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

SARASOTA COUNTY
BUY-UP AREA

STATE OF FLORIDA
DIVISION OF EMERGENCY MANAGEMENT

CONTRACT NO. 07-HS-34-14-00-22-469
PURCHASE ORDER P737935

SEPTEMBER 16, 2008

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PREPARED BY:
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SEPTEMBER 16, 2008

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MINIMUM TECHNICAL STANDARDS REPORT
REPORT OF TOPOGRAPHIC SURVEY

Contract No. 07-HS-34-14-00-22-469
Purchase Order P737935

SARASOTA COUNTY BUY-UP AREA

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

Sarasota County, Florida
1660 Ringling Boulevard
Sarasota, Florida 34236

By:
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Richard R. Hudson, PE, PSM
Florida Professional Surveyor and Mapper PSM 5473

SUMMARY OF CONTENTS

REPORT OF TOPOGRAPHIC SURVEY SARASOTA COUNTY BUY-UP AREA: 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 contracted by Sarasota County as a Buy-up to the FDEM Contract.

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 number 19. 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 Sarasota County Buy-up Area 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 August 28-30, 2007. The GPS ground control and QA/QC observations occurred from November 6-8, 2007.

Survey Area

The survey encompassed approximately 272 square miles within Sarasota County, 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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Florida Certificate of Authorization No. LB-0006777

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
LAS – LASer File Format Exchange

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/QC – Quality Assurance/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.

Sarasota County Buy-up Area encompasses approximately 272 square miles within Sarasota County, 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 13 control points located by rapid static GPS methods to second-order horizontal and third-order vertical accuracies in Sarasota County Buy-up Area. 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 69 new field-surveyed QC checkpoints using rapid static 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 a Leica ALS50-II LiDAR sensor, August 28-30, 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, PID AG5053 at the Sarasota Bradenton Airport (SRQ), VENIPORT AZ MK, PID AG9387 at Venice Airport (VNC), ARCPORT, and PID AF7410 at Arcadia Airport (X06).

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 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 the Sarasota County Buy-up Area is dated 2007 with a 0.5-foot pixel resolution (with the exception of tiles 87116, 87117, 87118, 87119, 87120, 87121, which are dated 2006 and have 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
- 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

Note: As there is no coastline within the Sarasota County Buy-up Area, no Coastal Shorelines breaklines were collected.

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. A list of the 303 LAS files delivered for Sarasota County Buy-up Area may be found in Appendix C.

