![NCALM — National Center for Airborne Laser Mapping, University of Houston • University of California, Berkeley (NSF logo)]

NCALM Data Collection & Processing Summary

1.   Instrumentation

1.1   Data Collection Specifications

Parameter	Specification
Laser Wavelength	Channel 1: 1550 nm
	Channel 2: 1064 nm
	Channel 3: 532 nm
Operating Altitude [1,2]	300–2000 m AGL (1550 nm)
	300–2500 m AGL (1064 nm)
	300–2000 m AGL (532 nm)
Horizontal Accuracy [2]	$1/5500 \times$ altitude (1σ)
Vertical Accuracy [2]	< 5–15 cm (1σ)
Minimum Target Separation	< 1.0 m
Pulse Repetition Frequency	50–300 kHz (each wavelength)
Scan Frequency	0–70 Hz
Scan Angle	0–60° maximum
Beam Divergence	0.5 mrad ($1/e^2$) (1550 nm)
	0.5 mrad ($1/e^2$) (1064 nm)
	1.0 mrad ($1/e^2$) (532 nm)
Range Capture	Up to 4 range measurements for each pulse, including last
Intensity Capture	12-bit dynamic measurement and data range
Image Capture	Integrated digital camera

Table 1: Optech Titan multispectral lidar system (from Commissioning Report)

[1]20% reflective target

[2]Dependent on selected operational parameters using nominal 50° FOV in standard atmospheric conditions and good GNSS data quality

Parameter	Specification
Sensor Type	60 MP full-frame CCD, RGB
Sensor Format (H $\times$ V)	8984×6732 pix
Pixel Size	6×6 μm
Frame Rate	1 frame/2 s
Lens Focal Length	70 mm
Filter	Color and near-infrared removable filters

Table 2: DiMAC ULTRALiGHT+ (i.e., Optech D-8900) aerial digital camera (from DiMAC datasheet)

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Parameter	Specification
Spectral Range	380–1050 nm
Spectral Channels	Up to 288
Across-Track Pixels	1500
Field of View	40°
Spatial Resolution	0.20–1.50 m
f/N	f/3.5
Spectral Width Sampling/Row	2.4 nm
Spectral Resolution (FWHM)	< 3.5 nm
Pixel Size	20×20 µm

Table 3: ITRES CASI-1500 visible near infrared sensor (from ITRES datasheet)

1.2   Technical Specifications

Parameter	Specification
Position and Orientation System	POSAV AP50 (OEM), 220-channel dual frequency
Laser Classification	Class IV
Power Requirements	28 V, 30 A, 800 W
Dimensions and Weight	Sensor head: $630 \times 540 \times 450$ mm, 65 kg
	Control rack: $650 \times 590 \times 490$ mm, 46 kg
Data Storage Hard Drives	Removable solid state disk SSD (SATA II)

Table 4: Optech Titan multispectral lidar system

Parameter	Specification
FMC	Electro-mechanical, driven by Piezo technology
Shutter	Electro-mechanical iris mechanism
	1/125–1/500 s, f-stops: 4, 5.6, 8, 11, 16
Power Requirements	24–28 V, 8 A, 168 W
Dimensions and Weight	$200 \times 150 \times 120$ mm, ~4.5 kg
Data Storage Hard Drives	500 GB removable solid state drives

Table 5: DiMAC ULTRALiGHT+ aerial digital camera

Parameter	Specification
Dimensions and Weight	$470 \times 467 \times 535$ mm, 25 kg
ICU	$483 \times 178 \times 523$ mm, 16 kg
Power Requirements	24–32 V, 13.5 A
Data Storage	Swappable mass storage

Table 6: ITRES CASI-1500 visible near infrared sensor

2   Processing

2.1   GNSS/IMU Data Processing

Reference coordinates (customarily NAD83(2011) epoch 2010.00) for all stations are derived from observation sessions taken over the project duration and submitted to the NGS's on-line processor OPUS, which processes static differential baselines tied to the international CORS network. For further information on OPUS see: www.ngs.noaa.gov/OPUS, and for more information on the CORS network see: www.ngs.noaa.gov/CORS.

