AN AFFORDABLE APPROACH TO MOBILE LIDAR DATA ACQUISITION

Josh Kowalski – PLS, CMS-UAS

S&F Land Services

Land Surveying & Remote Sensing

INTRODUCTION

Josh Kowalski, PLS, CMS-UAS
Remote Sensing Surveyor

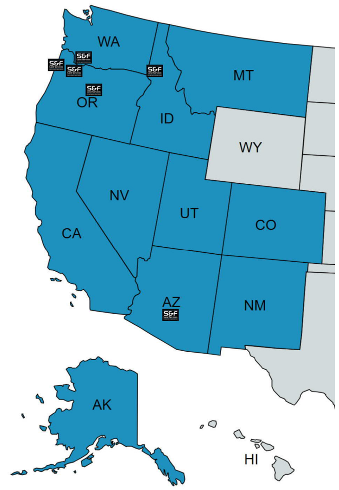
- Education:
  - BS Forestry & GIS/RS- University of Vermont (2007)
  - AAS Geomatics- Clark College (2016)
  - Master's Cert in Remote Sensing and Earth Observation- Penn State (2019)
- Certifications/Licenses:
  - OR PLS #94125- 3/14/23
  - ASPRS CMS-UAS- 11/18/22

INTRODUCTION

S&F Land Services

- Survey and Remote Sensing firm
- Established in 2016
- 6 office locations in OR, WA and AZ
- 14 field crews
- ~50 total staff
- 15 PLS covering OR, WA, CA, ID, MT, NV, UT, CO, AZ, NM and AK

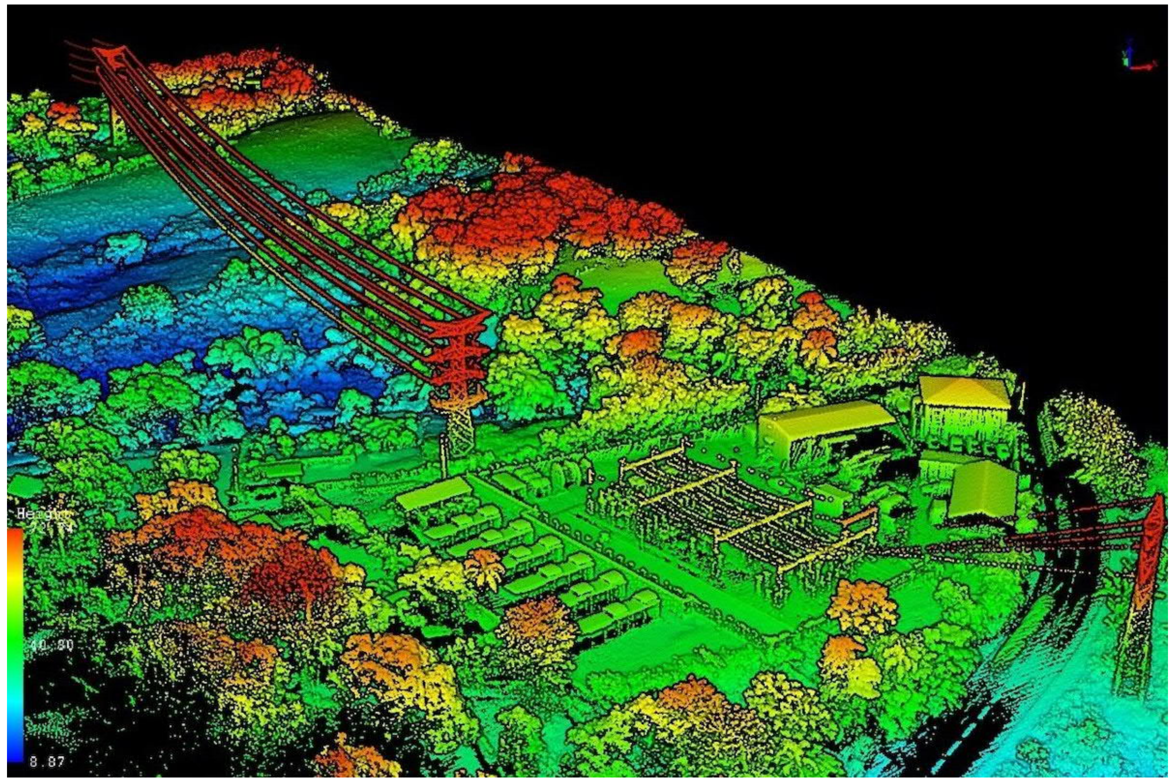
- 60% public sector and utilities
- 40% private development



OVERVIEW

S&F Land Services

- What is lidar?
- How does lidar work?
- Anatomy of a lidar system
- Lidar terminology
- Mobile mount
- Workflow
    - Route planning
    - Data acquisition
    - Office pre-processing
    - Office post-processing
    - Office drafting
- Accuracy assessment
- Software demo



WHAT IS LIDAR?

S&F Land Services

Light Detection and Ranging

Acronym (lidar)
vs.
Initialism (OGUG)

lidar
Lidar
LiDAR
LIDAR
liDAR
LiDar
LiDaR

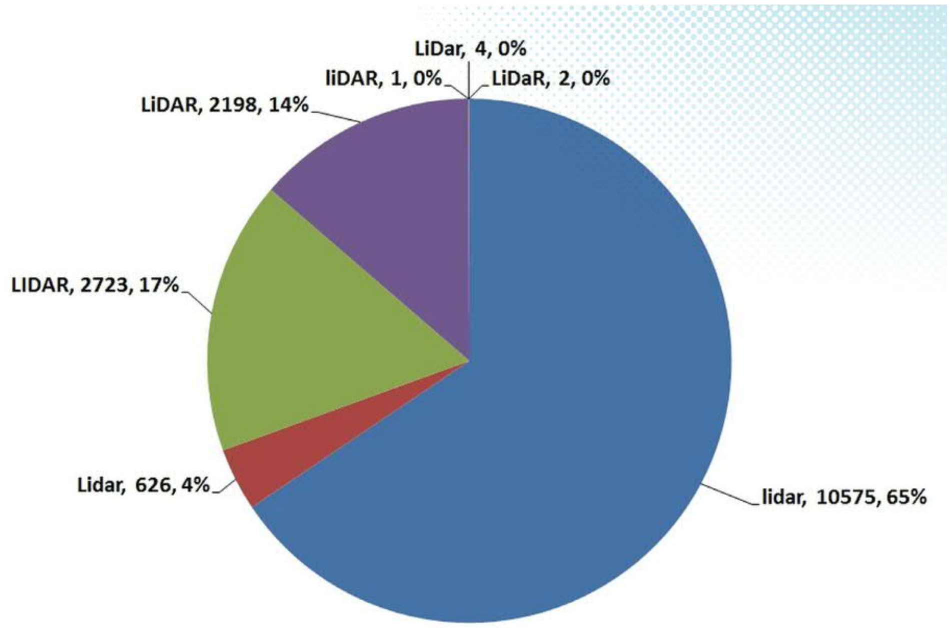


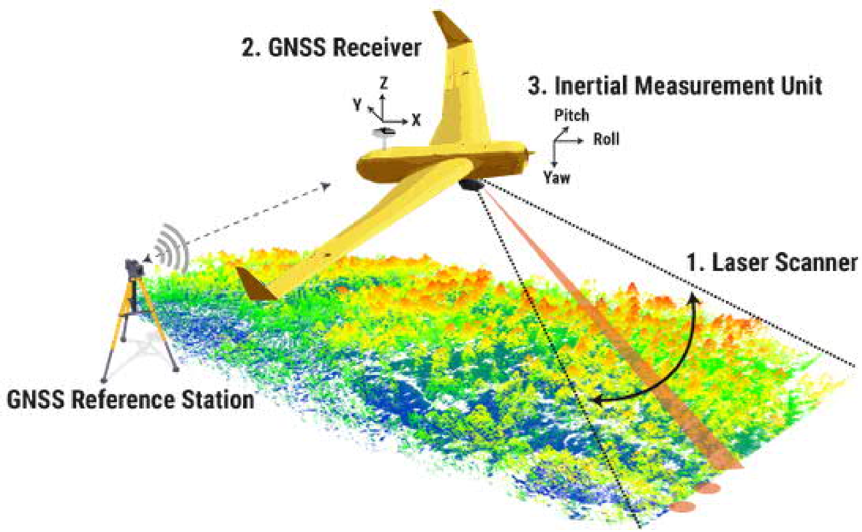
Figure 3: Casings for "light detection and ranging."

