MINIMUM TECHNICAL STANDARDS, VOL. 2
FINAL REPORT OF LIDAR MAPPING

PROJECT AREA D

STATE OF FLORIDA
DIVISION OF EMEGRENCY MANAGEMENT

TASK ORDER NO. 20070525-492720
CONTRACT NO. 07-HS-34-14-00-22-469

AUGUST 29, 2008

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PREPARED BY:
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LB 0006777

AUGUST 29, 2008

QUALITY

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TRADEMARKS

NOTICE OF PROPRIETARY INFORMATION

MINIMUM TECHNICAL STANDARDS REPORT
REPORT OF TOPOGRAPHIC SURVEY

Task Order No. 20070525-492720
Contract N0. 07-HS-34-14-00-22-469

PROJECT AREA D

For:
State of Florida, Division of Emergency Management
"State Emergency Response Team"
2555 Shumard Oak Boulevard
Tallahassee, Florida 32399-2100

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Florida Professional Surveyor and Mapper PSM 5473

SUMMARY OF CONTENTS

REPORT OF TOPOGRAPHIC SURVEY
AREA D: LIDAR TOPOGRAPHIC MAPPING
FOR THE
FLORIDA DIVISION OF EMERGENCY MANAGEMENT

Purpose

This data set is one component of a digital terrain model (DTM) for the Florida Division of Emergency Management's (FDEM) Project Management and Technical Services for Mapping within Coastal Florida (Contract 07-HS-34-14-00-22-469), encompassing the entire coastline of Florida.

This survey was performed according to Baseline Specifications v 1.2. These specifications were developed by a coalition of GIS practitioners, including the Florida Division of Emergency Management, Florida Water Management Districts, Florida Fish and Wildlife Conservation Commission, Florida Department of Environmental Protection, Army Corp of Engineers Jacksonville District, and other state and federal agencies as the model requirements for orthophotography and LiDAR data collection for publicly funded projects within Florida.

The LiDAR topographic mapping survey is to support the Florida Division of Emergency Management (FDEM) development and maintenance of Regional Evacuation Studies (Study), which include vulnerability assessments and assist disaster response personnel in understanding threats to Florida's citizens and visitors. Additionally-intended uses for this survey are growth management, map modernization/floodplain mapping, natural lands stewardship, and homeland security planning.

Type of Survey

Topographic Survey – Line-Drawn (Vector) Topographic Features by LiDAR and Photogrammetric Methods.

Sensor Description

All data was acquired using Leica ALS50-II LiDAR sensor numbers 19 and 59. The ALS50 has a laser pulse rate of up to 150 kilohertz, records up to 4 returns per pulse, and records return intensities for 3 laser returns per pulse. The Area D LiDAR data was collected at 4,000' above ground level, at an average airspeed of 110 knots.

Dates of Survey

The LiDAR data was acquired July 17-29, 2007. The GPS ground control and QA/QC observations occurred from August 2 through October 31, 2007.

Survey Area

The survey encompassed approximately +/-515 square miles within Manatee, Sarasota, and Charlotte Counties, Florida.

Map Reference

There are no printed maps for this survey. All map data was delivered to the Florida Division of Emergency Management in digital form only.

Name of Responsible Surveyor

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Abbreviations

2D – Two-Dimensional
3D – Three-Dimensional
ABGPS – Airborne GPS
AGL – Above Ground Level
AT – Aerial Triangulation
CI – Confidence Interval
DEM – Digital Elevation Model
DTM – Digital Terrain Model
FDEM – Florida Division or Emergency Management
FGCC – Federal Geodetic Control Committee
GeoTIFF – Georeferenced Tag(ged) Image File Format
GPS – Global Positioning System
GSD – Ground Sample Distance
ID – Identification
IMU – Inertial Measurement Unit
Inc. – Incorporated
IPAS – Inertial Positioning and Attitude System

LiDAR – Light Detection And Ranging
NAD 83-HARN – North American Datum 1983 High Accuracy Reference Network adjustment
NAVD 88 – North American Vertical Datum of 1988
NGS – National Geodetic Survey
NMAS – National Map Accuracy Standards
NOAA – National Oceanic and Atmospheric Administration
NSSDA – National Standards for Spatial Data Accuracy
PSM – Professional Surveyor and Mapper
QA – Quality Assurance
QC – Quality Control
RGB – Red, Green and Blue Bands
RMSE – Root Mean Square Error
RTK – Real Time Kinematic
STD – Standard
TIFF – Tag(ged) Image File Format
TIN – Triangulated Irregular Network
USGS – United States Geological Survey
Vx – Residual Horizontal Error in the X Direction
Vy – Residual Horizontal Error in the Y Direction
Vxy – Residual Horizontal Error in the XY Direction (Resultant)
XYZ – Easting, Northing and elevation grid coordinates (ASCII format)

Definitions

Orthophoto: A digital image (raster) map produced from a series of aerial photographs and/or image strips that have been rectified to correct for aircraft tilt, terrain relief, and camera lens distortion. The resulting image has a consistent scale throughout, allowing the user to take direct measurements such as distances, angles, positions, and areas. The digital raster image is comprised of a digital grid of pixels, or picture elements. Each pixel has a row and column "address" (an X,Y coordinate) and an intensity value ranging from 0 to 255. Each pixel within an RGB image, will have an intensity value for the red, green, and blue bands. Orthophotos may be produced as a natural color image using natural color bands (red, green, blue) or as a false-color infrared image using the red, green, near-infrared bands.

Map Data Accuracy

Horizontal Feature Accuracy: Per contract specifications, the horizontal accuracy requirement is to meet or exceed a 3.8-foot horizontal accuracy at the 95% confidence level using RMSE(r) x 1.7308 as defined by the FGDC Geospatial Positioning Accuracy Standards, Part 3: NSSDA.

Vertical Feature Accuracy: Per contract specifications, the vertical accuracy requirement of the digital terrain model (DTM) is 0.6 foot at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standard for Spatial Data Accuracy (NSSDA).

For the following landcover point classifications,

1. Bare-earth and low grass
2. Brush lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

Vertical accuracy guidelines are as follows from FEMA's Appendix A:

In category 1, the RMSEz must be < .30 ft ($Accuracy_z$ < .60 feet)
In category 2, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 3, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 4, the RMSEz should be < .61 ft ($Accuracy_z$< 1.19 feet)
In all categories combined, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)

Additionally, two-foot contours in unobscured areas are certified to meet or exceed National Map Accuracy Standards (NMAS). These standards state that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval, and none will be in error by more than the full contour interval. Therefore, for a 2-foot contour interval, not more than 10 percent of the elevations tested shall be in error of more than 1 foot, and none will be in error by more that 2 feet. Two-foot contours within low confidence (obscured) areas are attributed as such and are not required to meet NMAS. Additionally, 1-foot contours are delivered for graphical purposes, and are not required to meet these accuracy standards.