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.**

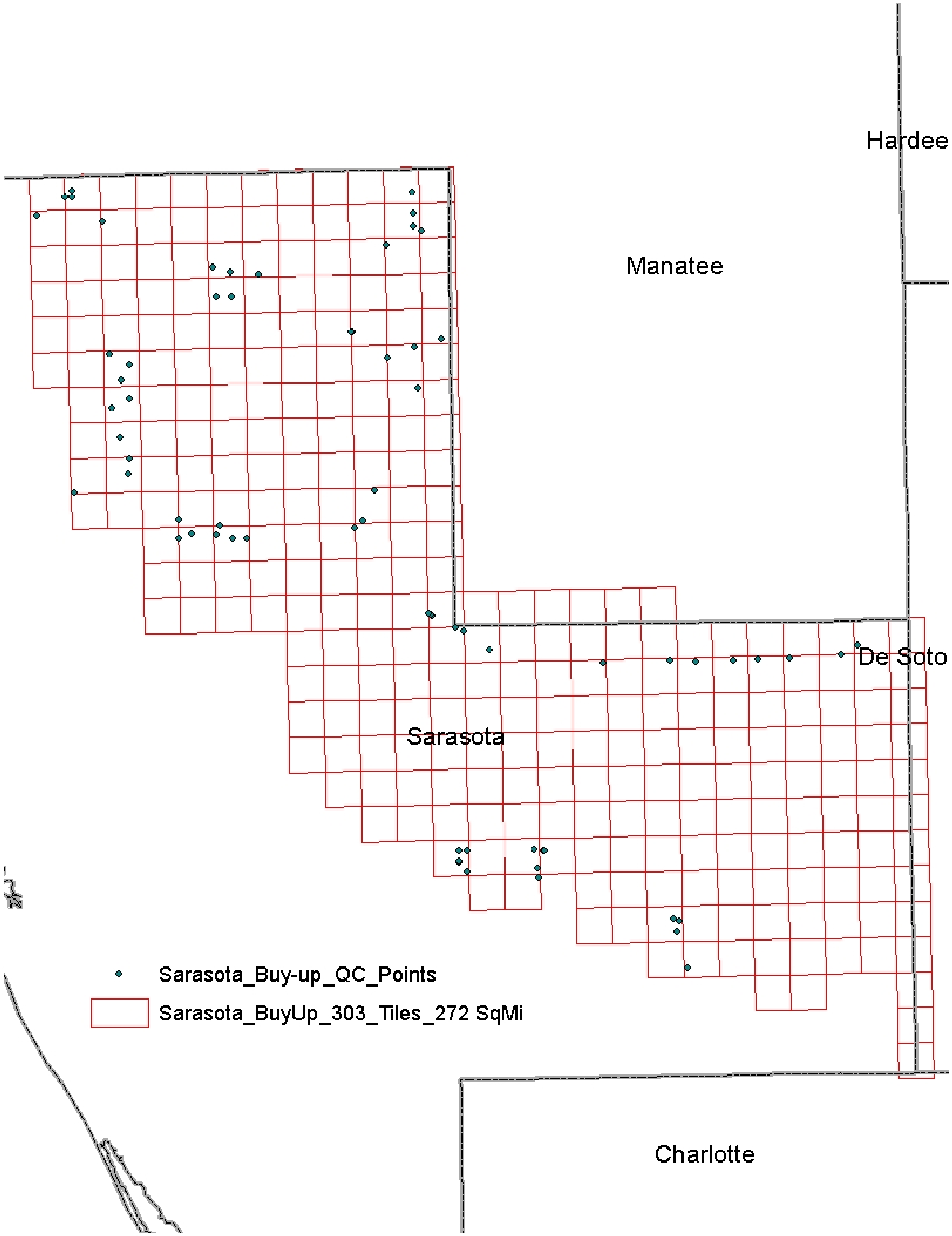
THIS REPORT IS NOT VALID WITHOUT THE SIGNATURE AND RAISED SEAL OF A FLORIDA LICENSED SURVEYOR AND MAPPER IN RESPONSIBLE CHARGE.

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 272 square-mile area, 65 checkpoints are required – a total of 69 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 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	0.19	ft	Calculated RMSEz	0.45	ft
Target RMSEz	0.30	ft	Target RMSEz	0.61	ft
Calculated 95% CI	0.37	ft	Calculated 95% CI	0.88	ft
Target 95% CI	0.60		Target 95% CI	1.19	
Min	0.01	ft	Min	0.10	ft
Max	0.43	ft	Max	0.97	ft
Average	0.14	ft	Average	0.38	ft
Count	17		Count	17	
Forested Areas Fully Covered by Trees			**Urban Areas**		
Calculated RMSEz	0.53	ft	Calculated RMSEz	0.22	ft
Target RMSEz	0.61	ft	Target RMSEz	0.61	ft
Calculated 95% CI	1.04	ft	Calculated 95% CI	0.42	ft
Target 95% CI	1.19		Target 95% CI	1.19	
Min	0.03	ft	Min	0.01	ft
Max	1.07	ft	Max	0.38	ft
Average	0.41	ft	Average	0.18	ft
Count	15		Count	20	
Overall at All Checkpoints			**Unobscured LANDCOVER NMAS**		
Calculated RMSEz	0.37	ft	Calculated 90th Percentile	0.33	ft
Target RMSEz	0.61	ft	Target 90th Percentile	1.0	ft
Calculated 95% CI	0.72	ft	Calculated Max	0.43	ft
Target 95% CI	1.19		Target Max	2.0	ft
Min	0.01	ft	Count	37	ft
Max	1.07	ft			
Average	0.27	ft			
Count	69				

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 following table lists the test results for all checkpoints:

