal accuracy may be affected by significant systemic errors, which may or may not dominate random errors (Maas, 2003). Most systemic errors can be minimized by a rigorous calibration procedure, though they are not easily eliminated, and may result in systemic errors. In this study, flight data was collected by fully calibrated ALTM Orion-M and C models so that any contribution from systemic errors was minimized, but no additional data adjustment or manipulation was applied.

Both the vertical and horizontal accuracy of the Orion-M and C models are characterized by root mean square error (RMSE) and standard deviation (Stdev). The RMSE, containing random and systemic errors, characterizes the absolute accuracy; the Stdev, including mainly random errors, characterizes the relative accuracy (precision). The RMSE of the ground data is typically obtained by comparing the measured data against an absolute reference. In this study, an Optech-developed algorithm that separates RMSE calculations in vertical and horizontal planes was used (Lane, 2005).

The control reference surface for the ground elevation data was an airport runway—large, open flat terrain, surveyed using traditional methods with sub-centimeter accuracy. The elevation of the collected data was compared with the elevation of the control differences, then the RMSE and Stdev of Z-coordinates were calculated. The horizontal accuracy parameters, X-Y RMSE and X-Y Stdev of the ground data, was obtained by comparing the horizontal coordinates of the collected data against a reference, a man-made linear feature densely surveyed by traditional methods also with sub-centimeter accuracy.

For the purpose of this study, 121 datasets were collected by ALTM Orion systems operating at various altitudes and different laser PRF to analyze the consistency of the lidar performance under different operational parameters.

Figure 5 shows the accuracy characteristics of Orion-M and C models for some of the data sets used in this study. They illustrate the comparison of field-achievable data accuracy for both systems with respect to the accuracy specifications indicated in the data sheets. Both bar diagrams represent various sample data sets collected at different AGL, PRF and other parameters, while keeping similar ground point density, which is sub-meter per point. It is evident that both systems consistently demonstrate not only much better accuracy characteristics than the data sheet specifications, but also attain a new lidar industry benchmark in data accuracy and precision by achieving precision of 2-3 cm, and absolute accuracy better than 6-8 cm, independent of flying altitude and data collection rate. These results also indicate that the Orion-M, with its higher-grade Position and Orientation System—POS/AV-510, as opposed to the Orion-C's POS/AV-410—consistently show a reduced contribution of systemic errors to the RMSE values when compared with Orion-C data, where the relative difference between RMSE and Stdev is more significant, owing to a downgraded POS. Nevertheless, Orion-C consistently demonstrates outstanding Stdev, beating the best precision numbers ever achieved in airborne lidar technology.



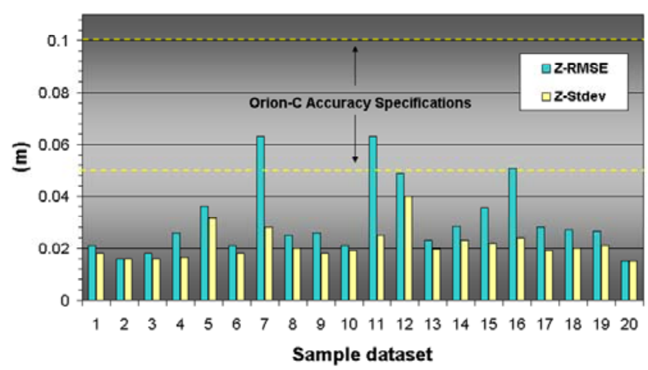


Figure 5. Left: Accuracy and precision characteristics, ALTM Orion-M against accuracy specifications. Right: Accuracy and precision characteristics, ALTM Orion-C against accuracy specifications.

Figure 6 shows the field data accuracy trends with respect to altitude in both models; this supports the claim of best elevation accuracy and precision in the lidar industry. Figure 7 shows XY accuracy trends based on flight data for both models. These results demonstrate consistently better field data accuracy than the specification numbers; at the same time, they also confirm the dominant role of the POS in determining XY data accuracy in an airborne lidar.

