Advanced Remote Sensing using LiDAR
Lecture 2

GEOG660

MPSGIS
Department of Geographical Sciences
University of Maryland

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UNIVERSITY OF MARYLAND

Acknowledgment

The contents of this course, lectures and labs, are mostly based on Dr Jonathan Resop's course materials.

Annoucements

- Lab 1 due on Friday
- Don't forget the Quiz !

Outline

Components of a LiDAR system

Typical airborne LiDAR system : a laser scanner, a ranging unit, control, monitoring, and recording units, a differential global positioning system (DGPS) and an inertial measurement unit (IMU).

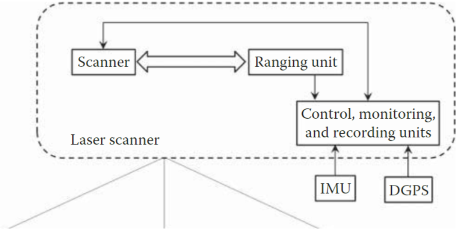
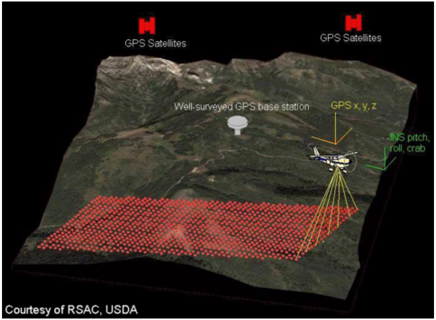


FIGURE – *Modified from Dong, 2018*



Why learn about the intrumentation ?

- Be familiar with acronyms and technical terms
- Be aware of the evolution of the technologies
- Know the potential sources of error

GNSS

- Global Navigation Satellite System
- Triangulation : 3 to 4 satellites
- Six (6) systems worldwide :
  - GPS(USA) : the oldest (1994), 24 operational satellites (72 launched)
  - GLONASS (Russia) : 1993, 27 satellites
  - Galileo (EU) : 2020, 30 satellites
  - BeiDou/COMPASS (China) : 2000, 35 satellites
  - QZSS (Japan) : 2018, 7 satellites
  - IRNSS-NAVIC (India) : 7 satellites

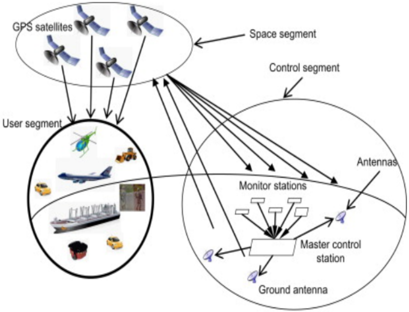


FIGURE – nasm

Global Positioning System (GPS)

- Two levels of service :
  - SPS : Standard Positioning Service
  - PPS : Precise Positioning Service
- 4m RMS accuracy (7.8m 95% confidence interval)
- Use of correction to increase the accuracy : RTK (up to 1cm accuracy)
- Determines the location of the sensor (x,y,z)
- Used for georeferencing
- Sources of Error :
  - Satellite-based (Orbital, System)
  - Propagation-based (Atmospheric)
  - Receiver-based (Receiver Noise)

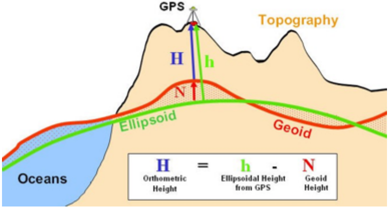
Coordinate systems

Coordinate system

Locate a point on the globe with an x,y position in an **absolute** referential system.

