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Airborne GPS Survey Report For

Data Access & Support Center

Kansas Geological Survey

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Contract ID 00036574 - Amendment

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Aerometric Project No. 1121109

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Kansas Department of Administration

Area 1, Eastern Kansas

Lidar Task Order/Contract ID 036574

Aerometric Project No. 1121109

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1 INTRODUCTION

This report contains a summary of the LiDAR data acquisition and processing for Area 1 located in **Eastern Kansas under Contract ID 036574 Amendment**.

1.1 Contact Info

Questions regarding the technical aspects of this report should be addressed to:
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1.2 Purpose

Aero-Metric, Inc. acquired high accuracy Light Detection and Ranging (LiDAR) data in the Area 1 region of eastern Kansas for the Kansas Department of Administration and Kansas Geological Survey in accordance with requirements specified to produce such dataset as outlined in contract ID 036574 and as defined by the National Digital Elevation Program (NDEP) and the American Society for Photogrammetry and Remote Sensing (ASPRS) and Other High Quality Digital Topography, as well as USGS National Geospatial Program Base LiDAR Specification, Version 13 (ILMF).

1.3 Project Locations

The project Area 1 Kansas which includes: Anderson, Allen, Neosho, and Labette counties. Areas were defined and supplied by Kansas Department of Administration and includes approximately 2250 square miles for analysis.

1.4 Time Period

LiDAR data acquisition was performed November 17th, 2012 to November 20th, 2012. Six (6) missions were logged to cover the project area. See Items 3.3 for a sketch of the acquisition passes and Section 7 contains each flight log.

1.5 Project Scope

To collect data over the approximately 2250 square miles of the project, aircraft were operated by; Aerial Surveys International (ASI) utilizing Optech Orion airborne LiDAR system. Data was collected at a nominal altitude of 2900 meters above ground to provide optimal data collection from the project area terrain.

2 GEODETIC CONTROL

QC surveys and control were completed between November 27th and December 4th, 2012.

2.1 Network Scope

Base horizontal control for the check point survey consisted of five NGS CORS stations: **KST6**, **MOBT**, **MOCA**, **MONE**, **ZKC1**: one NGS Order 0 station: **M 55**; one NGS Order B stations: **K 56**; one NGS First Order station: **KINNE**; and one NGS Second Order station: **CHETOPA**.

Horizontal control is referenced to the Universal Transverse Mercator (UTM) Coordinate System – Zone 15, based on the North American Datum of 1983/2007 (NAD83/07). Final coordinates are published in meters.

Base vertical control for the check point survey consisted of five NGS Second Order stations: **801.25, D 274**, **K 56**, **M 55**, **P 277**; one NGS Third Order station: **CHETOPA**. The NGS stations **F 246** and **PARSONS** were also observed, but not used as control due to large vertical misclosure. The NGS Model GEOID09 was applied to the derived ellipsoid heights to approximate the North American Vertical Datum of 1988.

Vertical control is based on the North American Vertical Datum of 1988 (NAVD88).

NGS recovery sheets are located in Section 9 of the Control Survey Report.

2.2 Network Computations

GPS measurements were collected using the RTK survey method. Passive NGS control stations were observed in the field and active NGS CORS stations were added in the office. GPS measurement computations were done in two stages. Initial computations were done with LEICA Geo Office (LGO), version 8.3. LGO permits the conversion of raw satellite data collected by the receivers to a meaningful coordinate difference between points (baseline solutions). Once the baseline solutions were determined, they were input into the GeoSurv-GeoLab2 series of programs (Geolab version 2.4d). A network adjustment was performed for analysis and quality closure holding the position and elevation of station **M 55** fixed as follows:

HORIZONTAL CLOSURES (in meters)

STATION	NORTHING	EASTING	LINEAR	DISTANCE	PROPORTION
CHETOPA	0.019	0.048	0.052	72371.4	1:1401000
K 56	0.045	0.019	0.049	62635.1	1:1282000
KINNE	0.033	0.050	0.060	9340.1	1: 155000
KST6	0.020	0.023	0.030	172485.8	1:5659000
MOBT	0.023	0.018	0.029	96882.1	1:3317000
MOCA	0.016	0.032	0.036	89589.8	1:2504000
MONE	0.017	0.003	0.017	77028.8	1:4531000
ZKC1	0.030	0.037	0.048	141198.2	1:2964000

VERTICAL CLOSURES (in meters)

STATION	ADJUSTED ELEVATION	PUBLISHED ELEVATION	DIFFERENCE	DISTANCE	ALLOWABLE 3rd ORDER CLOSURE

801.25	245.037	244.965	0.072	68255.4	0.099
CHETOPA	252.480	252.430	0.050	72371.4	0.102
D 274	281.172	281.214	0.042	79279.0	0.107
K 56	314.353	314.327	0.026	62635.1	0.095
P 277	319.916	319.950	0.034	49189.9	0.084

The above control was held in the fully constrained scaled least squares base network adjustments to derive the ground control checkpoint values.

