Airfield Obstruction Survey – Calibration Test Reporting

Date: 12/22/2017 **Product:** AK Proof of Concept - UAS Calibration

Overview:

Under task order G17PD01249: Alaska Critical Infrastructure UAV Airfield Obstruction Survey the Dewberry team was tasked to perform a test of the sensors that would be utilized in the survey of the Kiana and Nulato Airfields. As part of this testing our partners Compass Data and Phoenix LiDAR performed the acquisition and post processing of the LiDAR data using two (2) sensors each flown at two different heights above ground. These parameters were designed in order to determine each of the following items:

- General Ability to meet project specifications – These tests were used to determine if each sensor could meet the general project requirements for data formatting and LAS point cloud data. Items like smooth surface repeatability, relative accuracy, intensity values, and other were tested for each sensor and flying height.
- LiDAR Density – Because we are utilizing a UAS based approach the intent was to determine what sensor and flying height would yield an appropriate density of points to determine the heights of obstructions.
- Geometric Calibration – Tested to determine if each sensor was providing accurate and repeatable measurements from the two different flying heights.
- Radiometric Testing – Tested to determine if each sensor was capable of identifying small or low-reflectance obstructions such as poles or antennas.
- Measurement Consistency – This was tested across each of the 4 flights to determine how consistently the maximum elevation could be determined on the test apparatus as well as on trees and other vertical features in the AOI.

The following report documents the calibration testing performed by the Dewberry team.

Calibration Testing

The Dewberry team collected LiDAR data over the test location in Duarte, CA. This location was selected as it has been used repeatedly by Phoenix LiDAR for testing their sensor and platform configurations. The site is a private recreational airstrip that contains multiple vertical features that were accessible for testing the differences between each of the flights. The two LiDAR sensors that were utilized in the testing are outlined in table 1. Each of these sensors was flown at an altitude of 40 meters above ground level (AGL) and 60 meters AGL. The intent of the different flying heights was to determine the optimal flying height to achieve a density sufficient for identifying vertical obstructions and determining heights of objects.

Table 1: LiDAR Systems		
LiDAR System	Phoenix miniRanger	Phoenix Ranger-LR
Sensor Model	Riegl miniVUX	Riegl VUX-1 LR
LiDAR System Weight (Kg)	2.9/3.5	5.44

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Sensor Weight (Kg)	1.55	3.65
Pulse Rate (KHz)	100	900
FOV °	345	330
Actual Scan Height (m)	40 & 60	40 & 60

All testing was performed on November 3rd, 2017. The acquisition was conducted using DJI M600 Pro platform and a flying speed of 6 meters per second. Table 2 outlines the platform used along with the information related to the IMU and GNSS Antenna.

Table 2: Collection Platform and Equipment	
IMU	STIM300
GNSS Antenna	Novatel 702 GG
Platform	DJI M600 Pro
Flight Speed	6 m/s
Reference Station	CHC X900-r

Acquisition Compliance

Dewberry evaluated each of the four flights to determine how well they complied with the project specifications. Table 3 provides an overview of each of the required acquisition parameters and the compliance from each of the flights. Based on the initial evaluate each of the four sensors would comply with the specific acquisition requirements. However, while each sensor meets the requirements the Phoenix Ranger provides improved detail on the features. Additionally, the miniRanger experienced difficulty in detecting the dark posts on the test platform whereas the sensitivity of the detector on the Ranger was able to be modified to pull some information from those posts. This will be covered in detail in the radiometric testing section of the report.

Table 3 - Acquisition Parameter Compliance

Parameter	Requirement	Phoenix Mini Ranger (40 meters AGL)	Phoenix Mini Ranger (60 meters AGL)	Phoenix Ranger (40 meters AGL)	Phoenix Ranger (60 meters AGL)
Nominal Pulse Spacing	Aggregate Nominal Pulse Spacing (ANPS) shall be no greater than 0.18 meters (30 ppsm); assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.	The Phoenix miniRanger collection at 40 meters resulted in an average density of 62 points per square meter or an ANPS of 0.127 meters.	The Phoenix miniRanger collection at 60 meters resulted in an average density of 41 points per square meter or an ANPS of 0.156 meters.	The Phoenix Ranger collection at 40 meters resulted in an average density of 364 points per square meter or an ANPS of 0.052 meters. This significantly exceeds the requirement.	The Phoenix Ranger collection at 60 meters resulted in an average density of 355 points per square meter or an ANPS of 0.053 meters. This significantly exceeds the requirement.
Signal Returns	The laser system shall be configured to collect multiple echoes per pulse, with a minimum of a	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant

	first return and a last return and at least one additional intermediate return. All returns captured during acquisition shall be delivered. Return number shall be recorded.				
GPS Times	Shall be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each return. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus $1*10^{9}$. See the LAS Specification for more detail	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant
Signal Strength	The signal strength (intensity) of each return pulse shall be recorded.	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant
Spatial Distribution	The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the data set: (a) A regular grid, with cell size equal to the design 2*ANPS will be laid over the data, (b) At least 90% of the cells in the grid shall contain at least 1 lidar point.(c) Clustering will be tested against the 1st return only data of points located in the geometrically usable center part (typically 95%) of each swath.(d) Acceptable data voids identified elsewhere in this task order are excluded.	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant
Foliage Penetration	Foliage penetration should be sufficient to generate an accurate bare earth surface model in order to determine the height of objects.	Foliage penetration appears adequate for determining ground and identifying features under vegetation.	Minimal foliage penetration. Large gaps present in ground under vegetation.	Excellent foliage penetration with objects under foliage present.	Excellent foliage penetration with objects under foliage present.

Data Voids	Data Voids [areas => 4(NPS^2), measured using 1st-returns only] within a single swath are not acceptable, except: (a) where caused by water bodies. (b) Where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing. (c) where appropriately filled-in by another swath	Fully Compliant	Fully Compliant	Fully Compliant	Fully Compliant

Geometric Calibration

Upon completion of the acquisition the LiDAR data from each collection was processed by Phoenix LiDAR in order to export a calibrated dataset. Dewberry performed a detailed evaluation of the calibration and used the checkpoints collected by the team to perform a vertical accuracy assessment of the data. In order to provide an accurate test location the LiDAR data was clipped to the extent of the runway in the test area. All points from the full point cloud were then compared using a 0.25 meter grid where minimum and maximum elevations of the points were compared. Each of the four flights meets the requirements for the geometric calibration with average differences of less than 3 cm on flat surfaces. That Ranger sensor performed better than the mini ranger and had averages closer to 1.25 cm between points while the averages from the mini ranger were closer to 2.5 cm. The miniRanger suffers from more inconsistencies in the 60 meter AGL flight and while the average variance is still under 3 cm there are enough locations that exceed that value that there would be potential concern with conducting the final flights using that flying height. The figures below were colorized to show the differences between the minimum and maximum elevations on the runway.