- **Geographic coordinate systems** are based on a spheroid and use angular units (degrees)
  - Ex. : WGS84
- **Projected coordinate systems** are based on a plane (spheroid projected on a 2D surface) and uses linear units (feet, meters)
  - Ex. : UTM

Coordinate systems



- Geographic datums
  - Reference surfaces of the Earth
    - Geoid : approx. of sea level
    - Ellipsoid : simple representation of the geoid
    - Height above ellipsoid
  - Horizontal datums
    - X and Y (lat and long)
  - Vertical datum
    - Z (elevation)

IMU/INS/AHRS

- IMU : Inertial Measurement Unit
- INS : Inertial Navigation System
- AHRS : Altitude Heading Reference System
- Be careful : sometimes terms used in place of each other
- IMU : sensor
  - 3 axis accelerometer (linear acceleration)
  - 3 axis gyrometer (rotational acceleration)
  - does not provide position, altitude, velocity
- INS
  - Contains an IMU
  - Provides navigation information
  - Provides relative position to a departure point
  - Dead-reckoning

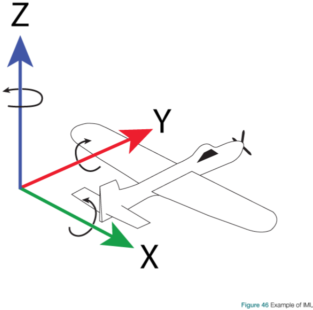


FIGURE – IMU orthogonal axis

Combined system GPS/INS for better positioning

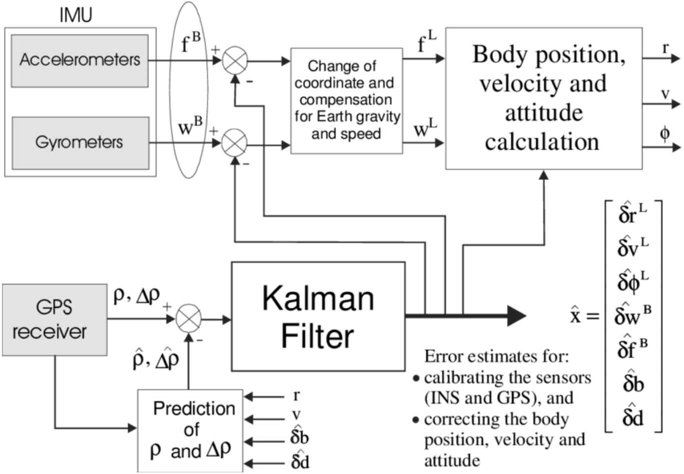


FIGURE – INS GPS integration

Combined system GPS/INS for better positioning

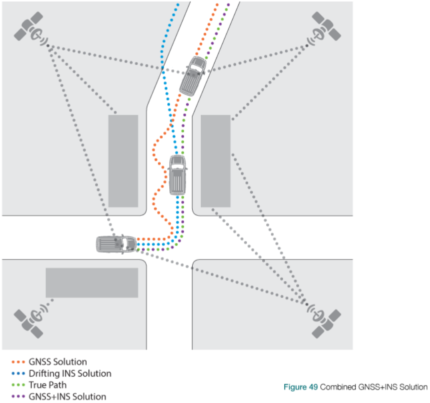
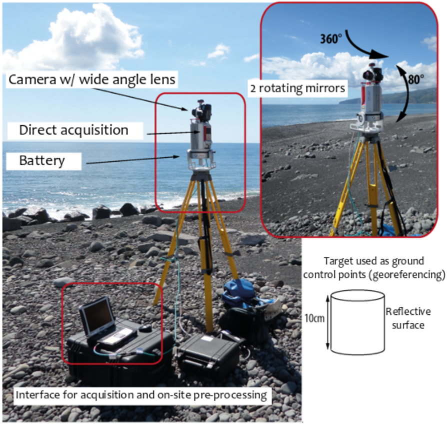


FIGURE – Example of a better path accuracy using combined GNSS and INS

Example : if you are a sighted person and somebody leads you in your own house with your eyes closed, you rely on your senses to know where you are -> INS/IMU, if you open your eyes you know your location (GNSS) but you don't know your previous itinerary for sure