The accuracy assessment was performed using a standard method to compute the root mean square error (RMSE) based on a comparison of ground control points and filtered LiDAR data points. Filtered LiDAR data has had vegetation and cultural features removed and by analysis represents bare earth elevations. The RMSE figure was used to compute the vertical National Standard for Spatial Data Accuracy (NSSDA).

The results of Woolpert's accuracy analysis are included in Appendix B, LiDAR Accuracy Checks.

Datums/Coordinate Systems

The LiDAR data and breaklines are in reference to the State Plane Coordinate System, Florida West Zone (0902), in units of US Survey Feet. The horizontal datum is NAD83-HARN, and the vertical datum is NAVD88.

Data Sources

Original Control Point Coordinates:	NGS Information Services NOAA, N/NGS12 National Geodetic Survey SSMC-3, #9202 1315 East-West Highway Silver Spring, Maryland 20910-3282 Phone: (301) 713-3242 Fax: (301) 713-4172 Email: info_center@ngs.noaa.gov http://www.ngs.noaa.gov/

Methodology

A digital terrain model (DTM) was developed from a combination of newly-flown LiDAR point data and existing orthophoto imagery. Stereo imagery was created from the LiDAR surface and

orthophoto imagery using GeoCue software, generating the stereo view from the 3D LiDAR data. Terrain breakline data was photogrammetrically collected to improve the digital elevation model within this stereo view.
Area D encompasses approximately 515 square miles within Manatee, Sarasota, and Charlotte Counties, Florida (see Appendix A: Mapping Area and QC Checkpoint Locations). The LiDAR data was collected at a maximum post spacing of 4 feet in unobscured areas for random point data. The end product complies with the Florida Administrative Code 61G17, Minimum Technical Standards for Surveying and Mapping.

A minimum of one hundred and twenty (120) ground survey quality control (QC) checkpoints are required for per 500 square miles of project area. These were surveyed by Woolpert throughout the project area and were used to confirm the accuracy of the LiDAR data. The accuracy analysis was based on methods outlined in the Geospatial Positioning Accuracy Standards, Part 3: National Standards for Spatial Data Accuracy (NSSDA) developed by the Federal Geodetic Data Committee (FGDC-STD-007.3-1998).

LiDAR Ground Control Survey

The ground control network to support the LiDAR survey was comprised of 21 control points located by rapid static GPS methods to second-order horizontal and third-order vertical accuracies in Area D. For a detailed overview of the ground control survey, refer to Volume 1 of this report.

QA/QC Checkpoint Survey

To support the accuracy analysis of the topographic mapping, Woolpert acquired 147 new field-surveyed QC checkpoints using a combination of rapid static and RTK GPS ground surveys, along with conventional surveying methods to locate points within dense tree cover. Again, a detailed overview of the QA/QC checkpoint survey may be found in Volume 1 of this report.

LiDAR Acquisition and Processing

The LiDAR data was acquired using Leica ALS50-II LiDAR sensors, on July 17-29, 2007. The LiDAR data was collected at a maximum post spacing of 4 feet in unobscured areas for random point data. ABGPS base stations used during acquisition were SRQ ARP, GIS 009, and VENICE CBL 800.

The ABGPS data was reduced using the GrafNav software package by Waypoint Consulting, Incorporated.

The IMU data for Sensor 19 was reduced using the PosProc software package by Applanix Corporation. The IMU data for Sensor 59 was reduced using Leica's IPAS Pro software to process the IMU data, with Leica's IPAS sensor embedded.

The initial LiDAR "point cloud" was derived through the ALS Post Processor software package by Leica Geosystems. The ground base stations were placed at no more than a 20-mile radius from the flight survey area.

Once the initial LiDAR "point cloud" was derived, the data was reviewed to look for any systematic error within the LiDAR flights using proprietary software. After systematic error was identified and removed, above-ground features were classified and removed using proprietary software to produce the bare-earth coverage. The overlap area between flight lines was maintained in order that potentially usable data is available.

LiDAR QC/Photogrammetric Compilation

To collect the breaklines, the LiDAR data was used as the main source data set in addition to orthophotography. Orthophoto imagery was provided by FDEM. All imagery for Area D within Sarasota County is dated 2007 with a 0.5-foot pixel resolution (with the exception of tiles 091015 - 091025, which are dated 2006 and have a 1.0-foot pixel resolution). The remaining imagery for Area D outside of Sarasota County (that is, in Charlotte and Manatee Counties) is dated 2006, with a 1.0-foot pixel resolution.

Stereo imagery was created from the LiDAR surface and orthophoto imagery using GeoCue software. From these stereo images, or LiDARgrammetry, breakline features were collected along linear topographic features as required. Breakline elevations were linearly ramped between identified critical elevation points.

In accordance with the Baseline Specifications v 1.2, the following breakline features were collected:

- Closed water bodies (lakes, reservoirs, etc) as 2-D or 3-D polygons
- Linear hydrographic features (streams, shorelines, canals, swales, embankments, etc) as 3-D breaklines
- Coastal shorelines as 2-D or 3-D linear features
- Edge of pavement road features as 3-D breaklines
- Soft features (ridges, valleys, etc.) as 3-D breaklines
- Low confidence areas as 2-D polygons; island features as 2-D or 2D polygons
- Overpasses and bridges as 3-D breaklines

The Coastal Shoreline breaklines were collected at a fixed elevation of -0.75 feet at the land-water interface. The value of -0.75 feet was the measured average shoreline water elevation for the delivery area. Breakline features were captured to develop a hydrologically correct DTM.

Automated QC processes were run on the breaklines and LiDAR elevation points to check for outlying elevations not probable within the mapping area. Additional visual QC was performed to verify the automated processes.

Breakline features were compiled in the softcopy environment using ImageStation SSK software on Pentium IV, quad processor, 3GHz photogrammetric workstations. Intergraph Corporation of Huntsville, Alabama, distributes the ImageStation SSK software.

The DTM was delivered as LiDAR mass points in LAS version 1.1 and the breaklines were delivered as an ArcGIS geodatabase.

Contours were generated from a 30-foot gridded DEM: 2-foot contours meet NMAS, with 1-foot contours for visualization purposes. The LiDAR masspoints are delivered in the LAS 1.1 file format based on FDEM’s 5,000' by 5,000' grid. Contours were generated using TerraScan software, distributed by TerraScan, Inc., of Lincoln, Nebraska.

The dataset is comprised of an ESRI ArcGIS geodatabase containing the mass points (ground only), 2-D and 3-D breakline features, 1-foot and 2-foot contours, ground control, vertical test points, and a footprint of the data set; and LAS 1.1 binary files of the classified LiDAR points.

The LiDAR point classification codes for LAS 1.1 files are as follows:

- Class 1 = Unclassified
- Class 2 = Ground
- Class 7 = Noise
- Class 9 = Water
- Class 12 = Overlap

Classes 1, 2, 7, and 9 include LiDAR points in the overlap area between flight lines.