LiDAR News Magazine • Vol. 4 No. 6 • Copyright 2014 Spatial Media • www.lidarnews.com
https://www.asprs.org/featured/how-do-we-spell-it-lidar-lidar-lidar.html

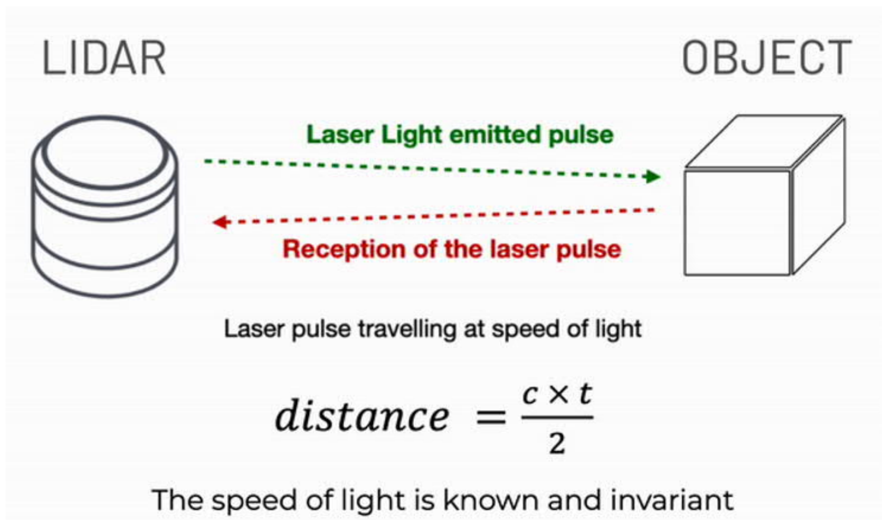
HOW DOES LIDAR WORK?

S&F Land Services

Li(ght) D(etection) A(nd) R(anging) is a remote sensing technology that measures the distance to an object. A laser illuminates the target through light pulses that move at the speed of light. The laser then returns to the sensor and the time it takes for the laser to return is calculated to determine the distance to the object.



Schema on how lidar for drone works



LIDAR SYSTEM ANATOMY

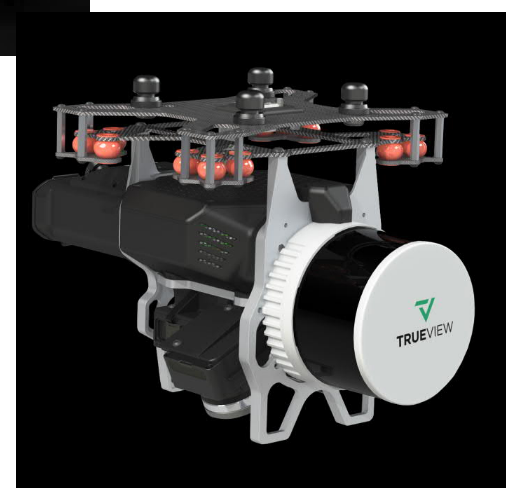
S&F Land Services

Lidar scanner
+
Inertial measurement unit (IMU)
+
GNSS receiver
+
On-board computer
+
Camera (optional)

https://inertiallabs.com/products/resepi-lidar-remote-sensing-payload-instruments/

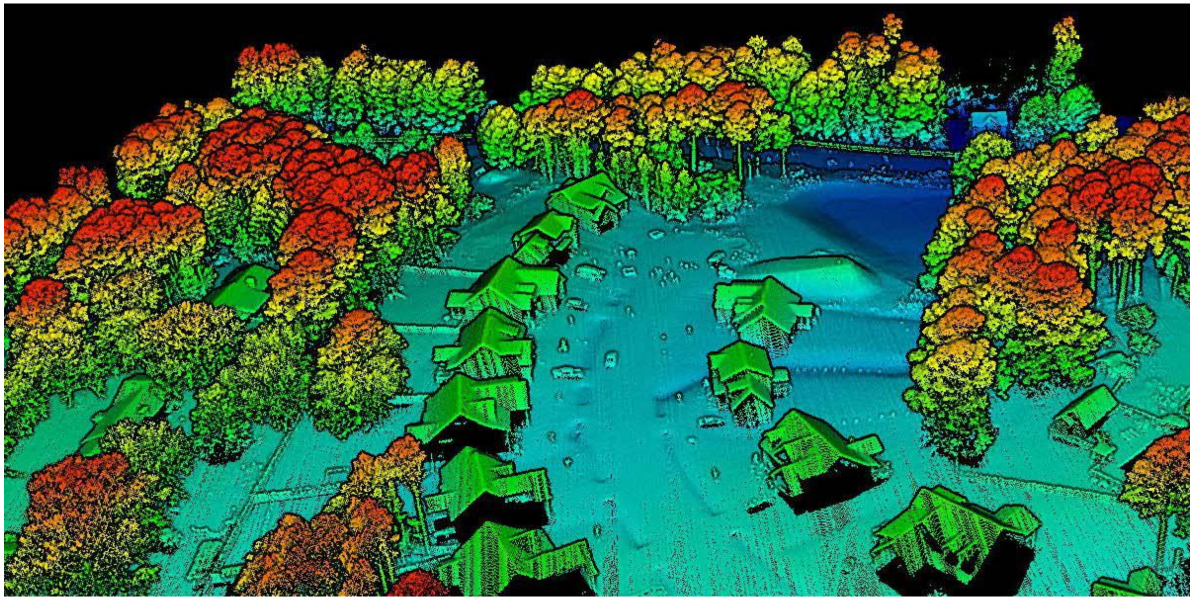
HESAI XT-32M2X

S&F Land Services



LIDAR TERMINOLOGY

Point cloud- a collection of individual data points in a three-dimensional plane, with each point having a set coordinate on the X,Y, and Z-axis. When each point is placed together, it creates a three-dimensional map or model.