Georeferencing without a couple INS/IMU

In general the acquisition will include an INS/IMU system
However, in the case of Terrestrial LiDAR we can use ground-control points to reach a centimeter accuracy



- Cyclinders with a reflective surface
- We spread 15-20 targets on the study area
- Their location is surveyed using a GPS RTK
- Georeferencing during the field acquisition

Components of a Laser Scanner

Three components :

- Transmitter
  - Sends out pulses of light very quickly
  - Beam expander used to reduce beam divergence
- Receiver
  - Telescope collects backscattered photons
  - Analyzer then selects specific wavelengths
- Computer
  - Calculates digital returns

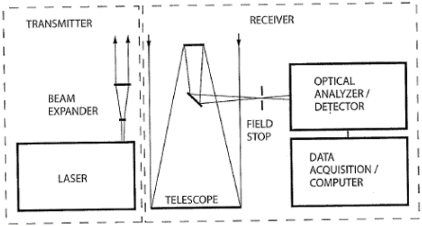


FIGURE – Wandinger, 2005

Example 1/2 - Aerial LiDAR specifications

atlantic

USDA Forest Service, Fremont-Winema, Willamette,
Deschutes, and Umpqua National Forests
Aerial Lidar Report, 16061
January 2017

1.7 Lidar System Acquisition Parameters

Table 2 illustrates Atlantic's system parameters for lidar acquisition on this project.

Lidar System Acquisition Parameters	
Item	**Parameter**
System	Leica ALS-70 HP
Nominal Pulse Spacing (m)	0.5
Nominal Pulse Density (pls/m²)	4.2
Nominal Flight Height (AGL meters)	1965
Nominal Flight Speed (kts)	110
Pass Heading (degree)	0
Sensor Scan Angle (degree)	30
Scan Frequency (Hz)	41.0
Pulse Rate of Scanner (kHz)	278.0
Line Spacing (m)	465
Pulse Duration of Scanner (ns)	4
Pulse Width of Scanner (m)	0.43
Central Wavelength of Sensor Laser (nm)	1064
Sensor Operated with Multiple Pulses	Varies
Beam Divergence (mrad)	0.22
Nominal Swath Width (m)	1098
Nominal Swath Overlap (%)	50
Scan Pattern	Triangle

Table 2: Atlantic Lidar System Acquisition Parameters

Example 2/2 - Terrestrial LiDAR specifications

RIEGL VZ-400i Technical Data

- 800m max. measurement range
- 1.2MHz pulse repetition rate PRR
- online waveform processing
- Wi-Fi and 3G/4G LTE
- optional camera
- multiple target capability
- Laser Class 1

Laser Pulse Repetition Rate PRR (peak)	**100 kHz**	**300 kHz**	**600 kHz**	**1,200 kHz**
Max. Effective Measurement Rate (meas./sec)	42,000	125,000	250,000	500,000
Max. Measurement Range ($\rho \geq 90$ %)	800 m	480 m	350 m	250 m
Max. Measurement Range ($\rho \geq 20$ %)	400 m	230 m	160 m	120 m
Minimum Range	1.5 m	1.2 m	0.5 m	0.5 m
Accuracy / Precision	5 mm / 3 mm			
Field of View (FOV)	100° vertical / 360° horizontal			
Eye Safety Class	Laser Class 1 (eyesafe)			
Main Dimensions (width x height) / **Weight**	206 mm x 308 mm / 9.7 kg			

Further details to be found on the current *RIEGL* VZ-400i Data Sheet.