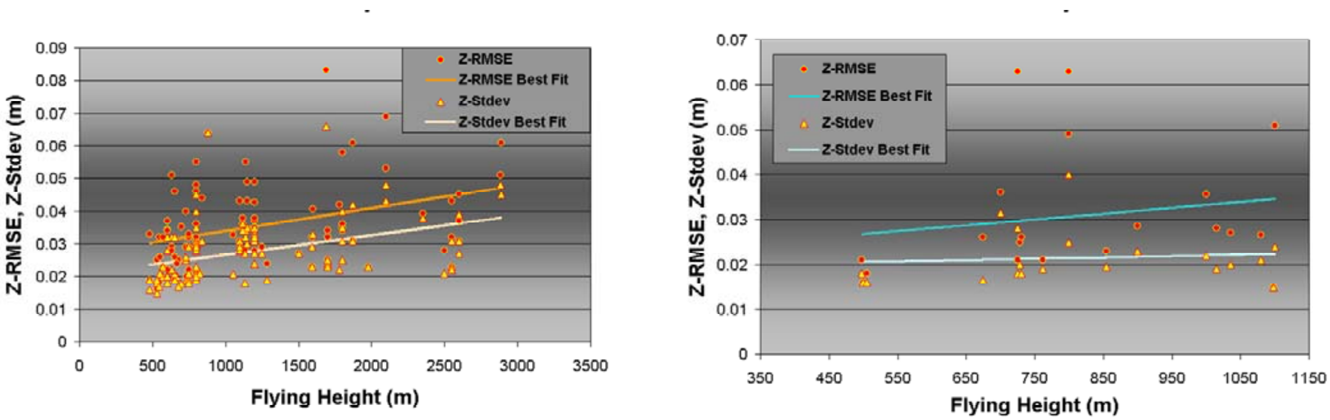


Figure 6. ALTM Orion-M (left) and C (right) elevation accuracy trends.

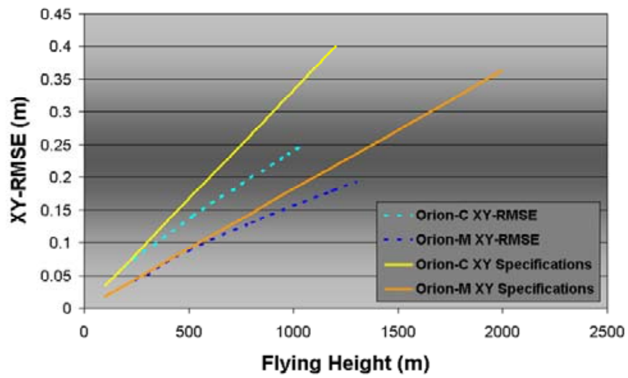


Figure 7. Orion-C and M, XY accuracy trend.

Precise Mapping of Small Objects

The next step in the study on field-qualified evaluation of ALTM Orion performance was to field-test the new systems' ability to detect small objects, and to characterize the quality of data comprising small objects. In particular, the main goal of this case study was to test the Orion's ability to detect power transmission wires, and characterize the quality of the wire data. Power transmission lines are among the most commonly surveyed small objects; therefore, questions about the accuracy of lidar data comprising wires and the ground below them are essential to assess the quality of all data sets, and especially important for further evaluation of the surveyed area.

The wires in the segment of power lines used in this study were positioned in the following configuration: three levels of conductors, and the top-level ground wire. The physical properties of the top wire assembly, typically 3/8" (≈ 9 mm) diameter wire, make it the most difficult wire for an airborne lidar to detect in a transmission line. This is due to *partial signal return* (Figure 8), which is typically several times weaker than that of a full return from the ground beneath the set of wires. It therefore represents a challenge to the lidar receiver electronics to detect without loss or saturation of signal levels from the top wire and ground returns, respectively. The ability to do so effectively, while providing complete eye-safe operation, without sacrificing wire or ground data quality, accuracy and precision is an excellent measure of lidar system performance.

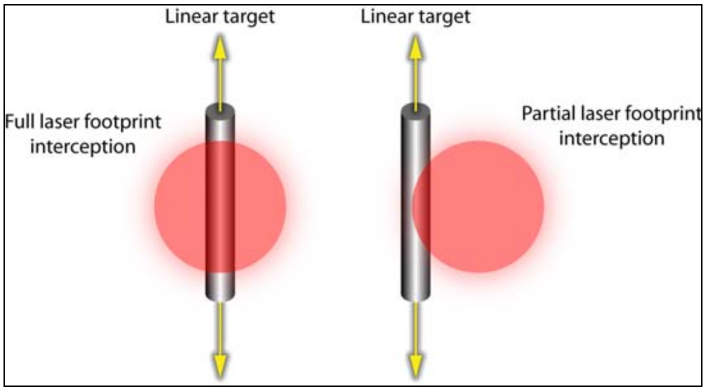


Figure 8. Wire signal return proportional to the area of interception between wire and laser footprint (wire diameter: 9 mm; laser footprint diameter: 10-20 cm depending on AGL).