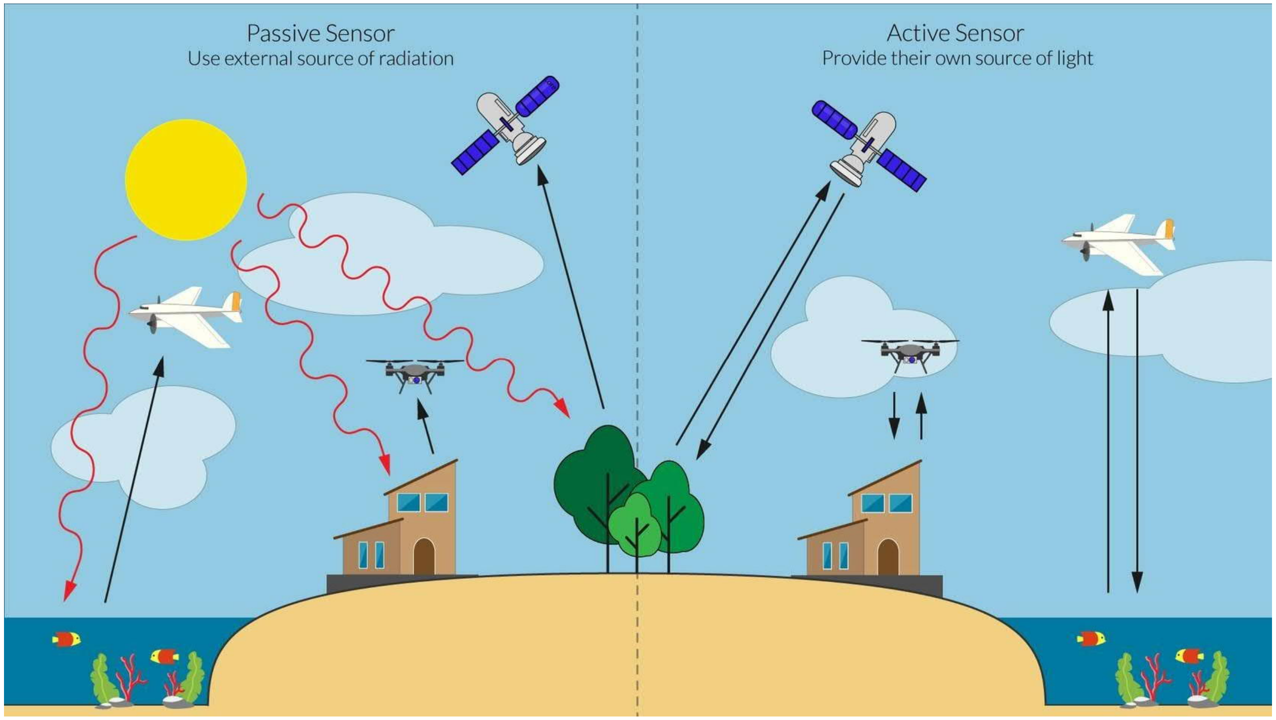
.las/.laz format

LAStools
https://rapidlasso.de/product-overview/

LIDAR TERMINOLOGY

S&F Land Services

Active sensor
vs.
Passive sensor

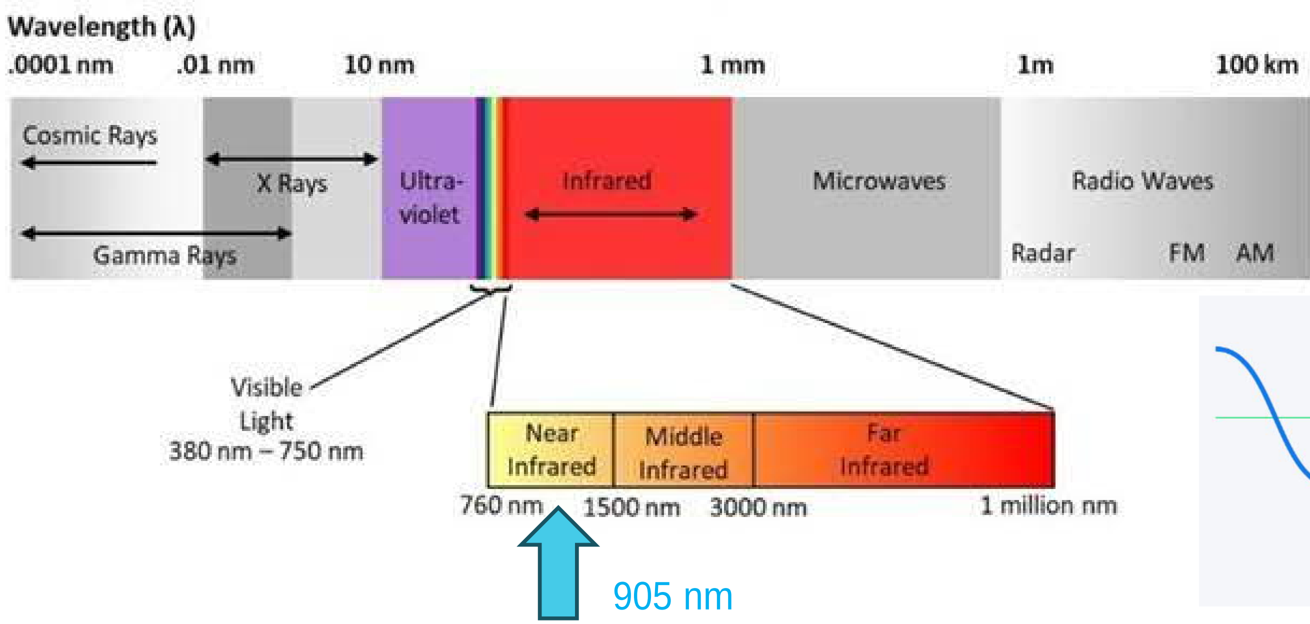


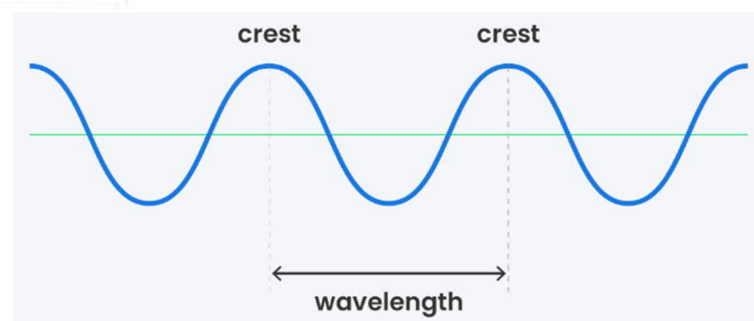
https://reefresilience.org/management-strategies/remote-sensing-and-mapping/introduction-to-remote-sensing/what-is-remote-sensing/