3 LiDAR ACQUISITION AND PROCEDURES

3.1 Acquisition Time Period

LiDAR data acquisition and Airborne GPS control surveys were completed between November 17th, 2012 and November 20th, 2012. Six flight missions were required to cover the project areas.

3.2 LiDAR Planning

The LiDAR data for this project was collected with Aerial Surveys International (ASI) Optech Orion H300 airborne LiDAR system. All flight planning and flights were completed using Optech FMS, version 4.4.12 (flight planning and LiDAR control software).

Item 3.2 Acquisition details for the project acquisition flights.

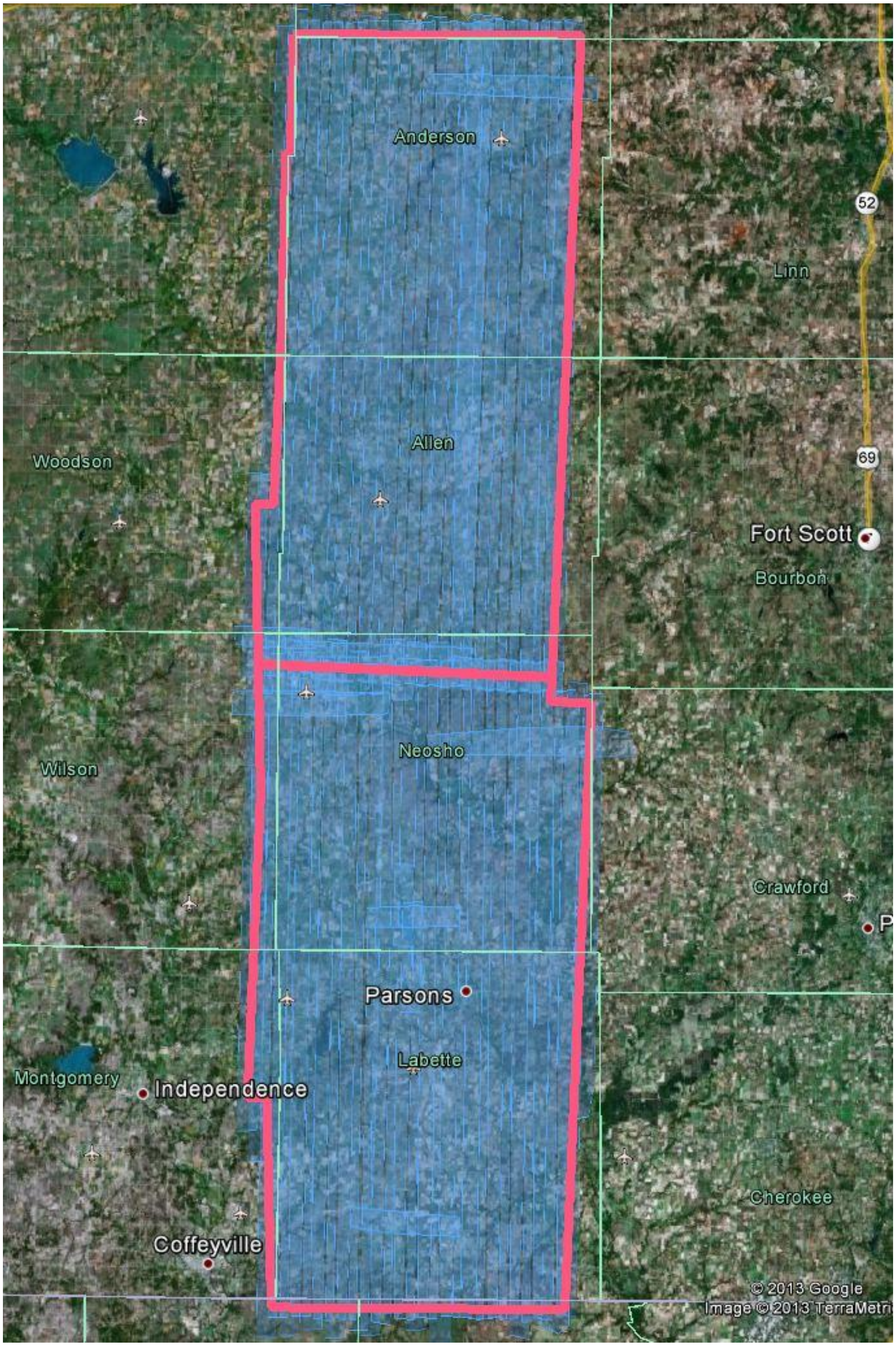
Flying Height (Above Ground)	2900 m
Laser Pulse Rate	125 kHz
Mirror Scan Rate Frequency	33 Hz
Scan Angle (degrees)	20
Side Lap	30%
Ground Speed	160 kts
Nominal Point Spacing/meter	1.25