Class 1 is used for all features that do not fit into the Classes 2, 7, 9, or 12, including vegetation, buildings, etc.

Class 7 represents artifacts not representing the earth's surface (cell towers, birds, etc.) – Noise as defined above.

Shorelines of water bodies are captured as breaklines and LiDAR points inside of water bodies are classified as Class 9 = Water in the LAS deliverable.

Class 12 LiDAR points are in areas of overlapping flight lines, which have been deliberately deleted and removed from all other classes because of their reduced accuracy, for example, due to their off-nadir position.

Accuracy Checks

The vertical accuracy of the final LiDAR DTM/Mass-Point Data mapping was verified using the field-surveyed QC checkpoints. Results of those field verifications are included in Appendix B.

References

Florida GIS
Baseline Specifications for Orthophotography and LiDAR, v 1.2
http://www.floridadisaster.org/GIS/specifications/Documents/BaselineSpecifications_1.2.pdf

UGSG Internet Site for National Map Accuracy Standards.
http://erg.usgs.gov/isb/pubs/factsheets/fs17199.html#Map%20Accuracy

General Notes

1. **THIS REPORT IS NOT COMPLETE WITHOUT THE PORTABLE HARD DRIVE OF THE DIGITAL MAPPING, AND VICE VERSA.**

2. **INTENDED DISPLAY SCALE – THIS MAPPING IS INTENDED TO BE DISPLAYED AT A SCALE OF 1:1,200 (1"=100') OR SMALLER.**

3. **THIS MAP COMPLIES WITH NATIONAL STANDARDS FOR SPATIAL DATA ACCURACY.**

4. **THIS MAP COMPLIES WITH THE FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA) "GUIDELINES AND SPECIFICATIONS FOR FLOOD HAZARD MAPPING PARTNERS, APPENDIX A: GUIDANCE FOR AERIAL MAPPING AND SURVEYING."**

5. **THIS PHOTOGRAMMETRIC MAPPING DATA AND REPORT IS CERTIFIED AS MEETING OR EXCEEDING, IN QUALITY AND PRECISION, THE STANDARDS APPLICABLE FOR THIS WORK, AS SET FORTH IN CHAPTER 61G17-6, FLORIDA ADMINISTRATIVE CODE.**

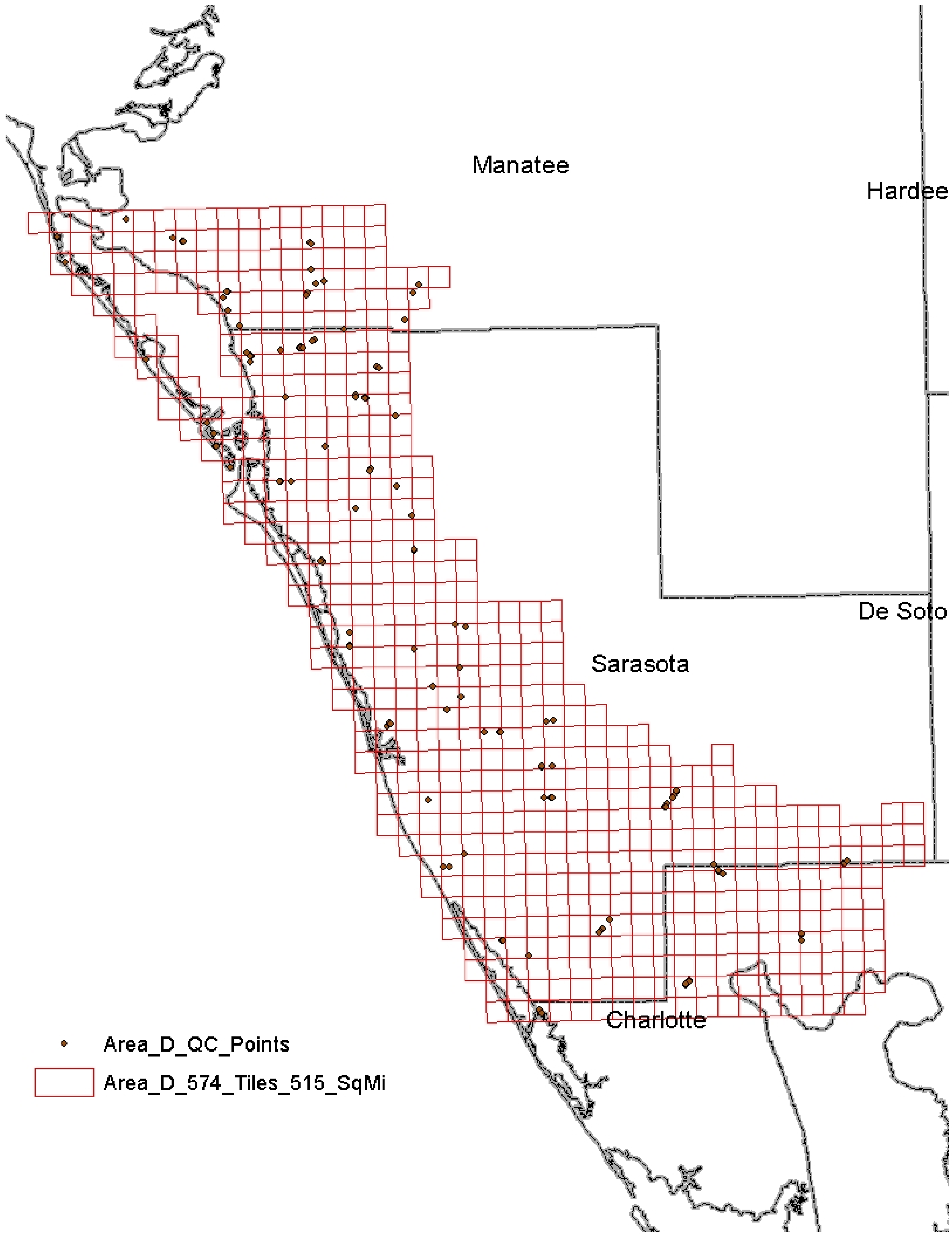
THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA LICENSED SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE.

Surveyor and Mapper in Responsible Charge
Richard R. Hudson, PE, PSM
Professional Surveyor and Mapper
License Number: PSM 5473

Signed: ____ Seal:

Date

APPENDIX A: MAPPING AREA AND QC CHECKPOINT LOCATIONS



APPENDIX B: LIDAR ACCURACY CHECKS

The vertical accuracy of the LiDAR DTM was verified by comparison of the DTM/TIN against the field-surveyed QC checkpoints. The requirements are to acquire a minimum of one-hundred twenty (120) three-dimensional LiDAR QA/QC checkpoints per 500 square miles of project area. To the extent allowed by the terrain, the LiDAR control points and checkpoints are distributed so that points were spaced at intervals of at least 10% of the diagonal distance across the dataset and at least 20% of the points were located in each quadrant of the project area.