LIDAR TERMINOLOGY

S&F Land Services

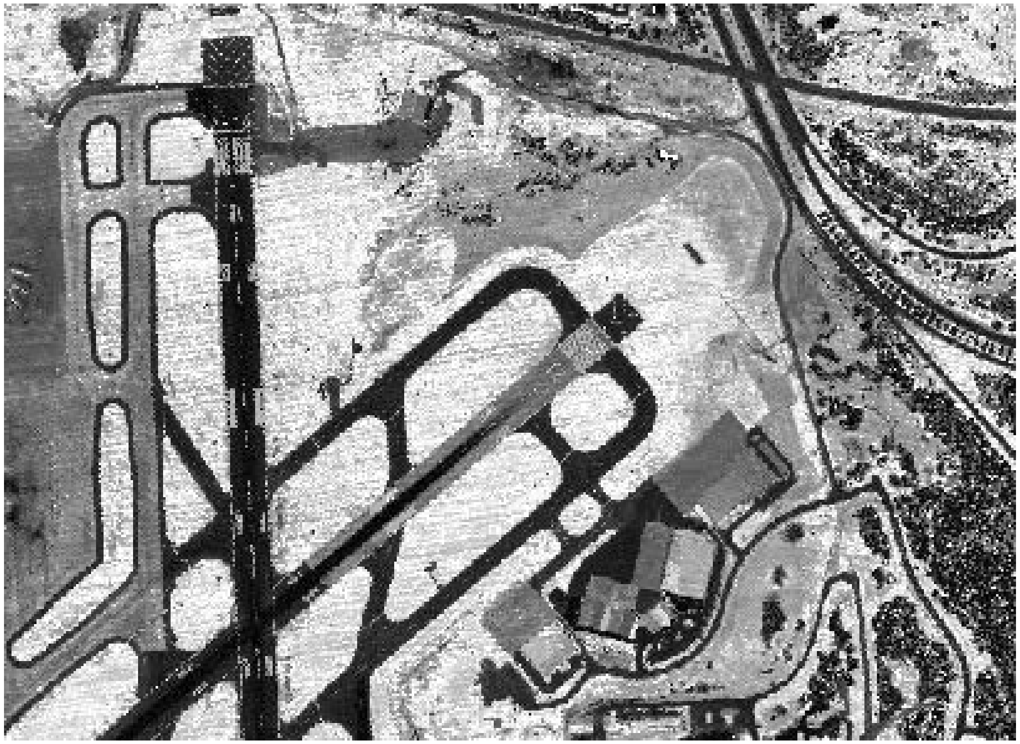
Wavelength (nm)- Distance between crests of a wave in the beam of light. Lidar sensors are usually either 905 or 1064 nm which are invisible to the human eye. One of the objectives of the lidar system is to emit a wave that does not interfere with other sensors (i.e. camera, human eye).





LIDAR TERMINOLOGY

Intensity- a relative measure, collected for every point, of the return strength of the laser pulse that generated the point. It is based, in part, on the reflectivity of the object struck by the laser pulse.



https://desktop.arcgis.com/en/arcmap/latest/manage-data/las-dataset/what-is-intensity-data-.htm

LIDAR TERMINOLOGY

S&F Land Services

Lidar range (m)- the maximum distance the laser can detect an object.

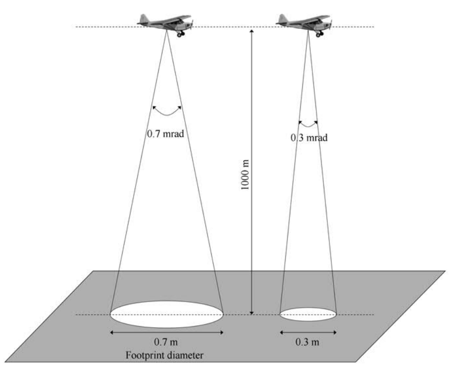
LiDAR

Laser Range Capabilities	80m @ 10% ref. (all channels); 0.05 to 300m
Range Accuracy	+/- 1 cm
FOV (Horizontal)	360°
FOV (Vertical)	40.3°
Scan Angle (Vertical)	-20.8° to 19.5°
Beam Divergence	0.21° (H), 0.047°(V)[3]
Number of Laser	32
Number of Returns	3
Pulse Rate	640k/s (single return); 1280k/s (dual return); 1920k/s (triple return)

LIDAR TERMINOLOGY

S&F Land Services

Beam divergence (mrad; millirad)- the deviation of photons from a single beam emitted by a LiDAR sensor. Because the total amount of pulse energy remains constant regardless of the beam divergence, at a larger beam divergence, the pulse energy is spread over a larger area, leading to a lower signal-to-noise ratio.



A Guide to LIDAR Data Acquisition and Processing for the Forests of the Pacific Northwest by Demetrios Gatziolis and Hans-Erik Andersen.

LiDAR

Laser Range Capabilities	80m @ 10% ref. (all channels); 0.05 to 300m
Range Accuracy	+/- 1 cm
FOV (Horizontal)	360°
FOV (Vertical)	40.3°
Scan Angle (Vertical)	-20.8° to 19.5°
Beam Divergence	0.21° (H), 0.047°(V)[3]
Number of Laser	32
Number of Returns	3
Pulse Rate	640k/s (single return); 1280k/s (dual return); 1920k/s (triple return)

LIDAR TERMINOLOGY

S&F Land Services

Channels- number of lasers

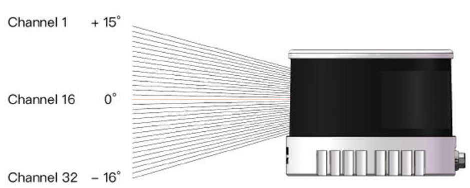


Figure 1.5 Channel Vertical Distribution

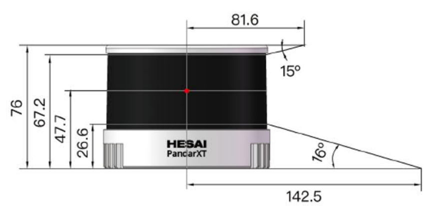


Figure 1.6 Laser Firing Position (Unit: mm)

Each channel has an intrinsic vertical angle offset.
The offsets are recorded in this LiDAR unit's calibration file, which is provided when shipping the unit.

LiDAR

Laser Range Capabilities	80m @ 10% ref. (all channels); 0.05 to 300m
Range Accuracy	+/- 1 cm
FOV (Horizontal)	360°
FOV (Vertical)	40.3°
Scan Angle (Vertical)	-20.8° to 19.5°
Beam Divergence	0.21° (H), 0.047°(V)[3]
Number of Laser	32
Number of Returns	3
Pulse Rate	640k/s (single return); 1280k/s (dual return); 1920k/s (triple return)

LIDAR TERMINOLOGY

S&F Land Services

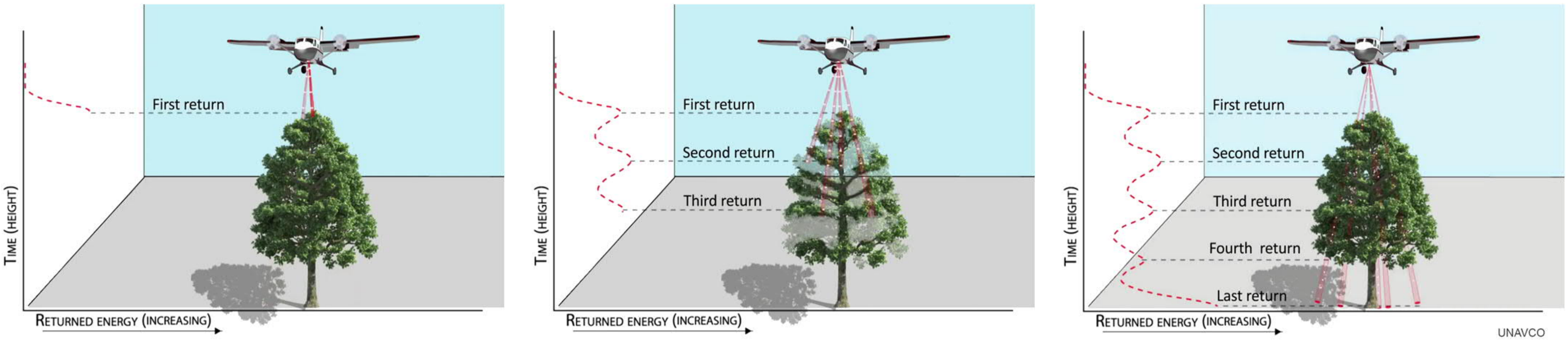
Returns- an attribute of a lidar pulse that signifies the order in which the energy pulse returned to the sensor based on threshold values

LiDAR

Laser Range Capabilities	80m @ 10% ref. (all channels); 0.05 to 300m
Range Accuracy	+/- 1 cm
FOV (Horizontal)	360°
FOV (Vertical)	40.3°
Scan Angle (Vertical)	-20.8° to 19.5°
Beam Divergence	0.21° (H), 0.047°(V)[3]
Number of Laser	32
Number of Returns	3
Pulse Rate	640k/s (single return); 1280k/s (dual return); 1920k/s (triple return)

LIDAR TERMINOLOGY

S&F Land Services



LIDAR TERMINOLOGY

S&F Land Services

Pulse rate- measured in pulses per second, describing how many individual pulses of infrared light are generated in one second.