Accuracy Analysis
Sarasota County Buy-up Area
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	
083505_W	9000	1106802.551	521115.445	28.171	28.044	-0.127	BARE EARTH AND LOW GRASS
085006_W	9007	1083006.697	528670.243	26.441	26.401	-0.04	BARE EARTH AND LOW GRASS
084409_W	9013	1092267.703	543324.551	41.519	41.599	0.08	BARE EARTH AND LOW GRASS
085014_W	9015	1083131.649	565106.413	48.088	47.999	-0.089	BARE EARTH AND LOW GRASS
084114_W	9022	1099053.977	565354.35	71.808	71.71	-0.098	BARE EARTH AND LOW GRASS
087115_W	9031	1047050.382	570097.442	31.473	31.446	-0.027	BARE EARTH AND LOW GRASS
087722_W	9036	1039460.931	607628.08	32.288	31.854	-0.434	BARE EARTH AND LOW GRASS
087726_W	9041	1039968.022	628281.773	41.249	41.13	-0.119	BARE EARTH AND LOW GRASS
089215_W	9051	1013442.472	573622.693	23.208	23.628	0.42	BARE EARTH AND LOW GRASS
089217_W	9056	1013348.657	584185.726	24.876	25.037	0.161	BARE EARTH AND LOW GRASS
089821_W	9061	1003306.042	603790.87	23.754	23.839	0.085	BARE EARTH AND LOW GRASS
085906_W	9076	1069681.984	528342.728	32.067	31.969	-0.098	BARE EARTH AND LOW GRASS
086509_W	9081	1058220.671	544691.501	30.082	30.074	-0.008	BARE EARTH AND LOW GRASS

086508_W	9086	1058388.964	535079.278	27.791	28.075	0.284	BARE EARTH AND LOW GRASS
086213_W	9026A	1060319.791	561170.011	16.896	16.707	-0.189	BARE EARTH AND LOW GRASS
087415_W	9031A	1044460.553	574970.691	32.263	32.398	0.135	BARE EARTH AND LOW GRASS
087416_W	9031B	1041731.461	578596.47	32.806	32.84	0.034	BARE EARTH AND LOW GRASS
083804_W	9002	1104318.644	515978.612	29.99	29.934	-0.056	URBAN AREAS
083505_W	9003	1106801.172	520070.495	28.452	28.279	-0.173	URBAN AREAS
085006_W	9006	1080817.467	527398.842	26.536	26.779	0.243	URBAN AREAS
085006_W	9008	1084608.138	525956.473	31.178	30.902	-0.276	URBAN AREAS
084109_W	9011	1095740.331	543227.843	43.923	43.928	0.005	URBAN AREAS
084110_W	9012	1095281.655	547173.249	47.183	47.439	0.256	URBAN AREAS
085314_W	9016	1078822.68	569352.515	26.781	27.069	0.288	URBAN AREAS
085014_W	9018	1084606.151	569006.569	51.094	50.789	-0.305	URBAN AREAS
083815_W	9021	1100962.47	570346.386	81.499	81.506	0.007	URBAN AREAS
083814_W	9023	1101726.886	569070.359	88.51	88.255	-0.255	URBAN AREAS
086213_W	9025	1064550.559	562818.865	16.593	16.224	-0.369	URBAN AREAS
087724_W	9040	1039573.07	616401.875	39.542	39.327	-0.215	URBAN AREAS
085906_W	9075	1067656.539	528136.241	30.59	30.543	-0.047	URBAN AREAS
086209_W	9080	1060114.551	540993.724	29.993	29.872	-0.121	URBAN AREAS
086508_W	9085	1058942.083	536927.513	29.991	30.366	0.375	URBAN AREAS
083505_W	9091	1107649.801	521110.118	29.388	29.29	-0.098	URBAN AREAS
084713_W	9092	1086969.096	560047.783	50.818	50.709	-0.109	URBAN AREAS
089215_W	9050A	1013409.146	574884.802	23.222	23.517	0.295	URBAN AREAS
089517_W	9055A	1009478.088	584778.162	23.419	23.491	0.072	URBAN AREAS
089821_W	9060A	1001403.389	604247.733	23.126	23.052	-0.074	URBAN AREAS
083806_W	9001	1103325.165	525312.836	41.414	41.706	0.292	BRUSH LANDS AND LOW TREES
085306_W	9005	1078200.648	528631.062	27.232	27.524	0.292	BRUSH LANDS AND LOW TREES
084409_W	9010	1092361.912	541118.925	37.936	38.087	0.151	BRUSH LANDS AND LOW TREES