For this 515 square-mile area, 124 checkpoints are required – a total of 147 checkpoints were captured across the delivery area. Woolpert field crews observed and established 3-dimensional coordinates on four different types of landcover:

1. Bare-earth and low grass
2. Brush lands and low trees
3. Forested areas fully covered by trees
4. Urban areas

Woolpert acquired the QC checkpoints using a combination of rapid static and RTK GPS ground surveys, along with conventional surveying methods to locate points within dense tree cover. A detailed overview of the QA/QC checkpoint survey may be found in Volume 1 of this report.

The accuracy analysis was based on methods outlined in the Geospatial Positioning Accuracy Standards, Part 3: National Standards for Spatial Data Accuracy (NSSDA) developed by the Federal Geodetic Data Committee (FGDC-STD-007.3-1998). The first step was to generate a TIN from the DTM. Each QC checkpoint was then compared against its corresponding TIN elevation. The difference between field-surveyed QC checkpoint and DTM/TIN elevation represents the residual error (Vz) at that point. A statistical analysis was then performed on the residual errors.

Per contract specifications, the vertical accuracy requirement of the digital terrain model (DTM) is 0.6 foot at 95% confidence level using RMSE(z) x 1.9600 as defined by the National Standard for Spatial Data Accuracy (NSSDA).

Vertical accuracy guidelines are as follows from FEMA's Appendix A:

In category 1, the RMSEz must be < .30 ft ($Accuracy_z$ < .60 feet)
In category 2, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 3, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)
In category 4, the RMSEz should be < .61 ft ($Accuracy_z$< 1.19 feet)
In all categories combined, the RMSEz should be < .61 ft ($Accuracy_z$ < 1.19 feet)

Additionally, two-foot contours in unobscured areas are certified to meet or exceed National Map Accuracy Standards (NMAS). These standards state that not more than 10 percent of the elevations tested shall be in error by more than one-half the contour interval, and none will be in error by more than the full contour interval. Therefore, for a 2-foot contour interval, not more than 10 percent of the elevations tested shall be in error of more than 1 foot, and none will be in error by more that 2 feet. Two-foot contours within low confidence (obscured) areas are attributed as such and are not required to meet NMAS. Additionally, 1-foot contours are delivered for graphical purposes, and are not required to meet these accuracy standards.

The following table summarizes the statistical tests for the four landcover classifications, for the overall accuracy at all checkpoints, and NMAS within unobscured areas:

Statistical Summary By LANDCOVER					
Bare Earth and Low Grass			**Brush Lands and Low Trees**		
Calculated RMSEz	0.25	ft	Calculated RMSEz	0.52	ft
Target RMSEz	0.30	ft	Target RMSEz	0.61	ft
Calculated 95% CI	0.50	ft	Calculated 95% CI	1.02	ft
Target 95% CI	0.60		Target 95% CI	1.19	
Min	0.00	ft	Min	0.01	ft
Max	0.75	ft	Max	2.21	ft
Average	0.20	ft	Average	0.29	ft
Count	35		Count	31	
Forested Areas Fully Covered by Trees			**Urban Areas**		
Calculated RMSEz	0.71	ft	Calculated RMSEz	0.22	ft
Target RMSEz	0.61	ft	Target RMSEz	0.61	ft
Calculated 95% CI	1.39	ft	Calculated 95% CI	0.43	ft
Target 95% CI	1.19		Target 95% CI	1.19	
Min	0.01	ft	Min	0.01	ft
Max	1.63	ft	Max	0.59	ft
Average	0.58	ft	Average	0.17	ft
Count	35		Count	46	
Overall at All Checkpoints			**Unobscured LANDCOVER NMAS**		
Calculated RMSEz	0.46	ft	Calculated 90th Percentile	0.36	ft
Target RMSEz	0.61	ft	Target 90th Percentile	1.0	ft
Calculated 95% CI	0.89	ft	Calculated Max	0.75	ft
Target 95% CI	1.19		Target Max	2.0	ft
Min	0.00	ft	Count	81	ft
Max	2.21	ft			
Average	0.30	ft			
Count	147				

The calculated RMSEz and 95% confidence interval (CI) are shown for each of the four landcover types, and for all landcover types combined. To calculate the correlation to NMAS, only the Bare

Earth and Low Grass, and the Urban Areas landcover types were considered, because these are the only "unobscured" landcover types. To calculate "not more than 10 percent" of the values, the 90th Percentile was determined for the combined Bare Earth and Low Grass, and the Urban Areas landcover measurements.

The Forested Areas Fully Covered by Trees Landcover type does exceed the recommended maximum values for RMSEz and 95% CI by 0.1 foot and 0.2 foot, respectively. This indicates that there is a greater degree of misclassification of LiDAR points within this Landcover type than within the other three Landcover types – which would be expected. The LiDAR DTM does meet the accuracy requirements of the Baseline Specifications (RMSEz *should* be < .61 ft ($Accuracy_z$< 1.19 feet), but it's important that users of the data be aware of the potential accuracy limitations within areas of heavy tree canopy.

The following table lists the test results for all checkpoints:

Accuracy Analysis
Area D
Map Projection: State Plane Coordinate System, Florida West Zone
Horizontal Datum: NAD 83/HARN
Vertical Datum: NAVD 88
Units: U.S. Survey Feet
Date: August, 2008

Image Tile	QC Point	Field Truth (US SV FT)			DTM Measurement (US SV FT)	Residual Error (US SV FT)	LANDCOVER
CELLNUM	ID	Northing	Easting	Elevation	Elevation	Vz	
088902_w	4003D	1015957.29	507929.09	6.68	6.57	-0.112	BARE EARTH AND LOW GRASS
088910_w	4008D-LC	1016349.37	547570.26	13.09	13.36	0.271	BARE EARTH AND LOW GRASS
087706_w	4011D	1039251.04	527182.26	17.66	17.55	-0.115	BARE EARTH AND LOW GRASS
087700_w	4014D	1038266.81	499428.16	15.21	15.48	0.27	BARE EARTH AND LOW GRASS
086499_w	4017D	1055326.58	493351.72	15.70	15.39	-0.305	BARE EARTH AND LOW GRASS
085597_w	4021D	1074630.01	483752.50	25.64	25.91	0.27	BARE EARTH AND LOW GRASS
083496_w	4025D	1105290.29	476506.31	21.47	21.37	-0.103	BARE EARTH AND LOW GRASS
082595_w	4027D	1120066.57	472209.57	11.27	11.11	-0.16	BARE EARTH AND LOW GRASS
081992_w	4030D	1133010.15	459371.47	20.50	20.36	-0.135	BARE EARTH AND LOW GRASS
081987_w	4034D	1133809.27	431942.94	4.49	4.11	-0.38	BARE EARTH AND LOW