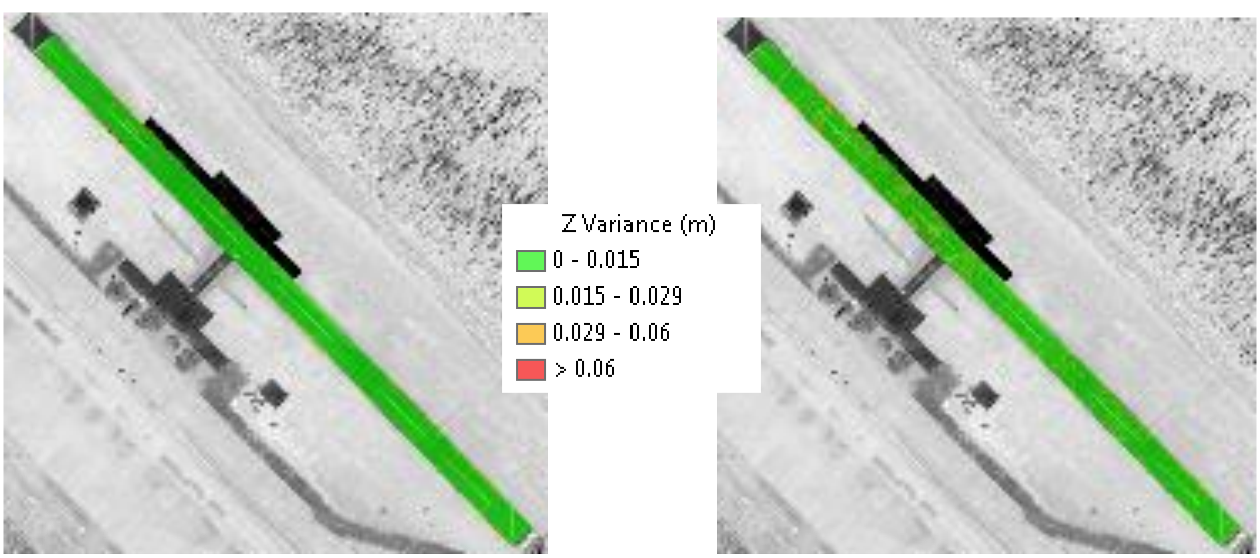


Figure 1: Ranger @ 40 meters AGL

Figure 2: Ranger @ 60 meters AGL

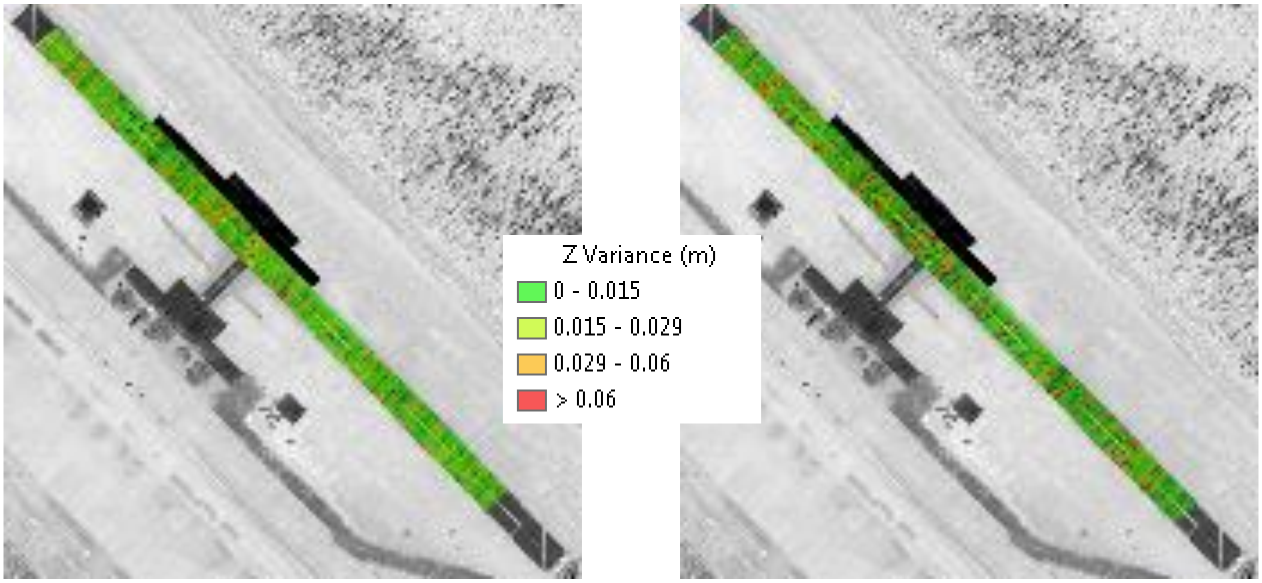


Figure 3: miniRanger @ 40 meters AGL

Figure 4: miniRanger @ 60 meters AGL

As can be seen in the examples the two flights using the Ranger sensor consistently meet or exceed the requirement. The miniRanger also meets the requirement but there are more inconsistencies in the elevation values with the 60 meter AGL flight containing the most significant levels of variation.

The relative accuracy between swaths was also tested to determine if they would meet the requirement of 4 cm RMSD. Each of the four tests meet the accuracy requirements. The Ranger performed better in each case than the miniRanger. Table 4 outlines the relative accuracy between swaths.

Table 4: Relative Accuracy Between Swaths

LiDAR System	Phoenix miniRanger	Phoenix miniRanger	Phoenix Ranger	Phoenix Ranger
Flying Height (m)	40	60	40	60
Flight Lines	7	5	4	5
Average Difference (cm)	2.303	2.903	1.765	2.138
Maximum Difference (cm)	2.91	3.2	2.15	2.53

Finally the absolute accuracy was tested against the checkpoints to ensure that the final calibrated data would meet the non-vegetated vertical accuracy requirement of 5 cm RMSEz. The test was conducted on 72 checkpoints distributed throughout the test area. The final RMSEz values are provided in Table 5. The individual measurements are included in the Ground Control Report also supplied to USGS as a separate document. As shown in the table each of the four test flights meets the absolute accuracy requirement.