Frame Rate	5 Hz, 10 Hz, 20 Hz	
Data Points Generated	Single Return:	640,000 points/sec
	Dual Return:	1,280,000 points/sec
	Triple Return:	1,920,000 points/sec

LiDAR

Laser Range Capabilities	80m @ 10% ref. (all channels); 0.05 to 300m
Range Accuracy	+/- 1 cm
FOV (Horizontal)	360°
FOV (Vertical)	40.3°
Scan Angle (Vertical)	-20.8° to 19.5°
Beam Divergence	0.21° (H), 0.047°(V)[3]
Number of Laser	32
Number of Returns	3
Pulse Rate	640k/s (single return); 1280k/s (dual return); 1920k/s (triple return)

LIDAR TERMINOLOGY

Figure 1.2 Partial Cross-Sectional Diagram

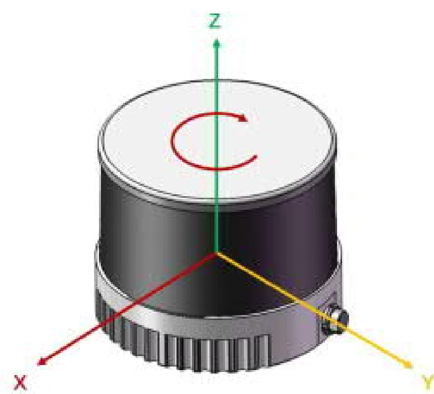


Figure 1.3 Coordinate System (Isometric View)

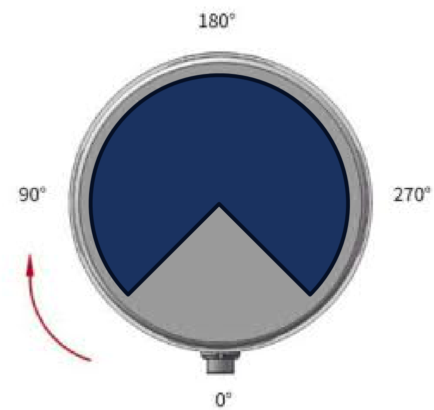
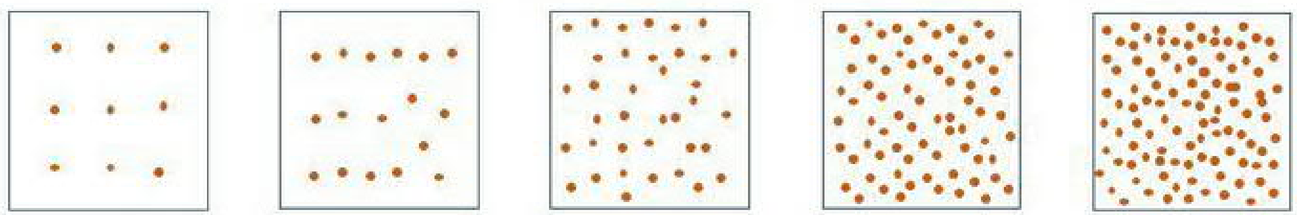


Figure 1.4 Rotation Direction (Top View)

LIDAR TERMINOLOGY



Point Density	0.5-1 pts/m2	1-2 pts/m2	2-5 pts/m2	5-10 pts/m2	10+ pts/m2
Application	• Basic Surface Model • Forest Inventory	• Flood Modelling • Dam and Water Inundation Calculations	• Multi-purpose data sets	• Basic 3D models	• Detailed 3D city models

https://felix.rohrba.ch/en/2015/point-density-and-point-spacing/

INERTIAL LABS IMU

S&F Land Services

Inertial Labs Tactical Grade IMU-P
vs.
Applanix (Trimble) APX-20

PERFORMANCE SPECIFICATIONS[2] (RMS ERROR)

Unmanned Airborne Vehicle Applications

AIRBORNE				
	SPS[9]	RTK[3,9]	PP-RTX[10]	POST-PROCESSED[4,9]
Position (m)	1.5 - 3.0	0.02 - 0.05	0.03 - 0.06	0.02 - 0.05
Velocity (m/s)	0.05	0.15	0.01	0.010
Roll & Pitch (deg)	0.03	0.025	0.015	0.015
True Heading[2] (deg)	0.10	0.08	0.035	0.035

GPS-Aided INS

GPS-Aided Inertial Navigation System

IMU	Inertial Labs Tactical Grade IMU-P
GNSS	Single or Dual Antenna
Constellations	GPS, GLONASS, Galileo, BeiDou, QZSS, NavIC (IRNSS), SBAS, L-Band[5]
Frequencies	L1, L2, L5[6]
Operation Modes	RTK and PPK
Output Rates	Up to 200Hz (INS); Up to 2,000Hz (IMU)
Pitch/Roll Accuracy	0.03° (RTK); 0.006° (PPK)[7]
Heading Accuracy	0.15° (RTK); 0.03° (PPK)[8]
Velocity Accuracy	<0.03 m/s
Position Accuracy	1cm + 1ppm (RTK); 0.5cm (PPK)

MULTI-FREQUENCY HIGH PRECISION SURVEY ANTENNA

S&F Land Services

Technical Parameter				
Frequency	GPS L1/L2/L5	GLONASS G1/G2	COMPASS B1/B2/B3	GALILEO E1/E5a/E5b
Max Gain	L1≥5.5dBi L2≥5.0dBi L5≥2.5dBi	G1≥5.0dBi G2≥4.0dBi	B1≥5.0dBi B2≥5.0dBi B3≥3.5dBi	E1≥5.5dBi E5a≥2.5dBi E5b≥5.0dBi
Polarization	RHCP	Output VSWR	≤1.5	
Coverage Angle	360o	Axis Ratio	≤3dB	
Output Impedance	50Ω	Phase Center Error	<±2mm	

LNA Parameter		Mechanical Characteristics	
Active Gain	38±2dB	Size	D 150mm H 58.4mm
Noise Figure	≤1.8dB	Connector	TNC-K
Input VSWR	≤2.0	Weight	≤360g
Output VSWR	≤2.0	**Operating Environment**	
Delay of Differential	≤5ns	Operating Temperature(°C)	-45°C~+70°C
Supply Voltage	3~5.5V	Storage Temperature(°C)	-55°C~+85°C
Working Current	≤48mA	Humidity	95% non-condensing

https://hyfix.ai/products/multi-frequency-high-precision-survey-antenna

MOBILE MOUNT

S&F Land Services

MOBILE MOUNT

S&F Land Services

MOBILE MOUNT COST

Item	Cost
Inertial Labs RESEPI	$42,000
Inertial Labs PCMaster (includes Novatel Inertial Explorer annual license)	$2500/year
Multi-frequency High Precision Survey Antenna	$95/unit x 2 = $220 w/shipping
Mounting bracket fabrication	$1000
Total	$45,720