							GRASS
085295_w	4038D	1078312.04	471883.37	1.74	1.47	-0.27	BARE EARTH AND LOW GRASS
083791_w	4040D	1104340.09	452525.54	4.52	4.16	-0.353	BARE EARTH AND LOW GRASS
084694_w	4044D	1086318.03	468321.06	1.76	1.60	-0.153	BARE EARTH AND LOW GRASS
082599_w	4046D	1121556.39	493099.79	14.22	14.21	-0.003	BARE EARTH AND LOW GRASS
081999_w	4049D	1131155.05	492064.84	14.01	14.03	0.023	BARE EARTH AND LOW GRASS
082904_w	4054D	1118733.16	516400.53	24.06	24.23	0.166	BARE EARTH AND LOW GRASS
083499_w	4055D	1108230.83	492763.22	32.76	32.59	-0.171	BARE EARTH AND LOW GRASS
083802_w	4059D	1101552.21	507152.60	27.94	27.84	-0.096	BARE EARTH AND LOW GRASS
084401_w	4061D	1094040.59	504472.42	26.38	26.07	-0.308	BARE EARTH AND LOW GRASS
084401_w	4063D	1094266.78	504446.95	26.10	25.85	-0.254	BARE EARTH AND LOW GRASS
085302_w	4064D	1077201.65	505240.65	24.95	24.91	-0.039	BARE EARTH AND LOW GRASS
090104_w	4077D	998085.30	517374.69	13.78	13.78	0.004	BARE EARTH AND LOW GRASS
090706_w	4080D	984994.72	525621.50	14.59	14.58	-0.009	BARE EARTH AND LOW GRASS
099207_w	4083D	964207.85	534086.88	12.38	12.38	0.004	BARE EARTH AND LOW GRASS
093109_w_	4086D	947005.60	543029.39	5.41	5.25	-0.167	BARE EARTH AND LOW GRASS
089509_w	4092D	1005353.92	544423.04	8.38	8.77	0.386	BARE EARTH AND LOW GRASS
091912_w	4093D	966691.03	558083.86	11.85	11.66	-0.188	BARE EARTH AND LOW GRASS
092816_w	4097D	953751.62	578532.48	6.31	7.07	0.753	BARE EARTH AND LOW GRASS
091024_w	4103D	981446.52	616657.48	20.85	20.41	-0.44	BARE EARTH AND LOW GRASS
091017_w	4107D	981275.93	584813.59	9.05	9.35	0.299	BARE EARTH AND LOW GRASS

090115_w	4108D	995946.41	574214.22	17.38	17.74	0.359	BARE EARTH AND LOW GRASS
090116_w	4109D	998911.39	576251.84	17.74	17.69	-0.047	BARE EARTH AND LOW GRASS
090116_w	4110D	998020.11	575851.70	17.95	18.04	0.088	BARE EARTH AND LOW GRASS
084999_w	4703D	1082778.70	494724.08	19.27	19.22	-0.043	BARE EARTH AND LOW GRASS
085903_w	4705D	1065914.82	514882.74	35.90	36.19	0.292	BARE EARTH AND LOW GRASS
089207_w	4005D	1014005.22	534666.21	13.95	14.01	0.061	URBAN AREAS
089207_w	4006D	1013834.85	534913.28	12.76	13.08	0.319	URBAN AREAS
088910_w	4007D	1016075.29	545814.05	15.51	15.64	0.134	URBAN AREAS
088306_w	4010D	1029300.80	525563.62	17.11	17.08	-0.027	URBAN AREAS
087700_w	4015D	1038416.02	499446.20	15.21	14.90	-0.31	URBAN AREAS
085597_w	4020D	1074591.74	483648.68	26.77	26.56	-0.213	URBAN AREAS
084398_w	4024D	1094755.65	485296.54	28.21	28.05	-0.158	URBAN AREAS
083496_w	4026D	1105349.47	476470.15	21.43	21.40	-0.031	URBAN AREAS
082595_w	4028D	1120075.87	472138.42	11.71	11.86	0.151	URBAN AREAS
081993_w	4035D	1132240.07	461871.04	23.98	23.39	-0.59	URBAN AREAS
084994_w	4036D	1083259.21	468691.87	4.16	4.14	-0.021	URBAN AREAS
082287_w	4041D	1127932.19	433654.26	3.57	3.32	-0.249	URBAN AREAS
084694_w	4042D	1088877.04	466495.99	5.80	5.68	-0.122	URBAN AREAS
082600_w	4047D	1122077.30	495093.42	17.16	17.18	0.02	URBAN AREAS
081999_w	4051D	1130951.04	492431.56	15.87	15.63	-0.241	URBAN AREAS
082604_w	4053D	1120638.63	517769.82	23.11	23.04	-0.065	URBAN AREAS
083499_w	4057D	1107892.94	492158.93	34.59	34.37	-0.222	URBAN AREAS
083802_w	4058D	1101153.21	507684.26	28.70	28.55	-0.154	URBAN AREAS
084401_w	4060D	1094290.53	502022.23	23.92	24.01	0.092	URBAN AREAS
086504_w	4067D	1057713.79	515203.22	21.83	22.02	0.188	URBAN AREAS
088905_w	4070D	1019523.64	522291.60	37.01	36.96	-0.057	URBAN AREAS
088003_w	4072D	1034111.23	514596.95	18.59	18.69	0.1	URBAN AREAS
090104_w	4076D	998116.76	517273.84	15.89	15.63	-0.26	URBAN AREAS

091005_w	4079D	982160.64	521970.97	12.26	11.81	-0.449	URBAN AREAS
092207_w	4082D	964224.45	534366.17	13.35	13.17	-0.181	URBAN AREAS
093109_w_	4085D	946982.62	543102.40	5.94	5.83	-0.113	URBAN AREAS
089509_w	4091D	1005506.53	544343.63	8.66	8.92	0.259	URBAN AREAS
091912_w	4095D	966173.87	557511.71	12.69	12.40	-0.294	URBAN AREAS
092816_w	4096D	953727.85	578539.93	7.46	7.25	-0.213	URBAN AREAS
092222_w	4099D	962728.70	605334.52	7.64	8.23	0.593	URBAN AREAS
091024_w	4102D	981491.82	616615.35	17.61	17.28	-0.332	URBAN AREAS
091318_w	4105D	979064.26	587032.44	9.80	9.82	0.024	URBAN AREAS
090116_w	4112D	997390.46	575643.40	17.02	16.85	-0.174	URBAN AREAS
090109_w	4164D	998044.80	544762.97	10.44	10.68	0.24	URBAN AREAS
084398_w	4197D	1094765.66	485386.32	29.17	29.02	-0.152	URBAN AREAS
092816_w	4198D	952939.58	577520.04	8.85	8.87	0.013	URBAN AREAS
092209_w	4500D-LC	960584.58	540306.37	14.66	14.48	-0.187	URBAN AREAS
091912_w	4501D-LC	965889.29	557323.29	12.39	12.47	0.079	URBAN AREAS
083796_w	4507D-LC	1103170.12	477161.28	20.55	20.47	-0.087	URBAN AREAS
083796_w	4509D	1104671.77	477246.63	17.18	17.54	0.359	URBAN AREAS
083498_w	4510D	1106296.82	489855.16	37.64	37.61	-0.028	URBAN AREAS
088606_w	4701D	1022421.07	525634.53	15.03	15.20	0.169	URBAN AREAS
083195_w	4702D	1111800.41	474814.27	20.68	20.70	0.018	URBAN AREAS
085901_w	4704D	1067870.67	501595.63	28.23	28.29	0.058	URBAN AREAS
085603_w	4706D	1072902.62	511278.93	26.33	26.29	-0.04	URBAN AREAS
084703_w	4707D	1089490.34	511601.96	22.79	22.66	-0.138	URBAN AREAS
088902_w	4001D	1016293.16	508440.52	8.32	8.50	0.184	BRUSH LANDS AND LOW TREES
089207_w	4004D	1014026.60	534660.78	12.09	12.47	0.376	BRUSH LANDS AND LOW TREES
087705_w	4012D	1039756.79	524488.21	19.31	19.14	-0.169	BRUSH LANDS AND LOW TREES
087700_w	4013D	1038350.92	499398.48	14.69	14.76	0.072	BRUSH LANDS AND LOW TREES
086499_w	4016D	1055257.52	493334.95	15.89	15.99	0.105	BRUSH LANDS AND LOW TREES