084715_W	9017	1085727.916	572816.432	38.929	39.322	0.393	BRUSH LANDS AND LOW TREES
083514_W	9020	1106425.672	569126.175	94.188	93.959	-0.229	BRUSH LANDS AND LOW TREES
086512_W	9027	1059227.93	559982.308	14.276	15.248	0.972	BRUSH LANDS AND LOW TREES
087415_W	9032	1044982.945	573818.637	31.408	32.12	0.712	BRUSH LANDS AND LOW TREES
087721_W	9037	1039556.153	604033.573	35.553	34.955	-0.598	BRUSH LANDS AND LOW TREES
087723_W	9039	1039489.199	613057.154	34.877	35.385	0.508	BRUSH LANDS AND LOW TREES
087427_W	9042	1041145.095	630614.14	40.187	40.09	-0.097	BRUSH LANDS AND LOW TREES
089215_W	9052	1010448.882	574824.685	21.817	22.546	0.729	BRUSH LANDS AND LOW TREES
089217_W	9057	1010681.263	584698.91	27.936	28.145	0.209	BRUSH LANDS AND LOW TREES
089821_W	9062	1002854.861	604615.064	24.486	24.68	0.194	BRUSH LANDS AND LOW TREES
085905_W	9072	1065039.717	520561	35.622	35.253	-0.369	BRUSH LANDS AND LOW TREES
085606_W	9077	1072713.247	527041.417	34.894	35.067	0.173	BRUSH LANDS AND LOW TREES
086509_W	9082	1058184.442	542652.153	28.067	28.31	0.243	BRUSH LANDS AND LOW TREES
086208_W	9087	1060953.508	535217.582	25.775	26.146	0.371	BRUSH LANDS AND LOW TREES
083505_W	9004	1107621.131	521040.055	26.871	27.648	0.777	FORESTED AREAS FULLY COVERED BY TREES
084109_W	9009	1096447.657	540728.499	41.907	42.591	0.684	FORESTED AREAS FULLY COVERED BY TREES
083814_W	9014	1103434.925	569102.213	91.57	91.479	-0.091	FORESTED AREAS FULLY COVERED BY TREES
085306_W	9019	1076994.444	526110.658	31.144	31.1	-0.044	FORESTED AREAS FULLY COVERED BY TREES
084713_W	9024	1086939.832	560183.671	44.403	44.762	0.359	FORESTED AREAS FULLY COVERED BY

							TREES
087115_W	9029	1046732.154	570621.908	31.454	32.453	0.999	FORESTED AREAS FULLY COVERED BY TREES
086509_W	9034	1058696.135	540359.191	27.425	26.356	-1.069	FORESTED AREAS FULLY COVERED BY TREES
089215_W	9044	1011826.592	573573.914	21.822	21.714	-0.108	FORESTED AREAS FULLY COVERED BY TREES
087115_W	9049	1046817.508	570467.808	31.035	31.666	0.631	FORESTED AREAS FULLY COVERED BY TREES
087719_W	9054	1039470.532	594543.468	31.905	32.27	0.365	FORESTED AREAS FULLY COVERED BY TREES
089215_W	9059	1011968.102	573577.282	23.699	23.795	0.096	FORESTED AREAS FULLY COVERED BY TREES
087725_W	9064	1039578.719	620852.261	39.067	39.232	0.165	FORESTED AREAS FULLY COVERED BY TREES
089218_W	9069	1013244.382	585659.815	26.927	26.957	0.03	FORESTED AREAS FULLY COVERED BY TREES
089218_W	9074	1013243.561	585768.875	27.206	27.587	0.381	FORESTED AREAS FULLY COVERED BY TREES
090122_W	9084	996260.024	605647.558	22.901	23.325	0.424	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.