Key terms

- Properties of LiDAR flight line :
  - LiDAR **Swath**
    - A single pass of an aircraft over the coverage area
    - Defines the **flight line**
  - Scanning pattern
    - Pattern on the ground resulting from the LiDAR pulses
    - Defines the **scan line**
  - Scan angle
    - Angular extent of the LiDAR scanner
  - Swath width
    - The data extent or area resulting from a single flight line

LiDAR Swath

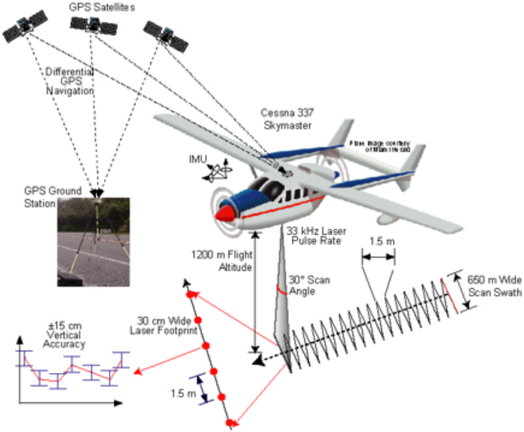
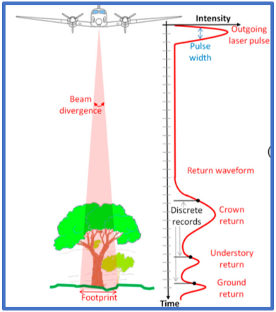


FIGURE – mdpi



Scanning pattern

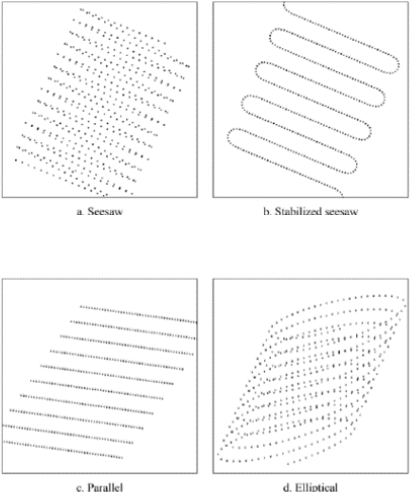


FIGURE – USDA

- Depends on the LiDAR system technology
- Seesaw (aka oscillating mirrors)
  - the "zig-zag" is the most popular scanning method
  - Pulses can "bunch up" (= higher density) at swath edges
  - Edge data usually thrown out (keep 95% in the middle)

Scanning pattern

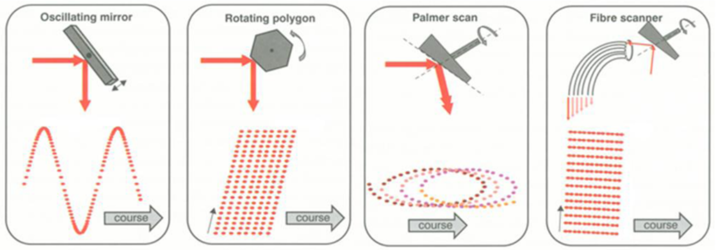
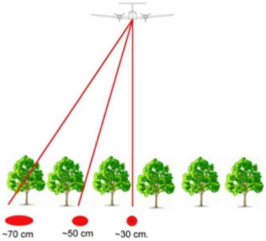
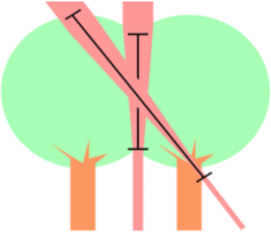


FIGURE – mdpi

- Parallel (rotating mirror)
  - Even spacing, but larger between-scan spacing
- Push broom (fiber scanning)
  - Uses fiber optics to split laser into a fixed linear array