The conductor wire is typically three times thicker than the top wire (about 27 mm diameter), so one could expect the conductor wire to be detected more easily, and to yield a stronger signal return than the top wire. Therefore, the main focus of this study was in analyzing the top wire data.

A fixed-wing aircraft equipped with the ALTM Orion-C flew over a set of power lines and ground control operating at 200 kHz PRF from an altitude of around 500 m AGL. The wire data was manually selected, then classified into four sub-categories: top-wire and three levels of conductors. What follows is an analysis of the top wire data compared with the ground data.

Summary statistics of the accuracy parameters of the ground data (i.e., RMSE and standard deviation) were calculated and compared with similar statistical parameters for top wire data. The RMSE for ground data was assessed against a control surface using the procedure described above, and is represented in the top portion of Table 2.

Table 2. Comparison of ground data with wire data accuracy characteristics

Ground Data					
ALTM model	Dataset	Laser PRF (kHz)	Altitude (m)	Z-RMSE (cm)	Z-Std Dev (cm)
Orion-C	1	200	500	1.60	1.60
	2	200	505	1.80	1.60
Orion-M	1	200	600	2.00	2.00
	2	200	600	2.10	2.00
Wire Data					
Orion-C	1	200	486	1.86	1.14
	2	200	500	2.21	1.14
	3	200	474	1.78	1.17
Orion-M	1	200	520	3.10	2.20
	2	200	548	3.10	2.30
	3	200	461	2.80	1.90

In order to quantify the quality of transmission and distribution wire detection, a recently developed approach was used to characterize the relative accuracy of lidar data comprising small linear objects (Ussyshkin, 2007). In the case of the transmission line, the conductors always hang in the vertical plane (Piernot and Leahy, 2001), which allows a 3D data set in an XYZ coordinate system to be considered in two 2D projections: XY (horizontal), and XZ (vertical) planes. As a first step, the top wire data set was manually selected, and the mean of easting (X), northing (Y), and elevation (Z) was calculated. Then, the wire data was translated to a new origin to simplify further analysis by working on a relative scale. Figure 9 shows translated and fragmented top wire data in a vertical plane with respect to a best-fit analytical curve (catenary, for power lines), which was used to calculate basic statistical characteristics of the top wire data (i.e., standard deviation and RMSE with respect to the best-fit curve).

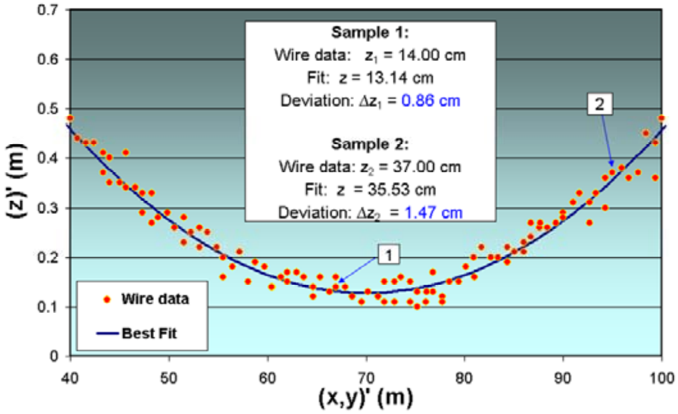


Figure 9. Top-wire data analysis shows sub-cm precision of elevation data comprising 9-mm diameter wire.

Based on this analysis, and taking into account the 9-mm diameter of the top-wire, one can conclude that the distribution of the 3D point cloud data comprising the power transmission wire is in the sub-centimeter range. Such outstanding data quality from the ALTM Orion enables the highest level of precision and accuracy for quality catenary modeling in PLS-CADD, increasing the reliability of engineering calculations of the physical parameters of power lines.

Figure 10 shows the accuracy and precision characteristics of both ground and wire data collected at the same or similar altitude. It is clear that RMSE values derived from wire data by using the procedure described above cannot represent absolute accuracy of wire data, but do represent relative accuracy, in addition to Stdev values. It is also very important to note that the same set of system calibration parameters has been applied to wire and ground data collected by the same system, and no additional data manipulation or adjustment has been applied to either data set. Hence, the importance of this analysis: it shows the consistency in data quality, accuracy and precision, irrespective of variations in lidar signal strength between full and partial signal return represented in the quality of wire and ground data.