Table 5: Relative Accuracy Between Swaths				
LiDAR System	Phoenix miniRanger	Phoenix miniRanger	Phoenix Ranger	Phoenix Ranger
Flying Height (m)	40	60	40	60
Number of Checkpoints	72	72	72	72
RMSEz (cm)	2.3	2.7	1.8	2.8
Maximum Difference (cm)	4.8	10.6	5.9	7.6

Based on the review of the geometric calibration both the Ranger and miniRanger systems are capable of meeting the project requirements. However, the Ranger systems appear to perform with slightly more consistency and repeatability in the measurements than the miniRanger. The absolute accuracy shows a slightly higher value for the Ranger at 60 meters than expected based on the other tests.

Radiometric Testing

One of the critical requirements of the testing was to determine how the sensors performed on targets with high and low reflectivity along with the ability of each of the flight parameters to detect small vertical obstructions. In order to perform this test a radiometric testing apparatus was constructed and placed in the flight area as shown in figure 5. This apparatus consisted of PVC pipes that were 6”, 4” and 2” in diameter. The PVC pipes would alternate between black and white.

Figure 5: Test apparatus placed in the test area.

For the testing Dewberry conducted measurements of heights and widths of each pole in the test apparatus to determine if it was visible and to determine if we could accurately measure the height and width of the target. While only the height is critical the width measurements allow us to determine how well the features are captured in the point cloud and give us a better understanding of the distribution of points on these features.

In order to calculate the maximum height of each pole a small polygon was drawn around each feature and the maximum elevation was extracted from the point cloud. The horizontal measurements were calculated using a 3D view of the points and measuring the distance between the points. The results of this testing is provided in table 6. The initial point cloud for both the Ranger and miniRanger were unable to determine the locations of the black pipes.

In order to identify the low reflectivity targets Phoenix LiDAR was able to change the settings in the post processing of the LiDAR on the Ranger system to allow the point with very low intensity values to be recorded as valid points. This shows that the sensitivity of the detector on the Ranger system is capable of recording these values but they are typically automatically filtered as invalid points because of the low intensity value. The downside to this modification is that there is more noise allowed into the system and the overall relative accuracy is negatively impacted. It should be noted that this was only possible on the Ranger system and the miniRanger did not detect these features. If the Ranger is used for the collection it would be our recommendation to output two sets of data. The primary dataset would utilize the traditional filtering setting so that the point cloud is consistent and meets the relative and absolute accuracy requirements. The second set would only go through initial calibration to ensure the ranging was correct and would be used as an ancillary layer to identify low reflectivity targets. These features could be added to the point cloud and surface model layers but would otherwise would only server to identify additional features that may not be present in the base LiDAR dataset.

As shown in table 6 it was not consistently possible to determine the widths of the pipes using the miniRanger. Points are present on the pipes in the miniRanger collects but the variability in the location of those points made it difficult to determine the width of most of the features. There did appear to be sufficient detail to record a maximum height for each of the highly reflective targets. The miniRanger was not capable of recording elevations for the low reflectivity targets. The Ranger sensor was able to accurately detect all of the highly reflective targets in the initial collection and all of the low reflectivity targets after the post processing of the LiDAR was modified to include low intensity returns as valid points.

Table 6: Radiometric Testing Results

Sensor	Phoenix miniRanger	Phoenix miniRanger	Phoenix Ranger	Phoenix Ranger	Phoenix Ranger - Additional Points	Phoenix Ranger - Additional Points
Flying Height	40	60	40	60	40	60
Max Height (All Pipes)	2.496m	2.482m	2.47m	2.456m	2.507m	2.497m
Width Pipe 1 (0.1524 m)	Not Visible	Not Visible	Not Visible	Not Visible	0.187609	0.182016
Width Pipe 2	0.191604	Not Visible	.158m	.188m	0.178362	0.160897

(0.1524 m)						
Width Pipe 3 (0.1016m)	Not Visible	Not Visible	Not Visible	Not Visible	0.097453	0.99865
Width Pipe 4 (0.1016m)	Not Visible	Not Visible	.09626m	0.128876	0.174132	0.137877
Width Pipe 5 (0.0508m)	Not Visible	Not Visible	Not Visible	Not Visible	0.1167788	0.058181
Width Pipe 6 (0.0508m)	Not Visible	Not Visible	.067602m	0.11729	0.10462	0.059414

The figures below show the profile view (1.5 meter width) of the apparatus visibility for each of the test scenarios.