WORKFLOW

S&F Land Services

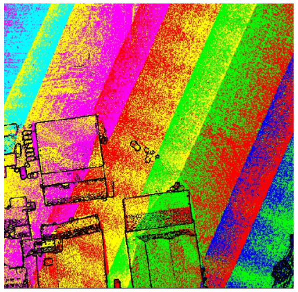
1. Route Planning
2. Data Acquisition (Survey and Mobile)
   - Trimble
3. Process Raw Data
   - Inertial Labs PCMaster
4. Process Point Cloud
   - Terrasolid
5. Extract Planimetric and Topographic Data
   - Virtual Surveyor
   - Carlson Point Cloud
   - Trimble Business Center
6. Draft Final Deliverable
   - Autodesk Civil 3D

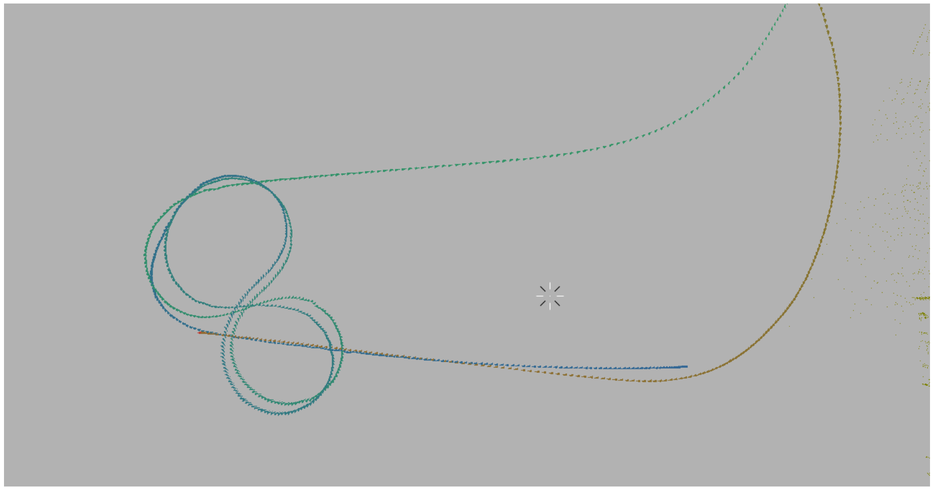
WORKFLOW

S&F Land Services

1. Route Planning
2. Data Acquisition (Survey and Mobile)
   - Trimble
3. Process Raw Data
   - Inertial Labs PCMaster
4. Process Point Cloud
   - Terrasolid
5. Extract Planimetric and Topographic Data
   - Virtual Surveyor
   - Carlson Point Cloud
   - Trimble Business Center
6. Draft Final Deliverable
   - Autodesk Civil 3D

- Goal:
  - Room for calibration routine
  - Overlapping data



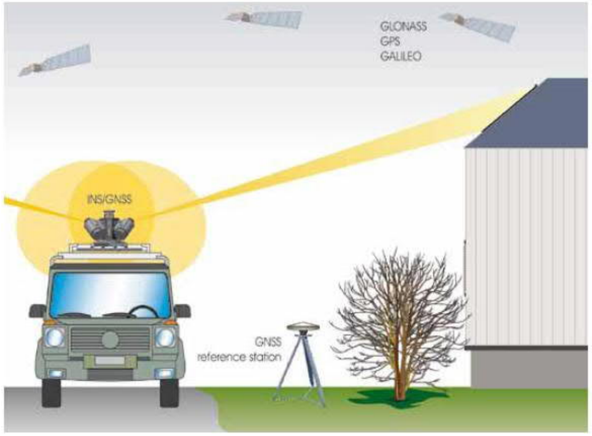


WORKFLOW

S&F Land Services

1. Route Planning
2. Data Acquisition (Survey and Mobile)
   - Trimble
3. Process Raw Data
   - Inertial Labs PCMaster
4. Process Point Cloud
   - Terrasolid
5. Extract Planimetric and Topographic Data
   - Virtual Surveyor
   - Carlson Point Cloud
   - Trimble Business Center
6. Draft Final Deliverable
   - Autodesk Civil 3D

- Ground:
  - Aerial Targets
  - GNSS base data
- Mobile:
  - Laser data
  - Imagery
  - GNSS rover data
  - IMU data



S&F Land Services

3:13 PM Thu Jun 20 ••• 13%

Inertial Labs RESEPI

192.168.12.1

Status Storage Settings RESEPI - 4.2.0.0

Status

INS : Navigation - 0.606,9.991,10.001,0.200,0.200,0.200 - 2024-06-20 22:13:07 UTC

Acc X	Acc Y	Acc Z
0.4927	-6.4841	6.8915

Lon	Lat	Alt
-121.4616891	43.8599910	1257.99

Heading	Pitch	Roll
1.99	-44.92	-3.48

GNSS Solution (Primary)	Satellites
COMPUTED,SINGLE	22

GNSS Solution (Secondary)	Satellites

S&F Land Services

3:13 PM Thu Jun 20

192.168.12.1

13%

Heading	Pitch	Roll
1.34	-44.90	-3.47

GNSS Solution (Primary)	Satellites
COMPUTED,SINGLE	21

GNSS Solution (Secondary)	Satellites
COMPUTED,NARROW INTEGER	23

LiDAR	PPS	GPRMC	Points Logged
Hesai PandarXT32	Present	Present	57701193

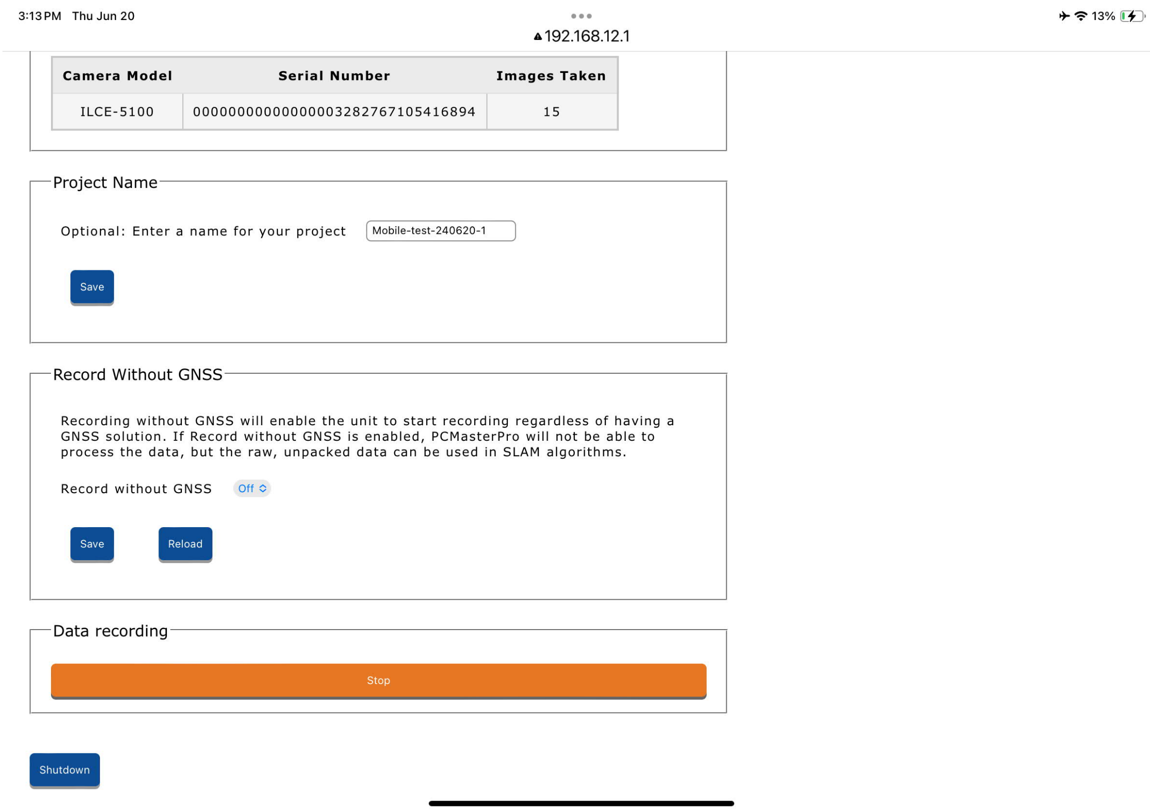
Camera Model	Serial Number	Images Taken
ILCE-5100	00000000000000003282767105416894	13