3.3 LiDAR Acquisition

A total of 6 flight missions were required to cover the project area. The missions were flown using the values in the chart above, Item 3.2. Images of the acquisition missions or flight lines in the three areas follow as Items 3.3. Section 7 contains images of the flight log sheets.

Airborne GPS and IMU position and trajectory data of the LiDAR sensor were also acquired during the time of flight.

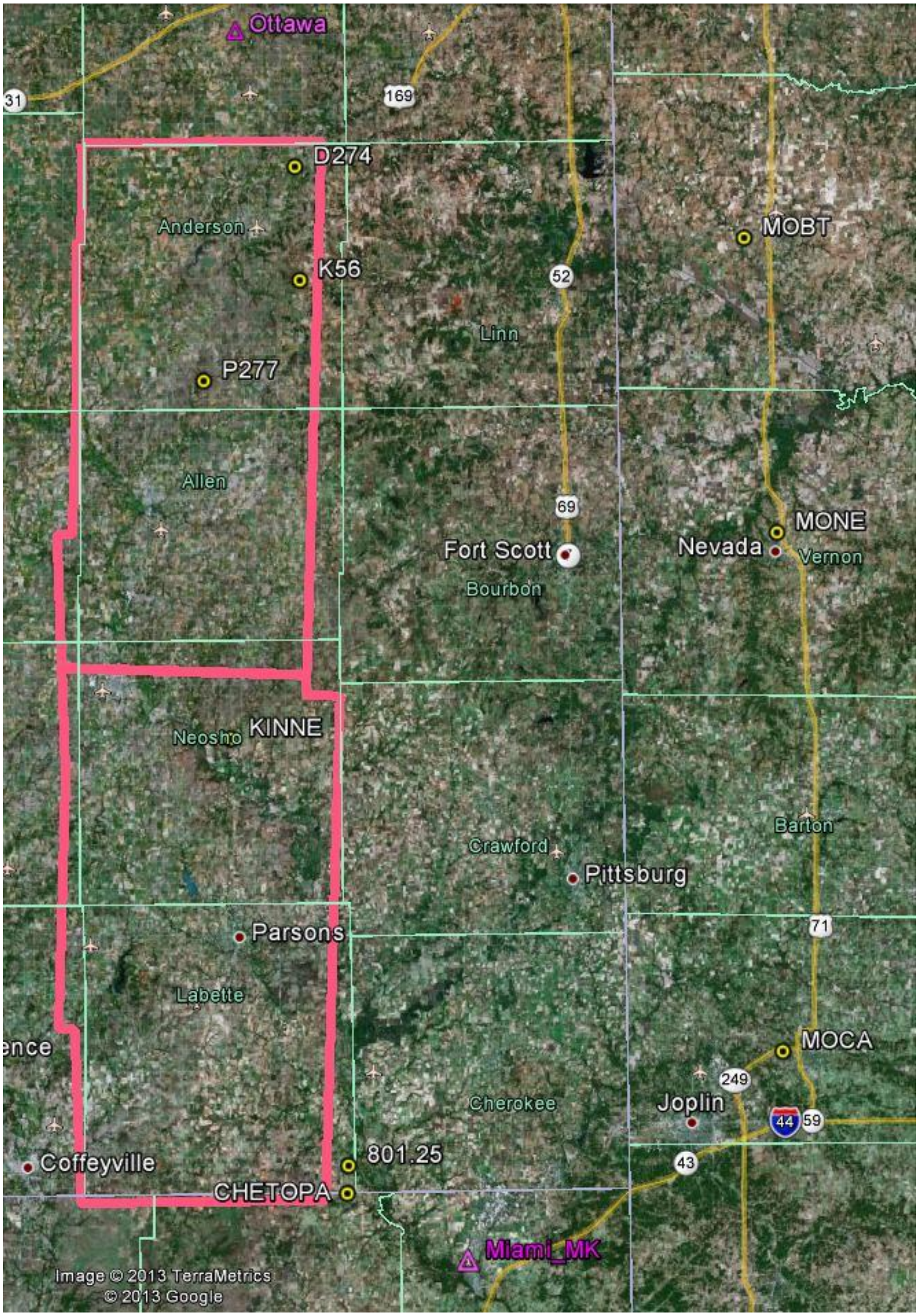
Missions were typically three to four hours long. Before take-off, the LiDAR system and the Airborne GPS and IMU system were initialized for a period of five minutes and in operation after landing for another five minutes. The missions acquired data according to the planned flight lines and included a minimum of one (usually two) cross flights. The cross flights were flown perpendicular to the planned flight lines and their data used in the in-situ calibration of the sensor.