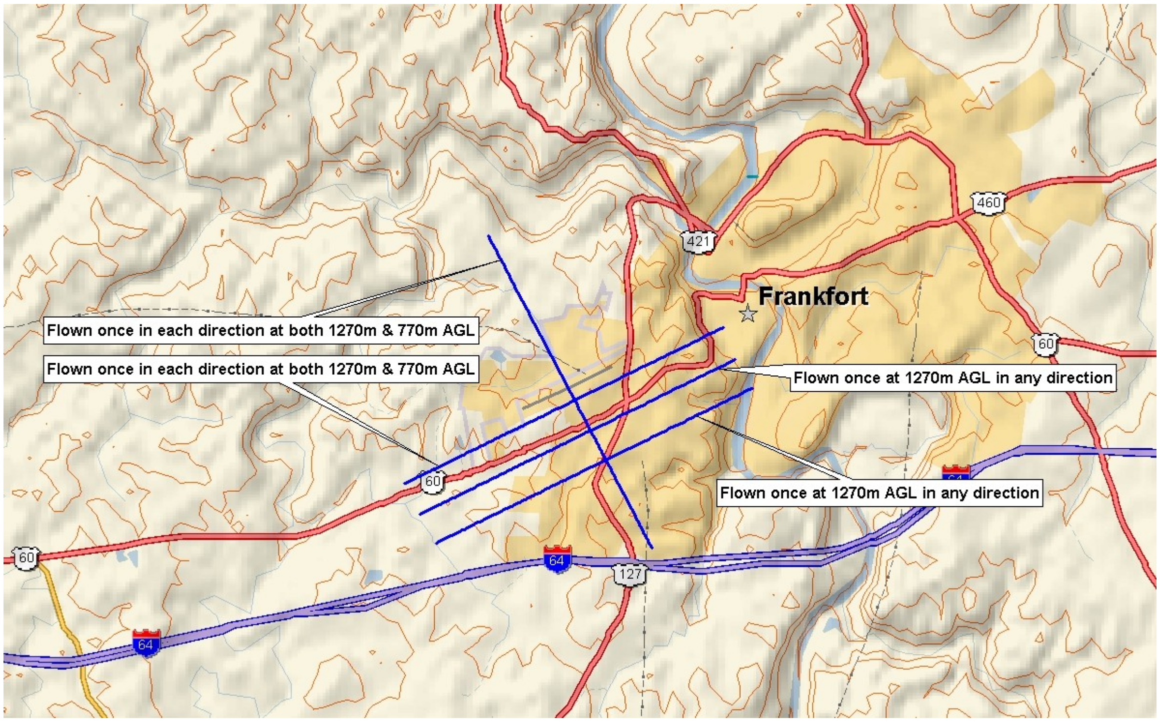
Overview

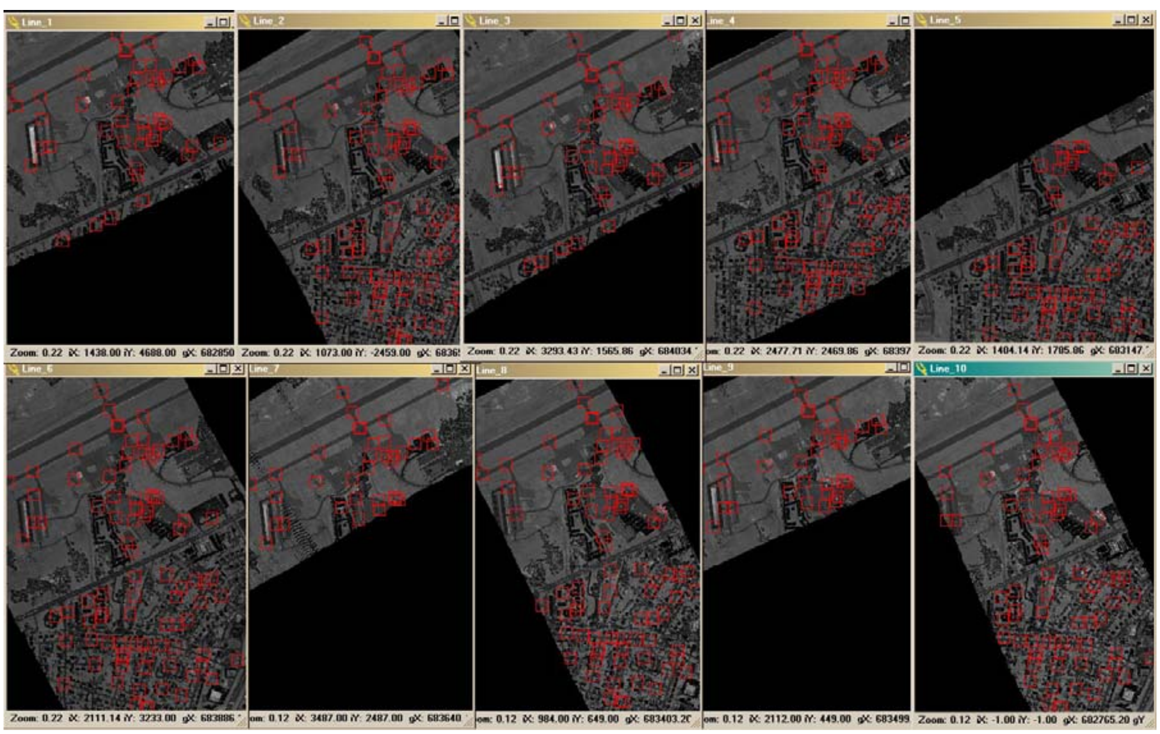
This Calibration Report shall be used to confirm LiDAR system specifications, performance, and requirements. The system functionality, elevation, and horizontal accuracy performance shall be demonstrated for calibration purposes. Photo Science completes calibration flights at regular intervals for ongoing 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