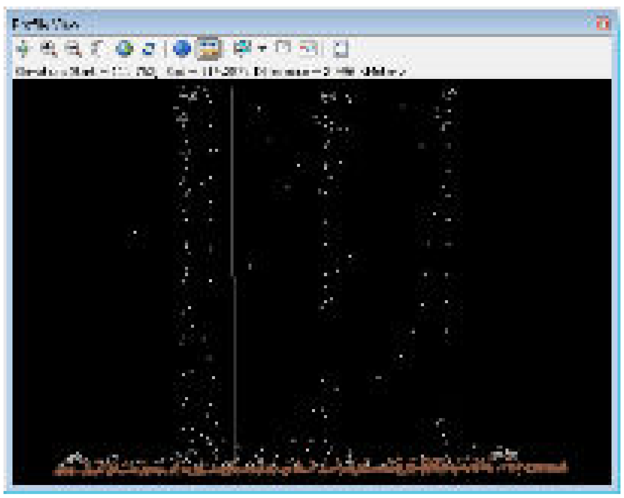


Figure 6: miniRanger @ 40 meters

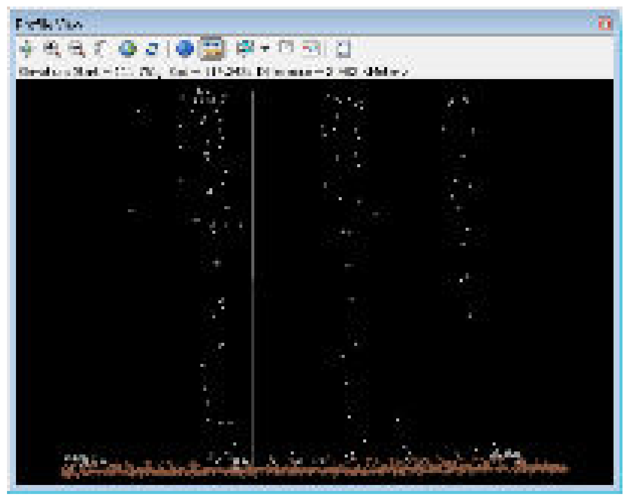


Figure 7: miniRanger @ 60 meters

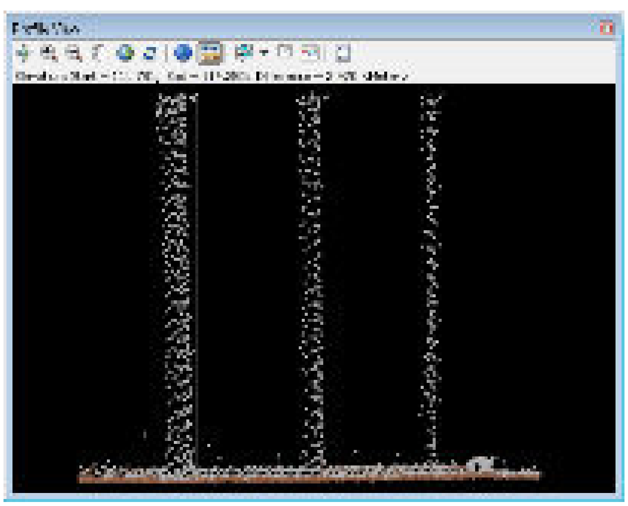


Figure 8: Ranger @ 40 meters

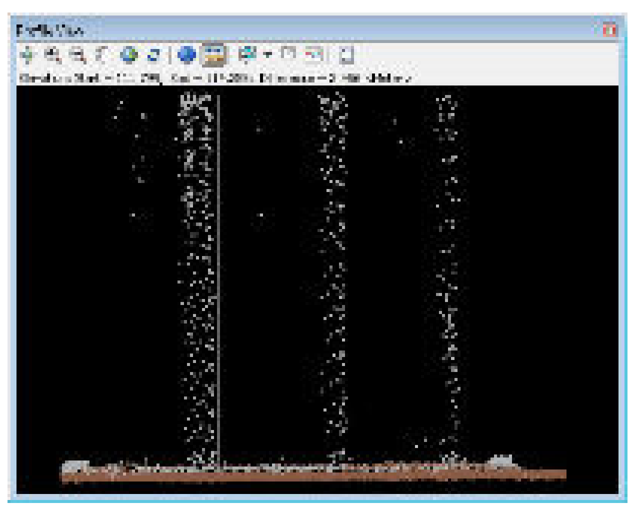


Figure 9: Ranger @ 60 meters

Figures 9 and 10 show the resulting point cloud after the Ranger data was reprocessed for improved low reflectance detectibilty. This shows a considerable improvement in the capability of this sensor for detecting vertical obstructions.