3.3 Acquisition area; missions and flight lines in Kansas, Area 1, Anderson, Allen, Neosho, and Labette counties.

3.4 LiDAR Trajectory Processing

The airborne positioning was based on the following control stations: Base stations were set at Ottawa and Miami_MK. The network computations include 801.25, K56, KST6, MOBT, MOCA, MONE, ZKC1, D274, KINNE, P277, and CHETOPA. See approximate locations in Item 3.4.



3.4 Control Station locations and Project boundary

4 QC SURVEYS

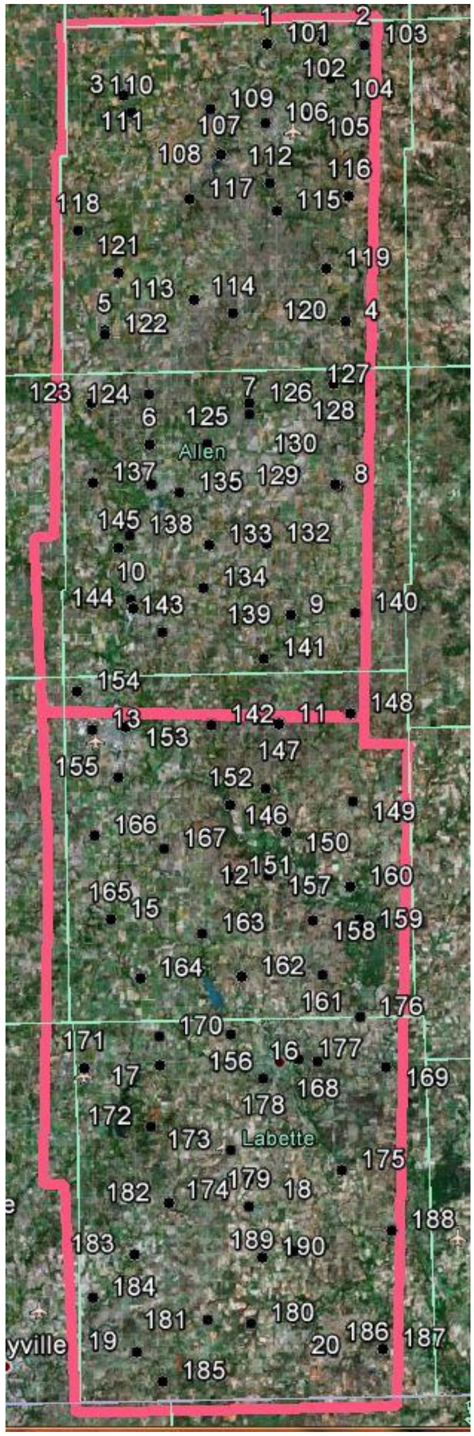
The check point survey was performed between November 27th and December 4th, 2012 using Rapid Static GPS techniques. The project consists of Anderson, Allen, Neosho, and Labette counties. Ground survey personnel collected a total of 90 survey points in these counties. These points were collected in all terrain categories to assess vertical accuracies in each category. A breakdown of the survey points are shown below.

Low Grass Land Category = 22 Points
Tall Grass Land Category = 22 Points
Forest Land Category = 22 Points
Urban Land Category = 24 Points

The control stations mentioned above to support the Airborne GPS acquisition were also used to complete the QC surveys.

See Section 8 of the control report for a complete listing.

Items 4.0 indicate an overview of check point locations on next page.



4.0 Area 1, Kansas Ground Survey Check Point Locations.

5 FINAL LiDAR PROCESSING

5.1 ABGPS and IMU Processing

Airborne GPS

Applanix - POSGPS

Utilizing carrier phase ambiguity resolution on the fly (i.e., without initialization). The solution to sub-decimeter kinematic positioning without the operational constraint of static initialization as used in semi-kinematic or stop-and-go positioning was utilized for the airborne GPS post-processing.

TerraTec – TERRAPOS

TERRAPOS represents a state-of-the-art solution to Precise Point Positioning (PPP). TERRAPOS has been implemented to be fully compliant with data and products from leading international organizations, e.g. the International Earth Rotation and Reference Systems Service (IERS) and the International GNSS Service (IGS). TERRAPOS thus allows kinematic positioning with sub decimeter accuracy within the globally consistent and long-term stable reference frames maintained by the IERS.