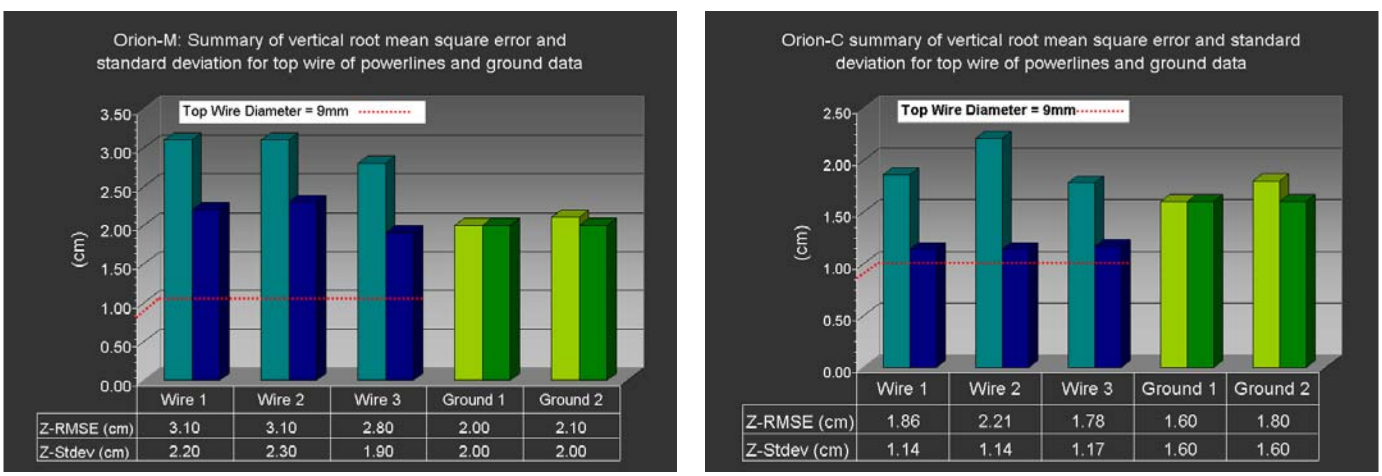


Figure 10. Summary of vertical RMSE and StdDev for top wire and ground data; Orion-M (left), Orion-C (right).

Figure 11 shows the exceptional data quality and the Orion's outstanding ability to resolve and map small objects such as conductor bundles and tower details, as well as to precisely map the ground beneath. Figure 12 demonstrates how the feature of ultra-short single-shot target-separation distance available only in ALTM-Orion systems enables super-precise mapping of low-canopy vegetation without leaving gaps between closely-separated consecutive signal returns.

The advanced high-speed and high-resolution electronics used in the ALTM Orion receiver provides single-shot target separation of less than 1 meter for Orion-M and less than 70 cm for Orion-C. Both systems offer unique built-in complex target detection ability that matches or approximates digitizer resolution without dramatically increasing data volume requirements during data acquisition and processing (Ussyshkin, 2010).