Aircraft trajectories for surveys are traditionally processed using Kintools software, written by Dr. Gerald L. Mader of the NGS Research Laboratory. Kintools kinematic GPS processing uses the dual-frequency phase history files of the reference and airborne receivers to determine a high-accuracy, fixed integer, ionosphere-free differential solution at 1 Hz. All final aircraft trajectories for projects (except in rare instances) are blended solutions from at least two of the available reference stations. For more information on Kintools, see: www.generalpositioning.com.

After GPS processing, the 1-Hz trajectory solution and the 200-Hz raw inertial measurement unit (IMU) data, collected during the flights, are combined in APPLANIX software POSPac MMS (currently Mobile Mapping Suite Version 7.1 SP2). POSPac MMS implements a Kalman filter algorithm to produce a final, smoothed, and complete navigation solution, including both aircraft position and orientation at 200 Hz. This final navigation solution is known as an SBET (Smoothed Best Estimated Trajectory).

2.2   Lidar Data Processing

The following diagram (Figure 1) shows a general overview of the NCALM lidar data processing workflow:
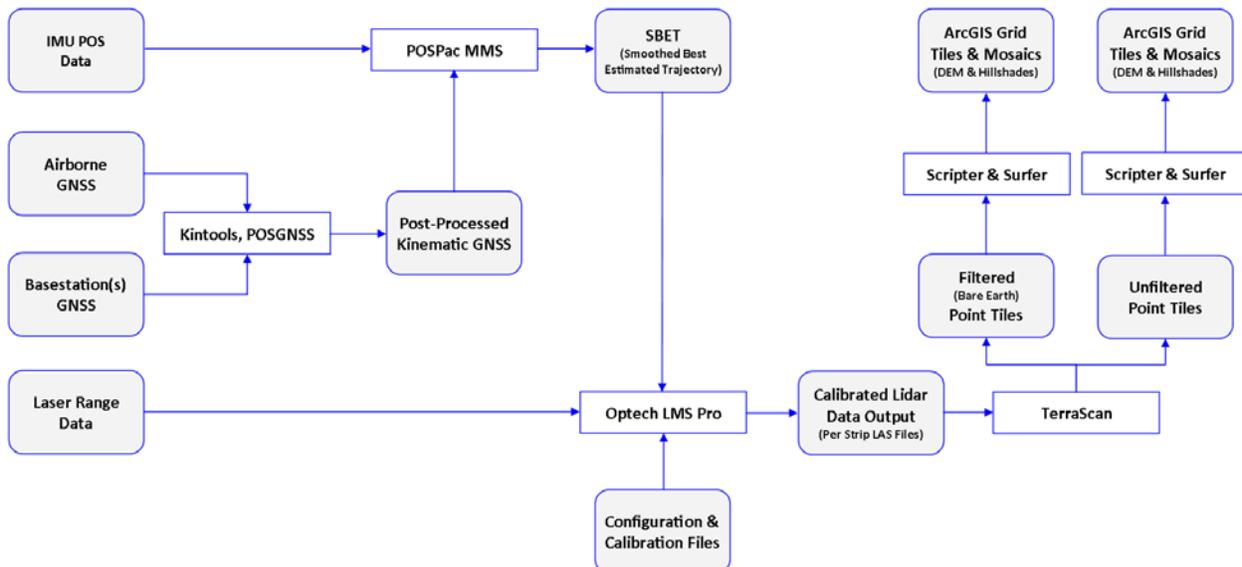
Figure 1: NCALM's typical lidar processing workflow

2.2.1   Bathymetry Processing

There are some important differences when processing range data from the Channel 3 laser, with respect to the processing of traditional topographic or bathymetric systems. The main difference concerns the fact that the laser pulse can travel through both air and water. For the accurate determination of ranges, it is necessary to determine what portion of the laser pulse trajectory occurred in each medium, therefore accounting for the difference of the speed of light. Accordingly, additional steps are involved in processing bathymetric data. This includes the classification of points representing laser shots that penetrated the water and correcting the elevation values for the above-mentioned phenomena.