Scan angle

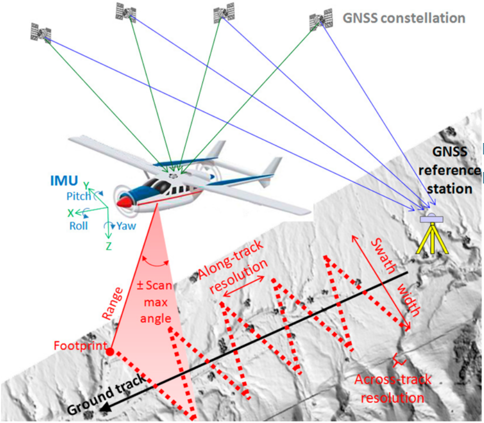




Canopy penetration gets worse with increasing scan angles

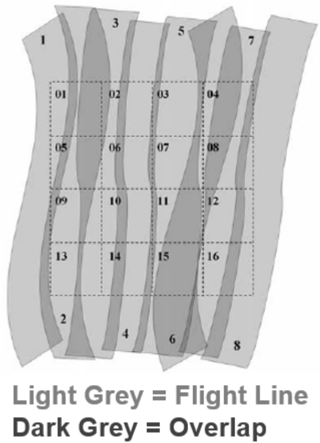
- Field of view from the aircraft
  - Along with the Scan Pattern, the Scan Angle defines the Scan Line
  - Scan Line = The line defined by a single "pass" of the laser scanner
- As Scan Angle increases, Accuracy decreases
  - Results in larger pulse footprint
  - More difficult to penetrate canopy
  - Recommended inf to 40° Total
  - Accuracy highest at nadir (0°)

Swath width



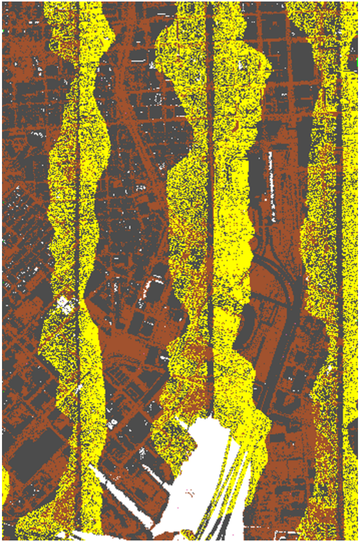
- Total width of a single flight line
- Defined by :
  - Flight line
  - Max scan angle
  - Flight altitude

LiDAR swath overlap



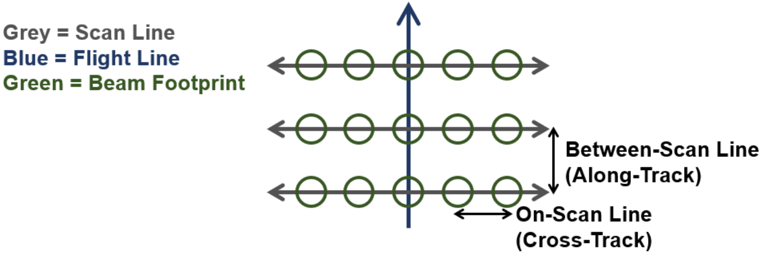
- Important to include overlap between LiDAR swaths
- Overlap is useful for :
  - Calibration and Validation
  - Georeferencing Flightlines
  - Increasing Point Density
  - Avoiding Data Gaps
- No set standard
  - Usually recommended to use between 20% and 50% overlap

LiDAR swath overlap



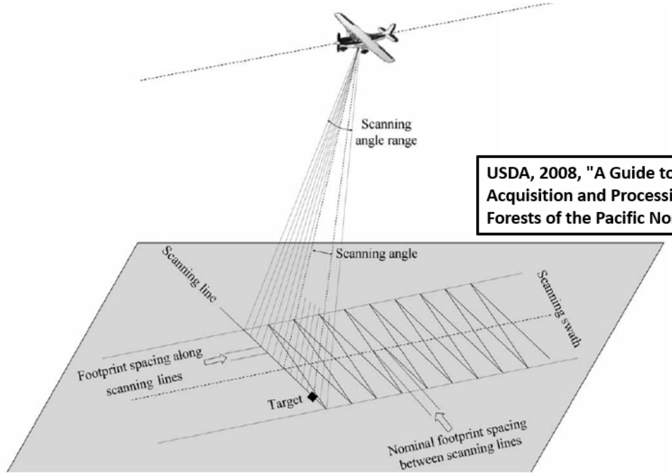
- Example : Baltimore, MD
- Classification legend :
  - Brown = Ground (LAS Code = 2)
  - Grey = Non-ground (LAS Code = 1-Unclassified)
  - White = No Data (LAS Code = N/A)
  - Yellow = Data Overlap (LAS Code = 12)