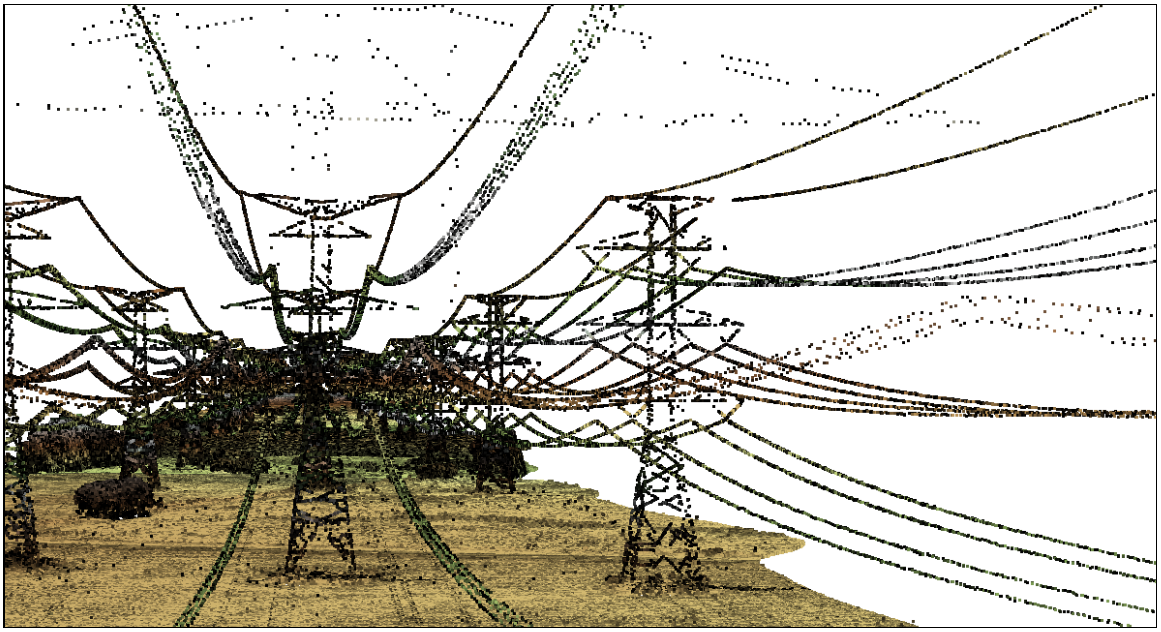


Figure 11. Orion-M data showing small structural elements such as conductor bundles, top wire and tower pillars clearly resolved.

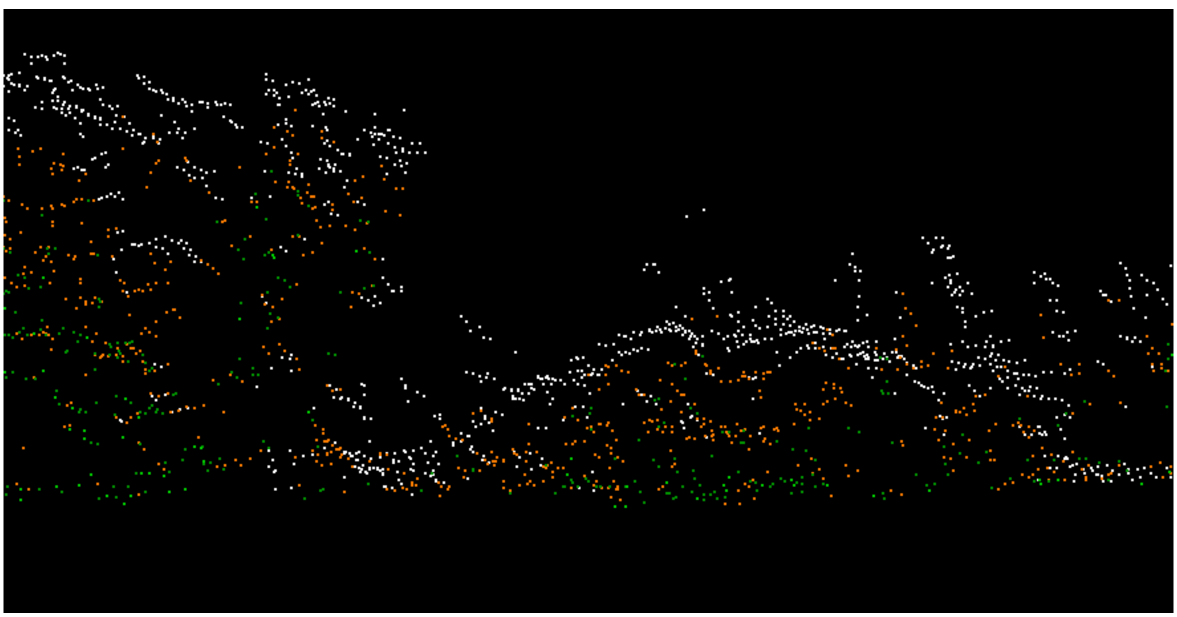


Figure 12. Ultra-short single-shot target distance separation available only in the ALTM-Orion enables super-precise mapping of low-canopy vegetation without leaving gaps between closely-separated consecutive signal returns.

CONCLUSION

Outstanding performance characteristics of the new ALTM models, Orion-M and Orion-C, have been demonstrated. An exceptionally efficient system design provides the best combination of maximizing area coverage rate without compromising ground point density, data collection rate and data quality. Both ALTM Orion models demonstrate exceptional ground data accuracy and precision, which is invariant to operational parameters, and set a new standard in lidar industry. Both ALTM Orion models demonstrate unique performance characteristics, including sub-meter target separation and sub-centimeter precision, which are of particular importance for small and complex target mapping applications such as power line and low-canopy vegetation mapping. The ALTM Orion's unique performance capabilities represent a revolutionary change in system design and achievable data quality in the airborne lidar industry.

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