In the PPP solution the carrier phase biases are estimated as real numbers (a so-called “float solution”). This confirms that the precision of the solution benefits from an increased data rate using an increased number of observations. However, this gain is ultimately limited by the time correlated errors in the observations that include but not limited to multipath and residual satellite clock errors. The data requires both dual-frequency code and carrier phase observations and uses respective ionosphere-free linear combinations. Doppler observations are also included in the computation for all kinematic profiles which assists the algorithm in the pre-processing to aid cycle slip detection and also helps to improve the position estimates.

Inertial Data

The post-processing of inertial and aiding sensor data (i.e. airborne GPS post processed data) is to compute an optimally blended navigation solution. The Kalman filter-based aided inertial navigation algorithm generates an accurate (in the sense of least-square error) navigation solution that will retain the best characteristics of the processed input data. An example of inertial/GPS sensor blending is the following: inertial data is smooth in the short term. However, a free-inertial navigation solution has errors that grow without bound with time. A GPS navigation solution exhibits short-term noise but has errors that are bounded. This optimally blended navigation solution will retain the best features of both, i.e. the blended navigation solution has errors that are smooth and bounded.

The resultant processing generates the following data:

- Position: Latitude, Longitude, Altitude
- Velocity: North, East, and Down components
- 3-axis attitude: roll, pitch, true heading
- Acceleration: x, y, z components
- Angular rates: x, y, z components

These procedures are utilized with the TerraTec TERRAPOS, version 2.0.4 (1851) software to determine the ABGPS trajectory. The blending of inertial data utilized only the Applanix software, version 4.4.

The airborne GPS and blending of inertial and GPS post-processing were completed in multiple steps.

The collected data was transferred by the field data collectors to the main computer. Data was saved under the project number and separated between LiDAR mission dates. Inside each mission date, a sub-directory was created with the aircraft's tail number and an A or B suffix was attached for the time of when the data was collected. Inside the tail number sub-directory, five sub-directories were also created EO, GPS, IMU, PROC, and RAW.

The aircraft raw data (IMU and GPS data combined) was run through a data extractor program. This separated the IMU and GPS data. In addition to the extracting of data, it provided the analyst the first statistics on the overall flight. The program was POSPac (POS post-processing PACkage), version 4.4.

Executing POSGPS program to derive accurate GPS positions for all flights:

TerraTech – TERRAPOS

The Applanix POSPac software requires ground base stations along with the airborne GPS data to compute the position and velocity of the sensor. Given the difficulties due to the ground stations as mentioned in Conditions Affecting Progress, a new processing technique was also employed to achieve the same superior accuracy as found with the traditional Applanix POSPac processing without the need of any base station support. This software used was TERRAPOS

The TERRAPOS procedure is to convert the binary structure of the GPS collected data to a Receiver Exchange format (RINEX) and is ingested into software and subsequently runs its advance and fully automated algorithms.

Once the data has been executed a graphical and a textual log is displayed. These values are inspected and accepted. An accepted accuracy would indicate an accuracy of 0.1m or less at a 95% of the entire mission. This accepted post-processed trajectory is relative to the ITRF, but the user could then relate the accepted trajectory positions to another Global Datum (e.g. NAD83). TERRAPOS has many fixed datums to pick from to relate it to their local reference datum. However, the reference for this project is the same as the processing it was completed in, and the accepted trajectories did not require a translation to another known datum.

When the processed trajectory data was accepted after quality control analysis, the combined solution is stored in a file format acceptable for the IMU post processor (i.e. POSProc).

Execute POSProc.

POSProc comprises a set of individual processing interface tools that execute and provide the following functions:

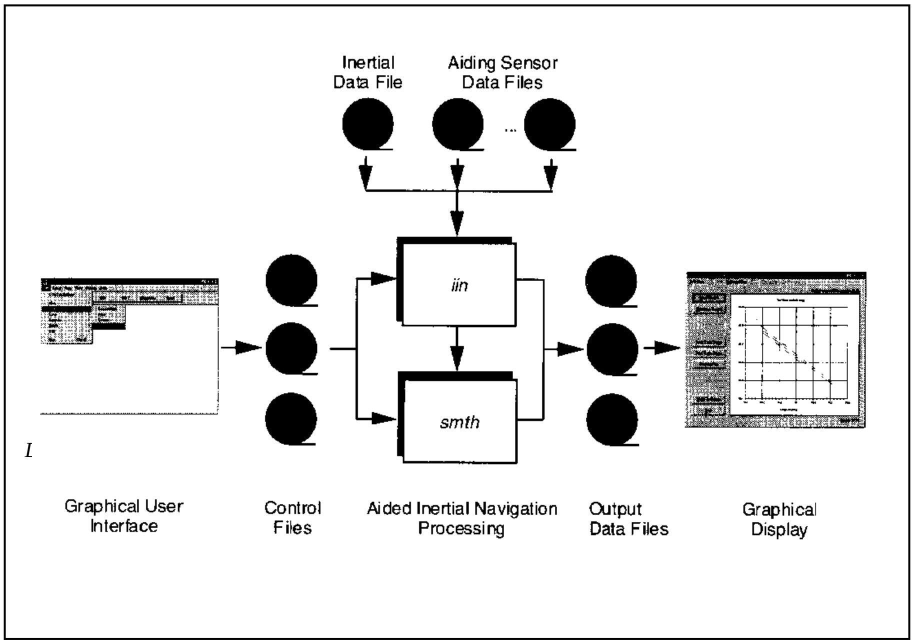


Diagram 3 shows the organization of these tools, and is a function of the POSProc processing components.

Integrated Inertial Navigation (iin) Module.

The name *iin* is a contraction of Integrated Inertial Navigation. *iin* reads inertial data and aiding data from data files specified in a processing environment file and computes the aided inertial navigation solution. The inertial data comes from a strapdown IMU. *iin* outputs the navigation data between start and end times at a data rate as specified in the environment file. *iin* also outputs Kalman filter data for analysis of estimation error statistics and smoother data that the smoothing program *smth* uses to improve the navigation solution accuracy.[3]

iin implements a full strapdown inertial navigator that solves Newton's equation of motion on the earth using inertial data from a strapdown IMU. The inertial navigator implements coning and sculling compensation to handle potential problems caused by vibration of the IMU. [3]

Smoother Module (smth).

smth is a companion processing module to *iin*. *smth* is comprised of two individual functions that run in sequence. *smth* first runs the *smoother function* and then runs the *navigation correction function*. [3]

The *smth* smoother function performs backwards-in-time processing of the forwards-in-time blended navigation solution and Kalman filter data generated by *iin* to compute smoothed error estimates. *smth* implements a modified Bryson-Frazier smoothing algorithm specifically designed for use with the *iin* Kalman filter. The resulting smoothed strapdown navigator error estimates at a given time point are the optimal estimates based on all input data before and after the given time point. In this sense, *smth* makes use of all available information in the input data. *smth* writes the smoothed error estimates and their RMS estimation errors to output data files. [3]

The *smth* navigation correction function implements a feedforward error correction mechanism similar to that in the *iin* strapdown navigation solution using the smoothed strapdown navigation errors. s*mth* reads in the smoothed error estimates and with these, corrects the strapdown navigation data. The resulting navigation solution is called a Best Estimate of Trajectory (BET), and is the best obtainable estimate of vehicle trajectory with the available inertial and aiding sensor data. [3]

The above mentioned modules provide the analyst the following statistics to ensure that the most optimal solution was achieved: a log of the *iin* processing, the Kalman filter Measurement Residuals, Smoothed RMS Estimation Errors, and Smoothed Sensor Errors and RMS.

5.2 LiDAR “Point Cloud” Processing

The ABGPS/IMU post processed data along with the LiDAR raw measurements were processed using Optech Incorporated’s ASDA software. This software was used to match the raw LiDAR measurements with the computed ABGPS/IMU positions and attitudes of the LiDAR sensor. The result was a “point cloud” of LiDAR measured points referenced to the ground control system.

5.3 LiDAR CALIBRATION

Introduction

The purpose of the LiDAR system calibration is to refine the system parameters in order for the post-processing software to produce a “point cloud” that best fits the actual ground.

The following report outlines the calibration techniques employed for this project.

Calibration Procedures

All Companies involved in collection routinely performs two types of calibrations on its airborne LiDAR system. The first calibration, system calibration, is performed whenever the LiDAR system is installed in the aircraft. This calibration is performed to define the system parameters affected by the physical misalignment of the system versus aircraft. The second calibration, in-situ calibration, is performed for each mission using that missions data. This calibration is performed to refine the system parameters that are affected by the on site conditions as needed.

System Calibration

The system calibration is performed whenever the LiDAR system is installed in the aircraft. This calibration is performed to define the system parameters affected by the physical misalignment of the system versus aircraft. The main system parameters that are affected are the heading, pitch, roll, and mirror scale.