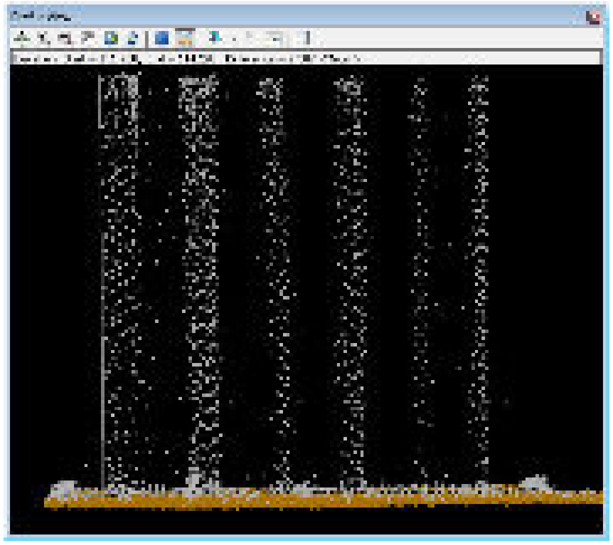


Figure 9: Ranger @ 40 meters

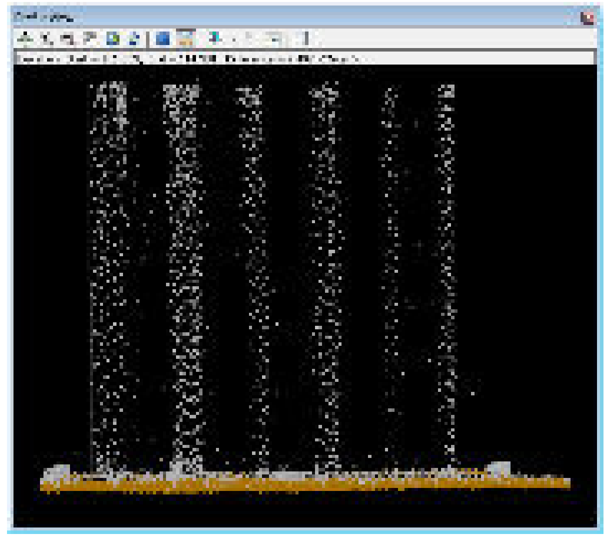


Figure 10: Ranger @ 60 meters

The radiometric testing shows that the miniRanger, while capable of detecting vertical obstructions for most features, is not capable of detecting low visibility targets such as those used in the testing apparatus. The Ranger was capable of detecting these features after changes to the post processing of the data.

Measurement Consistency

As a final test Dewberry extracted the elevations of a number of features in the test AOI. This test was to determine how consistent each of the sensors measured the maximum elevations of the features and to assess how well each sensor collected ground beneath foliage. The foliage penetration is an important factor for generating the height above ground model for vegetation. Enough points must reach the ground surface to provide an accurate representation of the ground.

The first example is a tree located next to a paved surface. In this example only the miniRanger at an altitude of 60 meters struggled to collect the features beneath the canopy. However, it did collect a sufficient number of points to accurately represent the ground. The overall height measurements were consisted to within 19 cm. The variation is likely due to the distribution and density of points on the vegetation which is expected. Table 7 provides an overview of the maximum height measurement for this example.

Figure 11: Test measurement area 1.