LiDAR Scan line



Variable	Between-Scan Line Pulse Spacing	On-Scan Line Pulse Spacing
Flight Speed	Decreasing Flight Speed Decreases Point Spacing	No Effect
Pulse Rate	No Effect	Increasing Pulse Rate Decreases Point Spacing
Renslow, 2012, Manual of Airborne Topographic Lidar		

LiDAR Scan line vs. Flight line

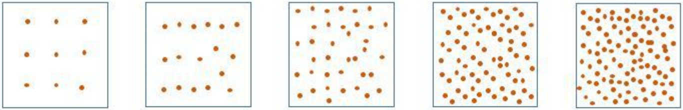


USDA, 2008, "A Guide to LIDAR Data Acquisition and Processing for the Forests of the Pacific Northwest"

LiDAR Data Collection

- Point Spacing vs. Point Density
  - Both related to the overall spatial resolution
  - Spacing = Distance (units) between points
  - Density = Points per square distance (units)
  - Spacing and Density have an inverse relationship
- Pulse Spacing vs. Return Spacing
  - Remember each pulse can produce multiple returns
  - Pulse Spacing = Determined by last returns
  - Return Spacing = Determined by all returns

LiDAR point density and applications



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

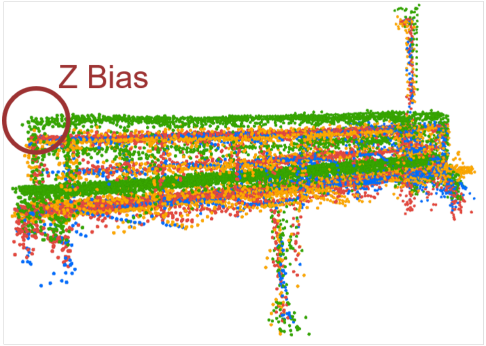
Outline

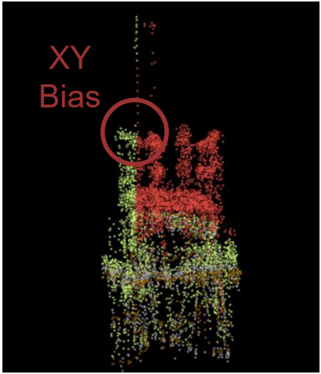
LiDAR Calibration

- Identifying and correcting systematic errors
  - Initial calibration during sensor manufacture and during installation on the aircraft
  - Additional calibration during every LiDAR flight
- Compare measured with know correct data
- Why do we care ?
  - Accuracy of data with respect to location and elevation
  - Laser range detection repeatability
  - Matching data between scans (edge matching)
  - Reducing bias between scans

Examples of LiDAR Bias

Left - Bias between repeat surveys **Right** - Bias within single survey





LiDAR Calibration

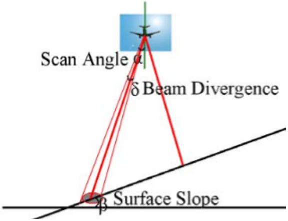
- Categories of LiDAR Calibration
  - Instrument Calibration – Specific to the LiDAR system
  - Data Calibration – Specific to the particular flight
- Types of Data Calibration
  - Geometrically – Location-based Data
  - Radiometrically–Reflected Intensity Data
- Variables of Interest
  - Roll, Pitch, Yaw Errors – Airplane parameters
  - Scan Angle Errors – Offset at edge of scan
  - Z-bias Errors – Elevation is offset

Components of Calibration

- Consists of several flight lines
  - Should be at different angles
  - i.e. Cross-flight lines
- Should use a well defined area
  - Well surveyed and well mapped
  - e.g. Airfield where LiDAR is flown
- Site usually consists of :
  - Flat terrain – Errors are more apparent
  - Structures – For positional errors
- Sloped and forested areas more difficult

Error of Ground Elevation tends to be higher...