The system calibration is performed by collecting data over a known test site that incorporates a flat surface and a large, flat roofed building. A ground survey is completed to define the flat surface and the building corners. The processed LiDAR data and ground survey data is input into TerraSolid's TerraMatch software to determine the systematic errors. The system parameters are then corrected according to the determined errors and used in the processing of future LiDAR acquisition missions

In-situ Calibration

The in-situ calibration is performed as needed using the mission's data. This calibration is performed to refine the system parameters that are affected by the on site conditions.

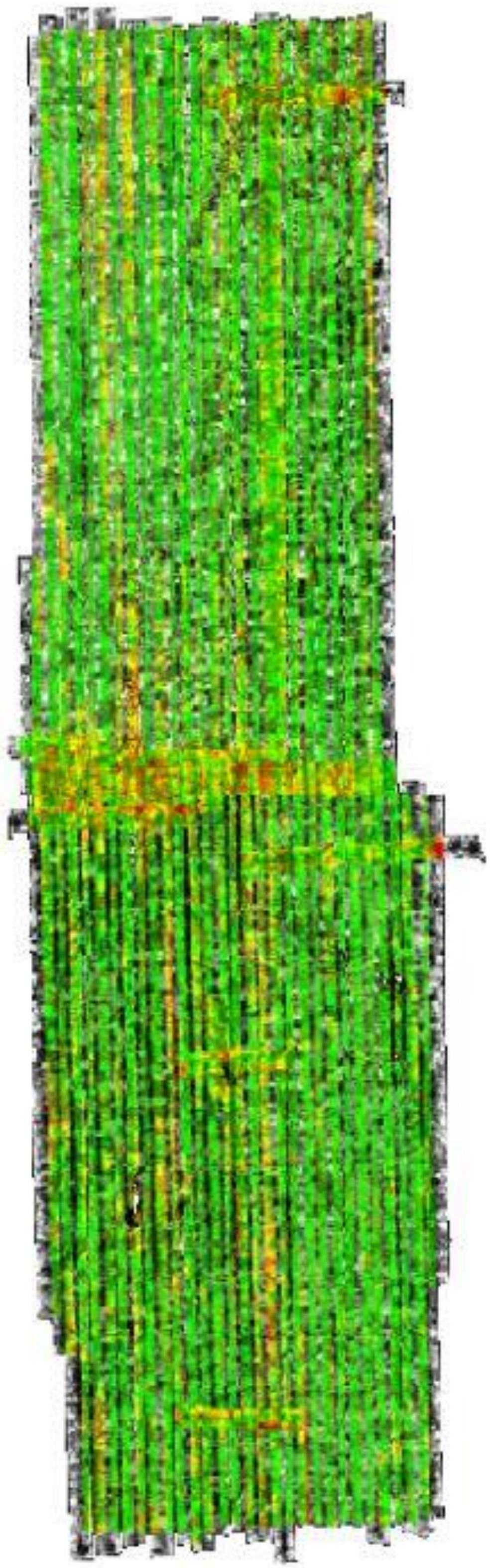
For each mission, LiDAR data for at least one cross flight is acquired over the mission's acquisition site. The processed data of the cross flight is compared to the perpendicular flight lines using either the Optech proprietary software or TerraSolid's TerraMatch software to determine if any systematic errors are present. In this calibration, the data of individual flight lines are compared against each other and their systematic errors are corrected in the final processed data.

5.4 LiDAR Processing

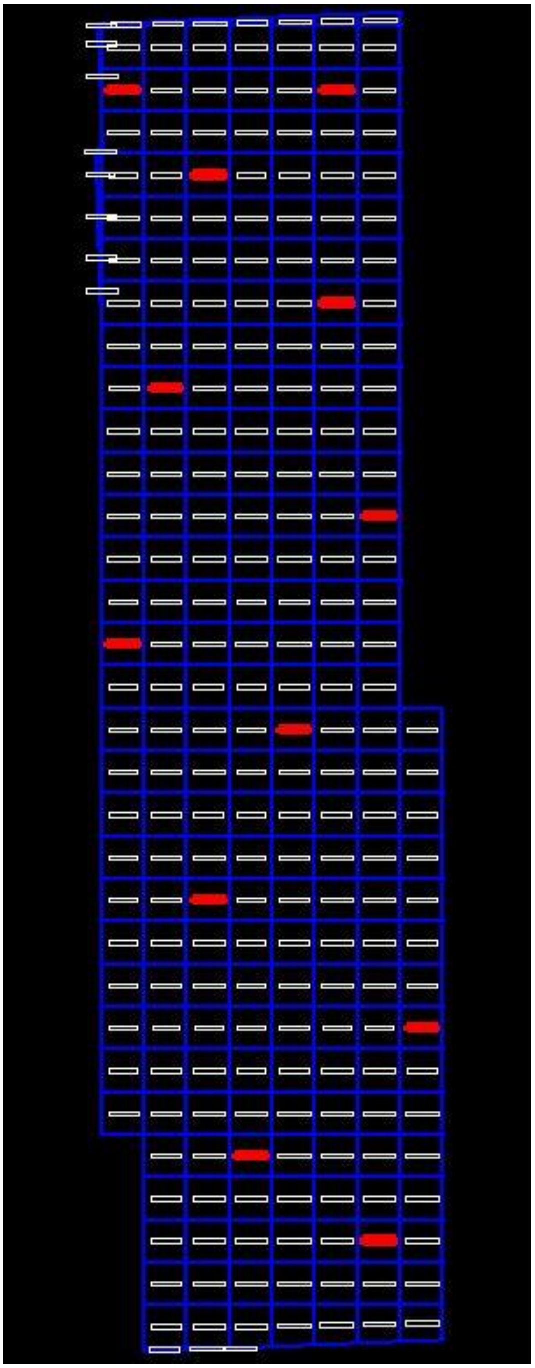
The LAS files were then imported, verified, and parsed into manageable, tiled grids using GeoCue version 2012.1.27.5. GeoCue allows for ease of data management and process tracking.