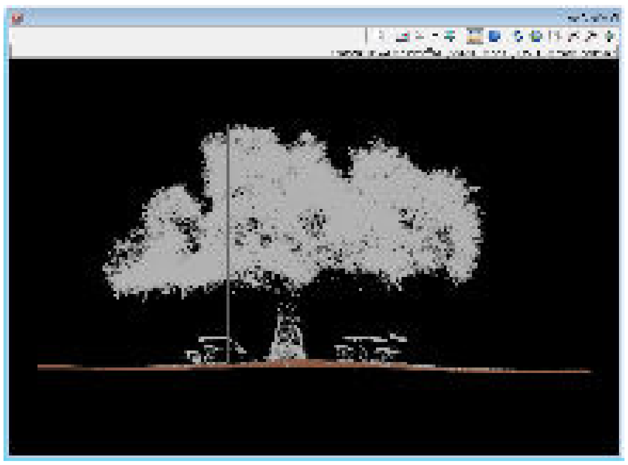


Figure 12: Ranger @ 40 meters

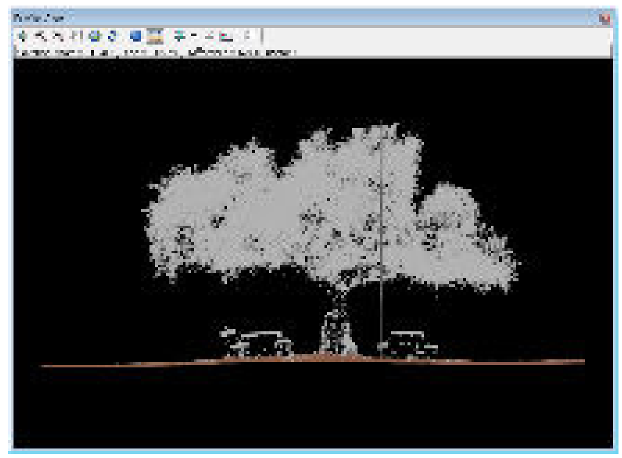


Figure 13: Ranger @ 60 meters

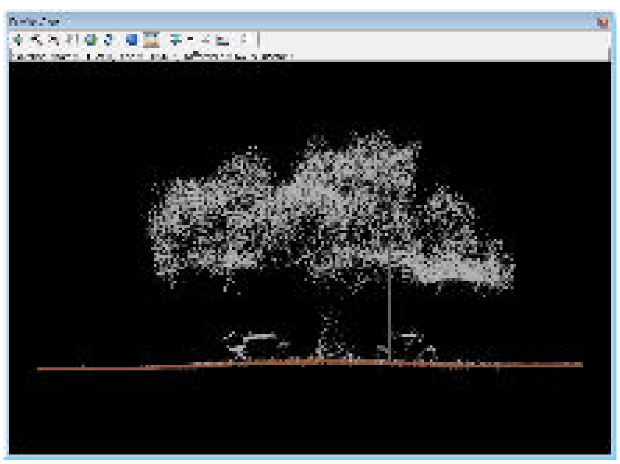


Figure 15: miniRanger @ 40 meters

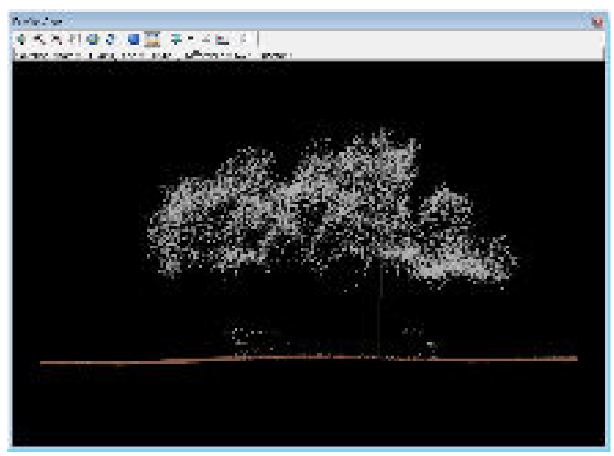


Figure 16: miniRanger @ 60 meters

Table 7: Maximum Height of Tree Example

LiDAR System	Phoenix miniRanger	Phoenix miniRanger	Phoenix Ranger	Phoenix Ranger
Flying Height (m)	40	60	40	60
Maximum Elevation (m)	6.7	6.76	6.77	6.89

The second example for the measurement consistency was taken on a small building in the AOI. The building was located just off the side of the taxiway. The figures below show the cross sections and table 8 shows the maximum height of the feature. The measurements on this feature were consistent to 2.6 cm across the different flights.