Project Name

Optional: Enter a name for your project Mobile-test-240620-1

Save

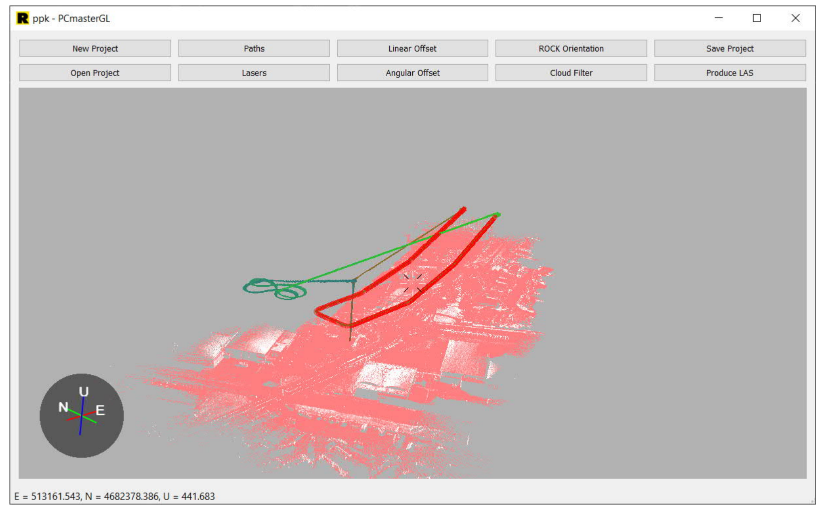
S&F Land Services



WORKFLOW

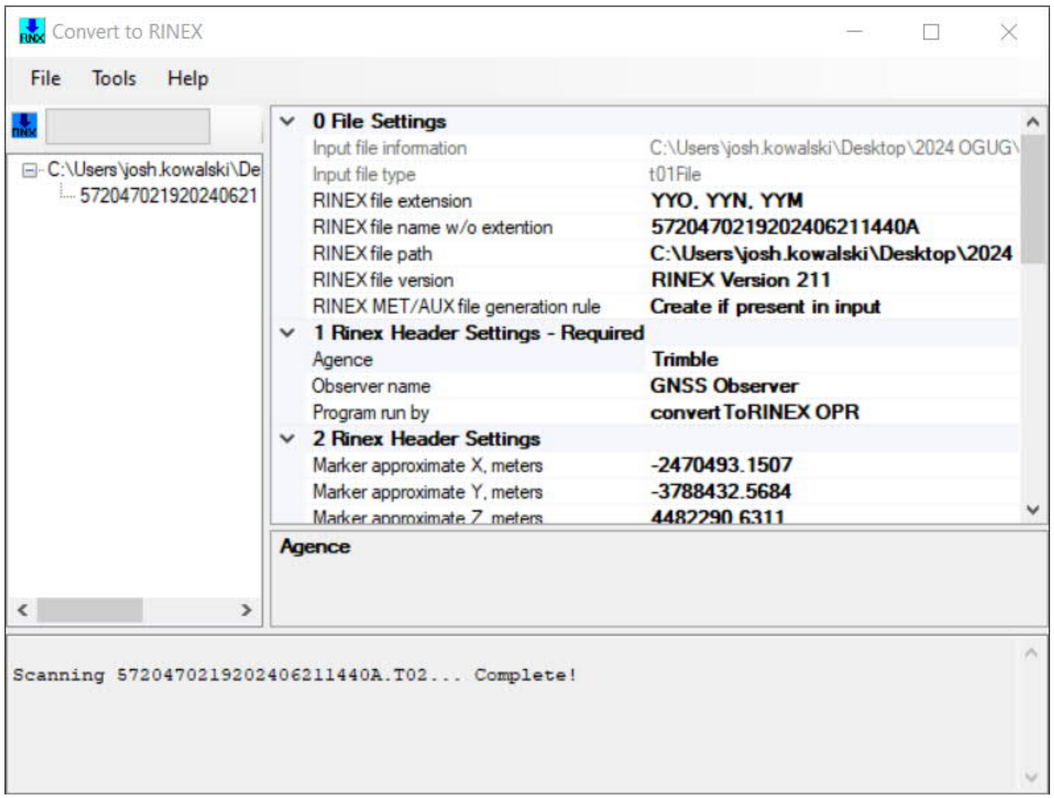
S&F Land Services

1. Route Planning
2. Data Acquisition (Survey and Mobile)
   - Trimble
3. Process Raw Data
   - Inertial Labs PCMaster
4. Process Point Cloud
   - Terrasolid
5. Extract Planimetric and Topographic Data
   - Virtual Surveyor
   - Carlson Point Cloud
   - Trimble Business Center
6. Draft Final Deliverable
   - Autodesk Civil 3D

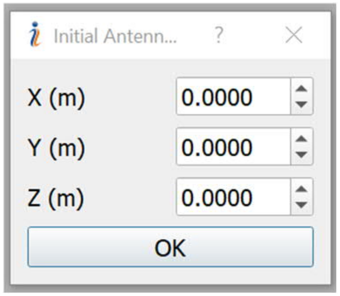


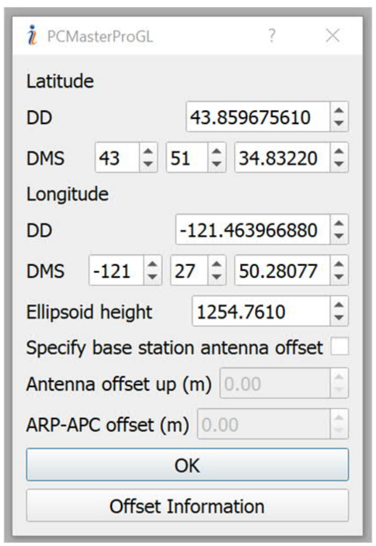
- Input:
  - Raw lidar data
  - Raw imagery
  - GNSS data
  - IMU data
- Output:
  - **Colorized point cloud (.las)**
  - **Smoothed Best Estimate of Trajectory (SBET)**