The first step after the data has been processed and calibrated is to perform a relative accuracy assessment on the flightline to flightline comparisons and also a data density test prior any further processing.

In addition to the relative accuracy assessment, Aerometric also reviews a few tiles to ensure that the desired point density has been met. Aerometric utilizes an in-house proprietary software to complete this task. Initially a grid is placed according to the version 12 specification that is based on the nominal post spacing. Point density is analyzed and the result indicates the density of the sampled tiles. The latest USGS specification, version 13, modifies the requirement allowing up to 2 times the nominal post spacing. Our data evaluation acknowledges this change.



Relative Accuracy assessment



Sample tile location in Area1 for point density analysis

Sampled tiles: (R6C124.las, R8C121.las, R11C125.las, R14C120.las, R18C122.las, R20C118.las, R23C124.las, R26C119.las, R28C123.las, R31C120.las, R33C118.las and R33C123.las)

Run 1 (Version 12 – 1.25 meter) Total number of cells: 192,096,012. Total number of cells with one or more points : 174,561,692. Percentage of tiles with 1 point or more: 90.8%

Run 2 (Version 13 – 2.50 meter) Total number of cells: 48,048,012. Total number of cells with one or more points: 47,692,493. Percentage of tiles with 1 point or more: 99.2%

Once both the accuracy between swaths and data density is accepted an automated classification algorithm is performed using TerraSolid's TerraScan, version 012.020. This will produce the majority of the bare-earth datasets.

The remainder of the data was classified using manual classification techniques. The majority of the manual editing involved changing points initially misclassified as ground (class 2) to unclassified (class 1). Erroneous low points, high points, including clouds are classified to class 7.

5.5 Check Point Validation

The data was then verified against ground control data. TerraScan computes the vertical differences between the surveyed elevation of ground control points and the LiDAR derived elevations at these points.

A report listing the differences and common statistics was created and can be found in Section 9, of this report.

5.6 LiDAR Data Delivery

The processed unclassified point cloud data supplied is in the following format:

- LAS, version 1.2
- GPS times adjusted to GPS Absolute
- Full swaths and delivered as 1 file per swath which did not exceed 2 gigabytes.

Classified point cloud data is also being supplied using the following criteria.

- LAS, version 1.2 in 5000 meter grid
- GPS times adjusted to GPS Absolute
- Classification scheme:
  - 1 – Processed, but unclassified
  - 2 – Bare Earth, Ground
  - 7 – Noise
  - 9 – Water
  - 10 – Ignored Ground (Breakline proximity)
  - 11 – Withheld
  - 17 – Overlap – unclassified
  - 18 – Overlap – Bare-Earth
  - 24 – Overlap – water
  - 25 – Overlap – Ignored Ground

Bare earth hydro-flattened 1 meter DEMs were created using TerraModeler (TerraSolid Ltd.). The ASCII grids were then imported into ARC and translated to raster format and placed in a geo-database DEM feature dataset.

First return 1 meter DEM images were created using GeoCue. They are geo-referenced and converted to IMG format.

Break lines polygon are first collected in a Microstation environment using the project specifications. They are checked for QC/QA. Upon acceptance the breaklines, either polygons or lines, are translated into ARC and imported to the final geo-database as separate features.

6 CONCLUSION

Sound procedures and use of new technology ensure this project data will serve the Kansas Department of Administration and Kansas Geological Survey and all users requiring the provided LiDAR derivative products for the project areas in eastern Kansas well into the future. Although this project presented challenges to equipment and personnel, the results are accurate and reliable.