085597_w	4019D	1074631.11	483623.48	27.74	27.64	-0.097	BRUSH LANDS AND LOW TREES
084398_w	4023D	1094736.35	485402.38	28.93	28.98	0.052	BRUSH LANDS AND LOW TREES
082895_w	4029D	1118601.02	471089.44	21.95	21.91	-0.04	BRUSH LANDS AND LOW TREES
081690_w	4032D	1137784.17	448303.60	12.51	12.55	0.042	BRUSH LANDS AND LOW TREES
081987_w	4033D	1133837.48	431983.75	3.70	3.67	-0.03	BRUSH LANDS AND LOW TREES
082895_w	4037D	1115627.16	472263.31	24.59	24.86	0.267	BRUSH LANDS AND LOW TREES
084994_w	4039D	1083394.59	468466.46	4.86	4.89	0.032	BRUSH LANDS AND LOW TREES
081993_w	4043D	1132217.49	461774.17	25.60	25.28	-0.323	BRUSH LANDS AND LOW TREES
083497_w	4045D	1105742.91	484519.62	23.53	23.53	-0.007	BRUSH LANDS AND LOW TREES
082599_w	4048D	1124824.45	492290.69	18.35	18.44	0.089	BRUSH LANDS AND LOW TREES
081999_w	4050D	1131152.28	491988.55	14.30	14.53	0.232	BRUSH LANDS AND LOW TREES
083203_w	4052D	1112434.85	514216.61	23.29	23.47	0.186	BRUSH LANDS AND LOW TREES
083200_w	4056D	1110517.84	499761.47	27.72	29.92	2.208	BRUSH LANDS AND LOW TREES
084401_w	4062D	1094927.80	502036.19	21.10	21.44	0.334	BRUSH LANDS AND LOW TREES
086504_w	4069D	1057525.29	515253.70	20.29	20.48	0.192	BRUSH LANDS AND LOW TREES
088304_w	4071D	1025062.71	518962.28	12.46	12.90	0.439	BRUSH LANDS AND LOW TREES
090104_w	4075D	998197.80	517160.60	15.15	15.20	0.046	BRUSH LANDS AND LOW TREES
091005_w	4078D	982181.64	520682.33	4.66	4.53	-0.127	BRUSH LANDS AND LOW TREES
092207_w	4081D	964189.83	534351.01	12.98	12.81	-0.166	BRUSH LANDS AND LOW TREES
093109_w_	4084D	947578.22	542678.90	5.60	5.52	-0.08	BRUSH LANDS AND LOW TREES
091912_w	4094D	968873.35	559888.56	10.28	9.94	-0.343	BRUSH

							LANDS AND LOW TREES
092816_W	4098D	953697.94	578534.27	5.44	6.63	1.193	BRUSH LANDS AND LOW TREES
092222_w	4101D	962805.31	605318.07	6.74	6.73	-0.01	BRUSH LANDS AND LOW TREES
091024_w	4104D	981535.10	616741.91	16.62	17.19	0.569	BRUSH LANDS AND LOW TREES
091318_w	4106D	979101.89	587063.65	10.12	11.00	0.88	BRUSH LANDS AND LOW TREES
090116_w	4111D	998973.10	576368.46	19.11	19.29	0.182	BRUSH LANDS AND LOW TREES
088910_w	4009D	1016298.88	547482.03	11.79	13.00	1.206	FORESTED AREAS FULLY COVERED BY TREES
086499_w	4115D	1055780.77	493124.93	15.42	15.52	0.098	FORESTED AREAS FULLY COVERED BY TREES
086499_w	4116D	1055589.25	492997.12	15.11	16.11	1.005	FORESTED AREAS FULLY COVERED BY TREES
085598_w	4120D	1074481.24	486281.00	14.13	14.53	0.4	FORESTED AREAS FULLY COVERED BY TREES
085301_w	4123D	1076753.45	504960.19	27.02	28.39	1.372	FORESTED AREAS FULLY COVERED BY TREES
084401_w	4126D	1093890.86	504204.66	26.13	24.87	-1.262	FORESTED AREAS FULLY COVERED BY TREES
083498_w	4130D	1106329.81	489576.82	37.50	36.96	-0.542	FORESTED AREAS FULLY COVERED BY TREES
083498_w	4131D	1106466.87	489393.55	37.29	37.18	-0.11	FORESTED AREAS FULLY COVERED BY TREES
083498_w	4132D	1106338.73	489083.94	38.19	38.13	-0.051	FORESTED AREAS FULLY COVERED BY TREES
083498_w	4133D	1106175.41	489314.14	37.83	37.90	0.0688	FORESTED AREAS FULLY COVERED BY TREES
082899_w	4136D	1119198.31	491217.01	18.69	19.15	0.459	FORESTED AREAS FULLY COVERED BY TREES