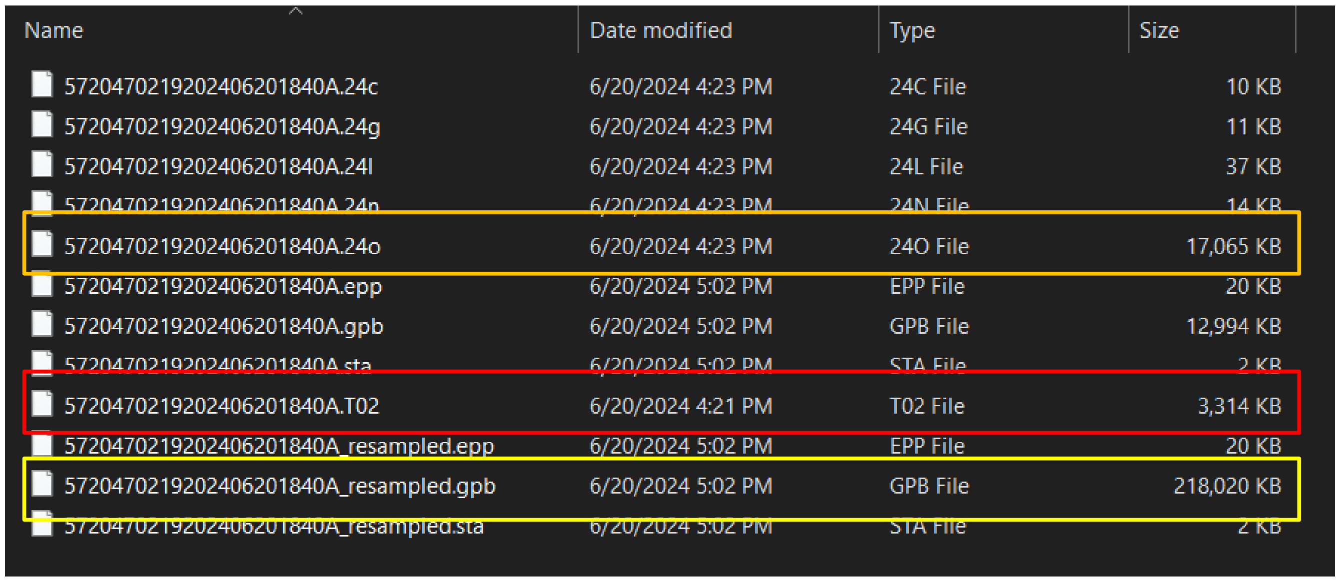
CONVERT TO RINEX



PCMASTER


Initial Antenn...
X (m) 0.0000
Y (m) 0.0000
Z (m) 0.0000
OK


PCMasterProGL
Latitude
DD 43.859675610
DMS 43 51 34.83220
Longitude
DD -121.463966880
DMS -121 27 50.28077
Ellipsoid height 1254.7610
Specify base station antenna offset
Antenna offset up (m) 0.00
ARP-APC offset (m) 0.00
OK
Offset Information


Name Date modified Type Size
5720470219202406201840A.24c 6/20/2024 4:23 PM 24C File 10 KB
5720470219202406201840A.24g 6/20/2024 4:23 PM 24G File 11 KB
5720470219202406201840A.24l 6/20/2024 4:23 PM 24L File 37 KB
5720470219202406201840A.24n 6/20/2024 4:23 PM 24N File 14 KB
5720470219202406201840A.24o 6/20/2024 4:23 PM 24O File 17,065 KB
5720470219202406201840A.epp 6/20/2024 5:02 PM EPP File 20 KB
5720470219202406201840A.gpb 6/20/2024 5:02 PM GPB File 12,994 KB
5720470219202406201840A.sta 6/20/2024 5:02 PM STA File 2 KB
5720470219202406201840A.T02 6/20/2024 4:21 PM T02 File 3,314 KB
5720470219202406201840A_resampled.epp 6/20/2024 5:02 PM EPP File 20 KB
5720470219202406201840A_resampled.gpb 6/20/2024 5:02 PM GPB File 218,020 KB
5720470219202406201840A_resampled.sta 6/20/2024 5:02 PM STA File 2 KB

HEXAGON WAYPOINT FILE TYPES

S&F Land Services

GPB File

Raw code, carrier and Doppler measurements are converted to a GPB file. These are the raw measurements required for post-processing. Also written to the GPB file is a position for each measurement epoch, date, time and other information.

GPB files can be opened within the *GPB Viewer*, which allows you to view the raw measurements collected and perform basic editing functions if needed.

STA File

A station file contains any decoded camera marks, antenna heights and station names. It is read automatically when adding a GPB file to a project. The first line of a station file should contain $STAINFO.

The station file may have a header record. If a *Pos* record is detected, it will be imported automatically when adding the GPB file as a base station to the project. The following is a description of the header format.

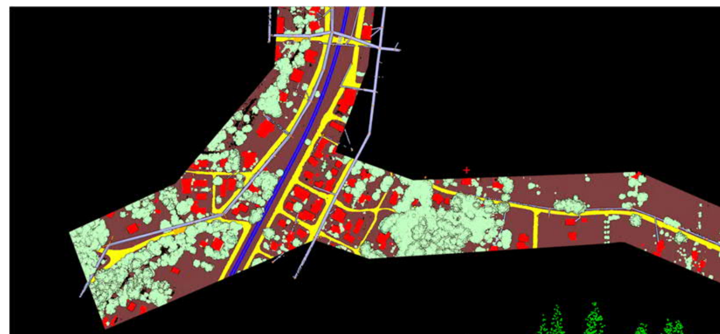
EPP File

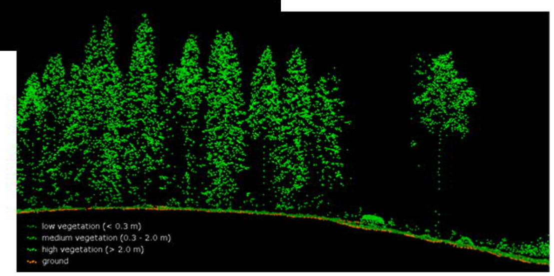
Waypoint's software uses a custom ASCII file format for the ephemeris records. These records are created by the *Convert Raw GNSS data to GPB* utility. Duplicate records will be automatically ignored by the software. Requests for the EPP file format should be made to support.novatel@hexagon.com.

WORKFLOW

S&F Land Services

1. Route Planning
2. Data Acquisition (Survey and Mobile)
   - Trimble
3. Process Raw Data
   - Inertial Labs PCMaster
4. Process Point Cloud
   - Terrasolid
5. Extract Planimetric and Topographic Data
   - Virtual Surveyor
   - Carlson Point Cloud
   - Trimble Business Center
6. Draft Final Deliverable
   - Autodesk Civil 3D





- Cleanup
  - **High/low**
- **Classification**
  - **Auto/manual**
  - **Number of returns**
- **Output:**
  - **Classified point cloud (.las)**
  - **Digital Terrain Model (DTM)**

WORKFLOW

S&F Land Services

1. Route Planning
2. Data Acquisition (Survey and Mobile)
   - Trimble
3. Process Raw Data
   - Inertial Labs PCMaster
4. Process Point Cloud
   - Terrasolid
5. Extract Planimetric and Topographic Data
   - Virtual Surveyor
   - Carlson Point Cloud
   - Trimble Business Center
6. Draft Final Deliverable
   - Autodesk Civil 3D

ACCURACY ASSESSMENT

S&F Land Services

ASPRS Positional Accuracy Standards for Digital Geospatial Data, Edition 2 was approved by the ASPRS Board of Directors on August 23, 2023

Addenda on best practices and guidelines

Addendum I: General Best Practices and Guidelines

Addendum II: Best Practices and Guidelines for Field Surveying of Ground Control and Checkpoints

Addendum III: Best Practices and Guidelines for Mapping with Photogrammetry

Addendum IV: Best Practices and Guidelines for Mapping with Lidar

Addendum V: Best Practices and Guidelines for Mapping with UAS

THANK YOU!

S&F Land Services

Josh Kowalski, PLS, CMS-UAS
josh.kowalski@sflands.com