2.2.2   Classification

Classification is done by automated means, using TerraSolid software (currently TerraScan Version 16.006): www.terrasolid.com/products/terrascanpage.php.

NCALM makes every effort to produce the highest quality lidar data possible, but every lidar point cloud and derived DEM will have visible artifacts if it is examined at a sufficiently fine level. Examples of such artifacts include visible swath edges, corduroy (visible scan lines), errors in bathymetry determination, and data gaps. A detailed discussion on the causes of data artifacts, and how to recognize them, can be found here: ncalm.berkeley.edu/reports/GEM_Rep_2005_01_002.pdf. A discussion of the procedures NCALM uses to ensure data quality can be found here:
ncalm.berkeley.edu/reports/NCALM_WhitePaper_v1.2.pdf.

Additionally, when surveying near or over urban areas, the difficulty of classification often increases, causing "urban artifacts." This is usually evident when viewing raster files (i.e., hillshades). The user will notice "pits" in the ground model where the laser penetrated skylights in buildings or storm drains on the sides of roads. Swimming pools, which can look like holes when bathymetry processing is completed, will also be observed.

NCALM cannot devote the required time to remove all artifacts from datasets, especially urban artifacts, when the study area is not over a city or town, or involving infrastructure specifically, but will attempt to provide the most aesthetically pleasing hillshades, etc. If researchers find areas with artifacts that influence their applications, they should contact NCALM (ncalm@egr.uh.edu), and we will assist them in removing the artifacts to the extent possible – but this may well involve the PIs devoting additional time and resources to this process.

2.3 Digital Imagery Processing

Digital imagery processing can be simplified in three steps: radiometric correction, calibration, and orthorectification. An overview of the processing steps is shown in the flowchart in Figure 2:
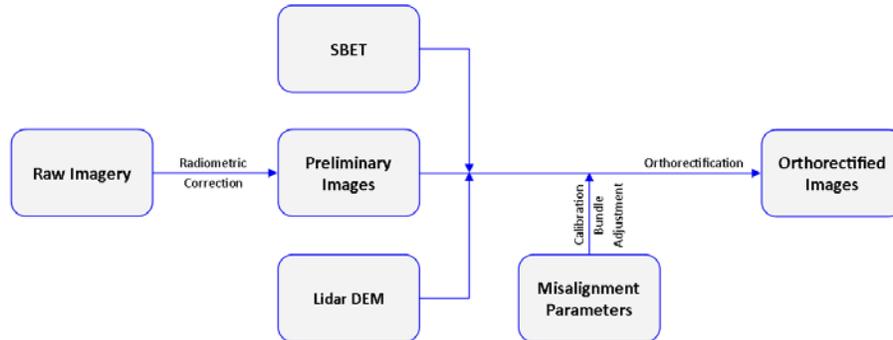
Figure 2: Imagery processing workflow

Calibration is typically done on a set of images taken over a calibration site with perpendicular and opposing headings. Calibration involves using a bundle adjustment to solve for linear and angular misalignments with tie points and ground control points. For this purpose, the calibration site is located over an area with distinct road markings, such as parking lots or an airport. Finally, the calculated misalignment values are fed back into the process to produce the orthorectified images.

2.3.1 DiMAC High-Resolution Visible Imagery

Radiometric correction for DiMAC images involves fine-tuning the white balance and exposure correction. This procedure is done using Capture One image processing software (www.phaseone.com/capture-one). The next two steps of calibration through bundle adjustment and orthorectification are completed using TerraPhoto (currently Version 16.005), part of the TerraSolid software suite.