082899_w	4137D	1118872.41	490961.80	17.39	18.04	0.648	FORESTED AREAS FULLY COVERED BY TREES
083796_w	4142D	1104931.52	477364.69	17.11	18.08	0.966	FORESTED AREAS FULLY COVERED BY TREES
083796_w	4143D	1104680.91	477462.45	15.76	16.43	0.671	FORESTED AREAS FULLY COVERED BY TREES
089207_w	4150D	1013933.32	531078.08	12.53	12.72	0.186	FORESTED AREAS FULLY COVERED BY TREES
089207_w	4151D	1014103.24	530991.44	11.85	12.10	0.258	FORESTED AREAS FULLY COVERED BY TREES
088902_w	4154D	1016686.48	508460.35	10.98	11.21	0.223	FORESTED AREAS FULLY COVERED BY TREES
088902_w	4155D	1016311.96	508867.81	10.36	10.94	0.583	FORESTED AREAS FULLY COVERED BY TREES
087700_w	4158D	1035275.21	499352.91	15.65	16.33	0.675	FORESTED AREAS FULLY COVERED BY TREES
087700_w	4159D	1035029.25	499559.71	12.95	14.58	1.631	FORESTED AREAS FULLY COVERED BY TREES
089510_w	4162D	1005521.82	547029.46	4.73	4.74	0.008	FORESTED AREAS FULLY COVERED BY TREES
089510_w	4163D	1005428.56	546910.84	3.88	4.65	0.767	FORESTED AREAS FULLY COVERED BY TREES
090110_w	4167D	998022.82	546582.13	6.87	7.02	0.15	FORESTED AREAS FULLY COVERED BY TREES
090110_w	4168D	998032.94	546951.56	6.46	6.93	0.477	FORESTED AREAS FULLY COVERED BY TREES
090115_w	4172D	995145.09	573565.17	13.23	14.09	0.863	FORESTED AREAS FULLY COVERED BY TREES
090115_w	4173D	995196.57	573793.93	13.90	14.46	0.552	FORESTED AREAS FULLY COVERED BY TREES
091318_w	4176D	979496.54	586017.31	9.01	9.68	0.674	FORESTED

							AREAS FULLY COVERED BY TREES
091318_w	4177D	979640.14	585861.74	8.87	9.86	0.987	FORESTED AREAS FULLY COVERED BY TREES
091318_w	4178D	979811.70	586020.88	8.47	9.09	0.611	FORESTED AREAS FULLY COVERED BY TREES
091024_w	4182D	981036.62	615955.65	16.07	16.64	0.566	FORESTED AREAS FULLY COVERED BY TREES
091024_w	4183D	980807.22	616009.45	16.72	16.78	0.059	FORESTED AREAS FULLY COVERED BY TREES
092222_w	4187D	964296.44	605428.40	8.81	9.26	0.449	FORESTED AREAS FULLY COVERED BY TREES
092222_w	4188D	964470.60	605305.32	7.75	7.94	0.192	FORESTED AREAS FULLY COVERED BY TREES
092816_w	4191D	953138.66	577477.71	8.39	8.92	0.531	FORESTED AREAS FULLY COVERED BY TREES
092816_w	4192D	952907.03	577483.88	10.65	11.68	1.027	FORESTED AREAS FULLY COVERED BY TREES

APPENDIX C: LAS FILES DELIVERED

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APPENDIX D: LIDAR CALIBRATION

Photo Science ALS50 LiDAR Calibrations

Introduction

Woolpert Team member Photo Science, Inc., performed all LiDAR acquisition and post processing. The following is the LiDAR system calibration report from Photo Science.