Figure 17: Small structure for measurement

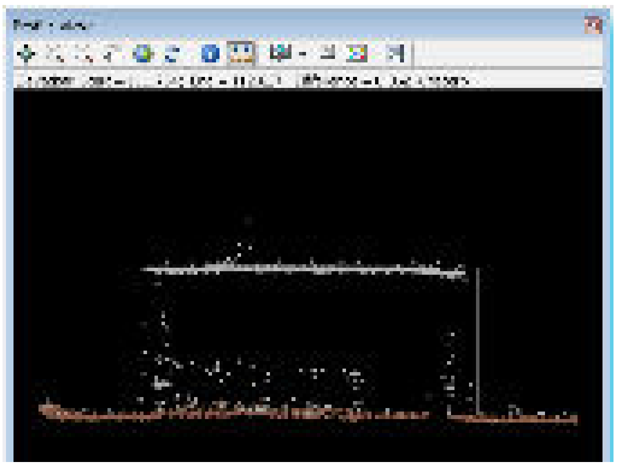


Figure 18: Ranger @ 40 meters

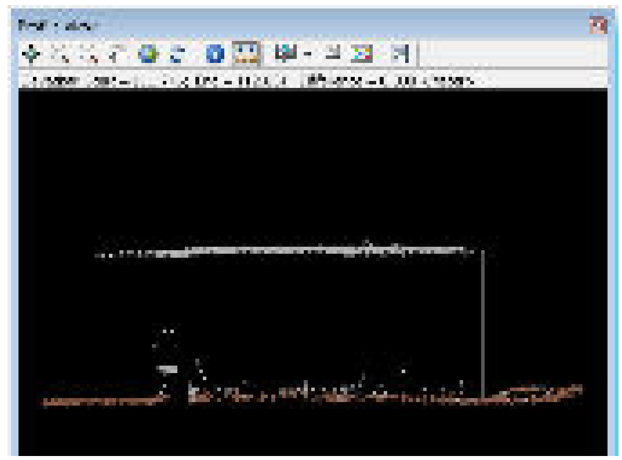
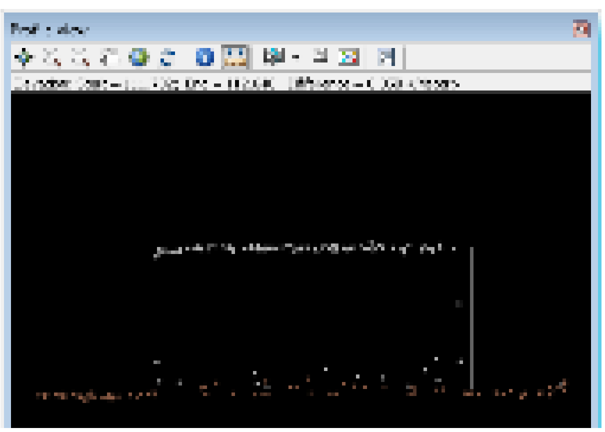


Figure 19: Ranger @ 60 meters



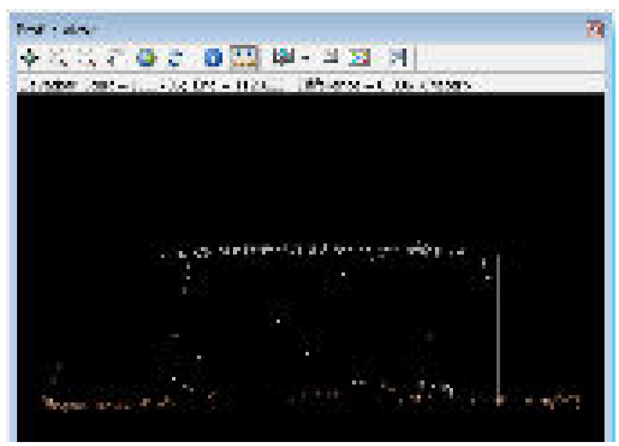


Table 8: Maximum Height of Tree Example

LiDAR System	Phoenix miniRanger	Phoenix miniRanger	Phoenix Ranger	Phoenix Ranger
Flying Height (m)	40	60	40	60
Maximum Elevation (m)	0.858	0.836	0.862	0.888

Based on the consistency of the measurements between each of the flights each of the sensors appears to be capable of collecting accurate height measurements for vertical obstructions and vegetation. This testing also indicates that the improvements to the density using the Ranger sensor may not yield much difference in absolute height measurements as the differences in maximum heights is well within the tolerance for the project. This is also consistent when comparing the values of the testing apparatus where the difference in maximum height between the test flights was 5.1 cm.

Conclusion

Based on the testing conducted by the Dewberry team it appears that any of the four test flights was capable of accurately detecting vertical obstructions in the test area. The accuracy testing for each of the flights also shows that the sensors are capable of meeting the accuracy requirements at either 40 or 60 meters. The primary difference observed is between the Ranger and miniRanger and the ability to detect low reflectivity targets. As this is a requirement of the project the miniRanger would not be capable of collecting these types of features and would therefore not be recommended for use on this project. If low reflectivity targets are not a concern then any of the flights would meet the intent of the project which is to determine vertical obstructions. If low reflectivity targets are of concern in the two airports that will be collected for this project than Dewberry would recommend using the Ranger system and an average flying height of 60 meters. The Ranger system does perform better across all tests and will provide a greater level of detail and confidence in the placement of vertical obstructions as well as more accurate height models because of the foliage penetration.