2.3.2 CASI-1500 Hyperspectral Imagery

The CASI-1500 is a push broom scanner, so most of the processing is done using software utilities developed in-house by ITRES. Radiometric calibration is accomplished using the "RCXSAV" utility, which does the following:

1. Corrects for the additive, non-target related components to the raw signal
2. Calibrates the raw measured DN value for each pixel through multiplying by coefficients generated during the calibration of the instrument. In doing so, the data are converted to units of Spectral Radiance. These coefficients are contained within the instrument's calibration files, which are unique to each CASI and calibration run
3. Scales the data from 14-bit to 16-bit values
4. Outputs raw CASI images in PIX files, which are a 16-bit unsigned integer BIP format

The next steps of bundle adjustment and orthorectification are carried out by "PBSbund" and "Geocor," respectively, software utilities provided by ITRES.

3. Accuracy Assessment

3.1 Relative Accuracy

System calibration of the sensor's three boresight angles (roll, pitch, and heading) and scanner mirror scale factor are done by automated means using Optech LMS Pro software (currently Version 3.1.0). Project lines or non-project lines flown with opposite headings, combined with perpendicular cross lines, are used as input. These calibration values are checked on a flight-by-flight basis.

After the calibration values are optimized, project flight lines are output and classified into ground and non-ground classes. Surfaces are developed for each flight strip from the ground class points, then these individual flight strip surfaces are differenced, and a value for the average magnitude of the height mismatch (unsigned vertical differences between flight strips) over the entire project area is calculated.

3.2 Absolute Accuracy

3.2.1 DEMs

Note that any lidar-derived DEM accuracy will usually degrade on steep terrain and under canopy.

3.2.2 Bathymetry

Bathymetry points from the green laser data are determined using infrared laser data as control, so any bias may potentially be compounded further.

4   Data Deliverables

4.1   Typical File Formats

1. Point cloud in LAS format (Version 1.2), classified with ground, bathymetry (where applicable), and non-ground returns, in 1000-m × 1000-m rectangular tiles
2. ESRI FLT format 1-m (or 50-cm) DEM from classified ground and bathymetry points
3. ESRI-created Hillshade raster from the grid listed above
4. ESRI FLT format 1-m (or 50-cm) DEM from first-return points (canopy and buildings included)
5. ESRI-created Hillshade raster from the grid listed above
6. Point cloud density image map

4.2   File Naming Convention

4.2.1 LAS Files

The 1000-m × 1000-m tiles follow a naming convention using the lower-left coordinate (minimum X, Y) as the seed for the file name as follows: *XXXXXX_YYYYYY*. For example, if the tile bounds are the coordinate values from Easting 550000 through 551000, and Northing 4330000 through 4331000, then the tile file-name incorporates *550000_4330000*. Additionally, since the data is classified, file names contain the prefix "C" (i.e., C550000_4330000.las). In the occasional instance where tiles are produced using non-classified data, the prefix will be "U."

4.2.2 ESRI Files

Due to the limited number of characters that can be used for ArcGIS data products, the resulting format is followed: *XXX_YYYY_aabb*. Again, the coordinates of the lower-left bound of the raster are used as the seed, e.g., 550_4330. Here the last digits are excluded to conserve characters. Next, the type of return used for creating the raster, represented as "aa," will be either "be" for bare earth (i.e., filtered or ground and bathymetry points) or "fr" for first-return (i.e., unfiltered or default points). Last, the raster-type of the file, represented by "bb," can be "gd" for a grid *.flt file or "hs" for a hillshade.

4.3   LAS File Information

Each of the returns contained on the LAS tiles are encoded with a laser channel value. As previously noted, the Optech Titan has three channels: 1550, 1064, and 532 nm. The values used are *1* (1550 nm), *2* (1064 nm), and *3* (532 nm), and are stored in the User Data record of the Point Data records in the LAS file. Additionally, the Classification Values of the points follow the ASPRS Standard:
www.asprs.org/Committee-General/LASer-LAS-File-Format-Exchange-Activities.html.

NCALM also includes the datum/projection information in the LAS file in the Variable Length Records.

4.4   Metadata

The end user is provided with a one- to two-page project and processing report that covers project-specific results and notes, along with the NCALM Data Collection & Processing Summary (this paper).