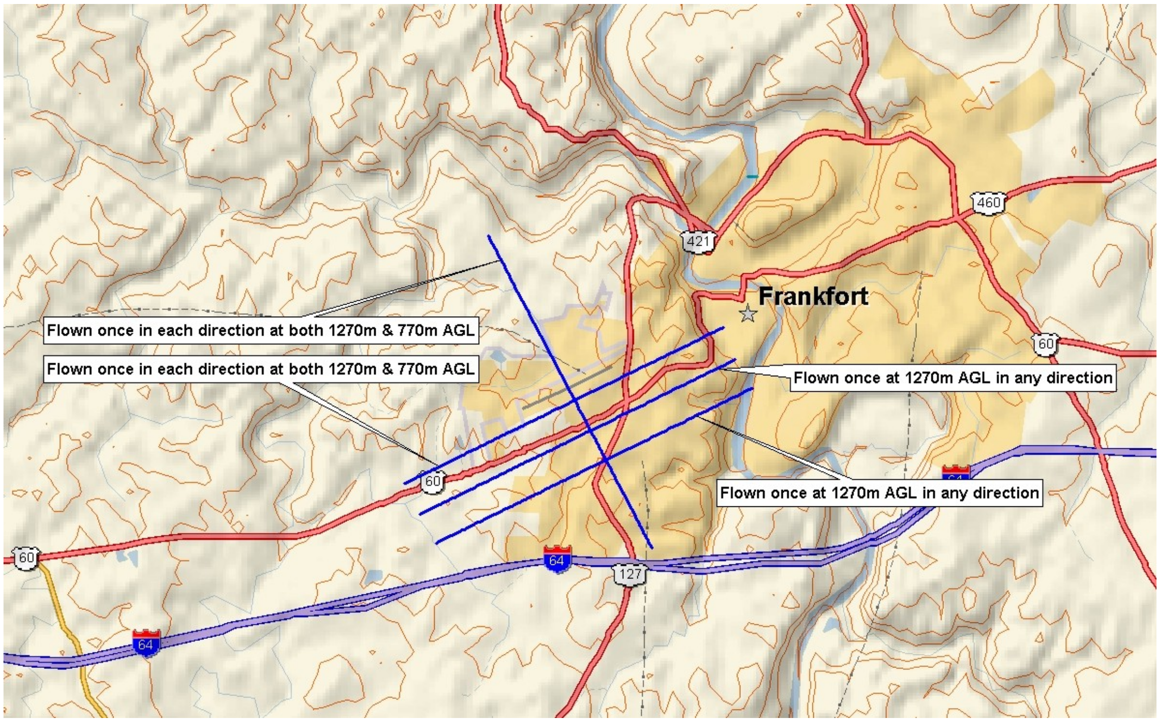
Overview

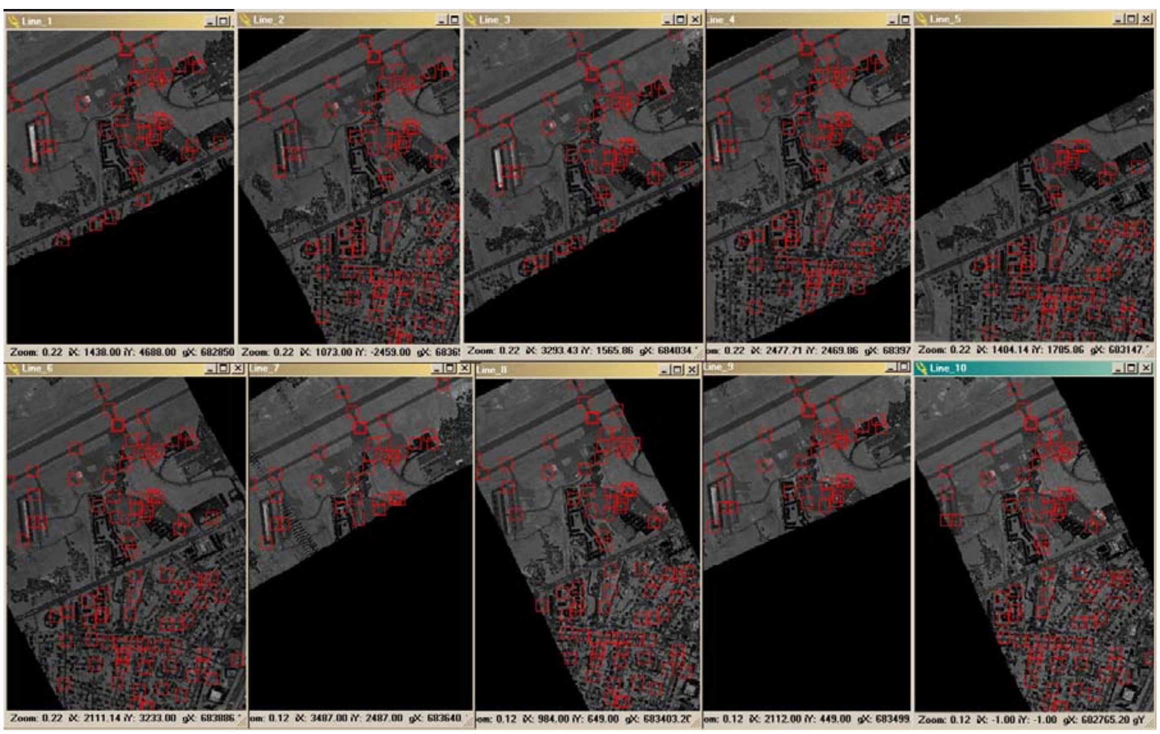
This Calibration Report shall be used to confirm LiDAR system specifications, performance, and requirements. The system functionality, elevation, and horizontal accuracy performance shall be demonstrated for calibration purposes. Photo Science completes calibration flights at regular intervals for ongoing monitoring of correction values, both at our home airport as well as in the field.

Once computed, the various derived values for correcting the inherent errors in the system should remain fairly constant, monitoring to ensure that no value starts to change more than expected. The sensors come from the factory with a set of values provided, measured by Leica, many of which will not change over the life of the system. Even moving a sensor in to and out of an aircraft should not appreciably change the correction values unless it experiences a hard bump or other trauma; the calibrated values are internal to the sensor.

Our main source of calibration data is collected in the form of Leica's prescribed Attune method. This involves collecting opposing passes at right angles to one another at 1270m above ground, and again at 770m above ground, centered over the same ground features, and using their proprietary calibration software for picking common tiepoints to determine roll, pitch, and heading correction values. They normally require 4 total passes at a minimum (2 high, 2 low) and have strong suggestions about types of features to use as tie-points.

We have slightly modified Leica's Attune flight procedure, with their guidance, wherein we fly 10 passes (4 high crisscross, 2 high offset, and 4 low crisscross) as seen below. This terrain includes not only the flat pavement of the airport and its surroundings, but a large amount of residential and commercial features in a gently rolling setting.





Periodically, roughly twice a year, we collect calibration data at 11000 feet above our home airport and have it analyzed by Leica with their higher-level calibration regimen. The increased flying height exaggerates the internal misalignments and makes them easier to measure, serving as tighter comparison benchmarks for the previous and subsequent Attune flights.

For this entire project we used the following sensors and aircraft:
Leica ALS50 Phase II Capable: serial number 019, mounted in N7320G
Leica ALS50 Phase II : serial number 059, mounted in N9471R and N2448G
Leica ALS50 Phase II : serial number 062, mounted in N2448G

Antenna Offsets

We mount our LiDAR systems exclusively in our fleet of Cessna 206 aircraft, removing them as little as possible to help maintain consistent system integrity. As such, our GPS antennas and the mounting plates for the sensor heads remain constant per plane. Once a new plane or sensor is incorporated in to our fleet and the initial sensor installation is completed, we have our ground survey team derive the offsets with a total station. That antenna offset value will not change unless the placement of a sensor's head within the aircraft changes.

N7320G, 1977 Cessna 206
X = -0.07
Y = 0.05
Z = -1.10

N9471R, 1985 Cessna 206
X = 0.875
Y = -0.125
Z = 1.012

N2448G, 2001 Cessna 206
X = -0.018
Y = -0.169
Z = -1.057

Leica provides their precisely measured internal IMU offsets, with respect to the focal point of the system's mirror, per each of the 2 types of IMU they use. These are embedded into the sensors' firmware for carrying forward into the subsequent trajectory-generating software, so these are not measured by us.

GPS Base Stationing

Whether calibration flights occur at our home airport (FFT – Capital City Airport in Frankfort, KY) or in the field on a project site, we strive to set up our GPS base station over the Primary Airport Control Station (PACS) as indicated by the National Geodetic Survey. If this is not possible, or the flight is only for purposes of resolving roll, pitch, and heading corrections, we can use almost any point because the software is solving the corrections for these parameters within the flight's data, not with respect to absolute positions on the ground.

Photo Science uses Trimble 5700 GPS data logging units paired with Trimble Zephyr Geodetic antennas. We log at a 2hz interval (every ½ second) and with a 5 degree elevation mask. We also use variable height tripods, measured and logged at the beginning and end of each session.

Ground Control Points / Vertical Bias

Due to electronic delay within the sensor, there is a constant element of vertical bias which must be corrected. We have surveyed many points along the length and width of the runway and taxiways of our home airport and reference this in to our calibration flights to monitor over time that the pertinent correction value is unchanging. In the case of an upgrade or repair to certain parts of the sensor, we recalculate this value.

Overall Calibration Results

The values below are a combination of constants provided by the manufacturer and variables derived from analysis of data collected over Photo Science's calibration site(s). These were the used throughout the Florida Gulf Coast 2007 project, with minor variations per individual aircraft sortie as needed.

June 23rd, 2007

	Parameter	Value
SN19	**Leica provided**	
	Encoder Latency	0.0 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	-0.48m
	Scan Angle Correction	-19120 ticks
	Pitch Slope	0.0000185 rad/deg
	Attitude	
	Roll	0.00088397 rad
	Pitch	0.00966448 rad
	Heading	-0.00282358 rad
	Mechanical	
	Torsion	-19370 units

June 14th, 2007

SN59	Parameter	Value
	Leica provided	
	Encoder Latency	0.5 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	1.258m
	Scan Angle Correction	8000 ticks
	Pitch Slope	0.000058 rad/deg
	Attitude	
	Roll	0.00170705 rad
	Pitch	0.01463471 rad
	Heading	-0.00165231 rad
	Mechanical	
	Torsion	-60000 units

Provided by Leica – their 'loaner' unit

SN62	Parameter	Value
	Leica provided	
	Encoder Latency	0.0 mcr sec
	Ticks Per Revolution	8388608 ticks
	Ranging Correction	2.425m
	Scan Angle Correction	23800 ticks
	Pitch Slope	0.00000011 rad/deg
	Attitude	
	Roll	0.004918 rad
	Pitch	0.00956337 rad
	Heading	0.0000545 rad
	Mechanical	
	Torsion	-35000 units