- In densely forested areas than in open areas
- On steeper slopes (25°) than on lower slopes (1.5°)
- With horizontal measurements than with vertical
- Remember, the Pulse Footprint depends on...
  - Flight Altitude
  - Beam Divergence
  - Scan Angle
  - Surface Slope



http : //asprs.org/a/publications/pers/2004journal/march/2004$_{m}$ar$_{3}$31 − 339.pdf http : //www.asprs.org/a/publications/proceedings/baltimore09/0099.pdf

Geometric (XYZ) Data Calibration

Filter target areas based on known target location and maximum expected error in LiDAR data

↓

Extract target points based on elevation and intensity data

↓

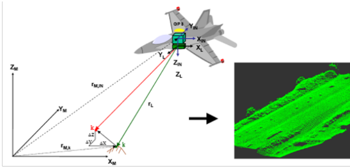
Horizontal and vertical positioning of target in LiDAR data (Hough transform, mean elevation)

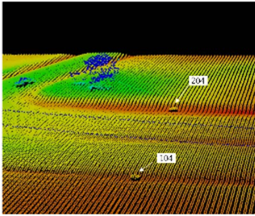
↓

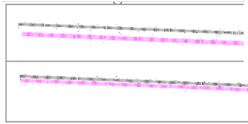
Error computation and analysis at target locations in LiDAR strips

↓

Applying correction to LiDAR strip by accepted transformation







Road area	Elevation difference [m]	
	Before	After
#1	-0.13	-0.04
#2	-0.14	-0.05

(b) Elevation difference at road area#2 before and after

Csanyi, N. 2006. "Precision LiDAR Mapping of Transportation Corridors Using LiDAR-Specific Ground Targets." *Geospatial Information System for Transportation Symposium, Columbus, OH.*

Radiometric (Intensity) Data Calibration

- More difficult than geometric calibration
  - Dependent on many more variables !
  - Should be performed by the manufacturer
- Possible intensity-related errors :
  - White paint strips (e.g. roadways) become more elevated
  - Elevation stripping in agricultural fields
  - Mismatched data at the edge of flight lines
  - Large shifts in elevation for nearby points (noise)
  - Very dark pavement results in lost data points

https://rapidlasso.com/2016/04/05/fixing-intensity-differences-between-flightlines-quick-and-dirty/

Accuracy

- Aerial LiDAR typically reports accuracies of $\pm 15cm$ vertical and $\pm 50cm$ horizontal
- Many sources contribute to this overall accuracy :
  - Precision in the GPS and IMU
  - Atmospheric Effects (laser, georeferencing, etc.)
  - Environmental Artifacts and Noise (birds, aerosols, etc.)
  - Resolution of Internal Clocks (0.2 nsec - 6 cm [z])
  - Footprint Size (0.2 to 0.3 mrad - 24 to 60 cm [xy])
- More on this topic during Lecture 5

$http://www.isprs.org/proceedings/XXXVII/congress/1_pdf/34.pdf$

Outline

LiDAR Data Processing

See GEOG660-Lecture2-SUMMER2020-DataProcessing

Concluding remarks

- Acquisition system
  - Always the same composition
  - Relies on other technologies (GNSS...)
  - You can adapt LiDAR to any platform
- Data collection
  - Important to know how the data was acquired
  - The choice of the parameter can make a field survey successful or completely useless
  - Based on basic geometry
  - Specialty depending on the acquisition conditions
- Calibration
  - Induce error in the data
  - Systematic errors difficult to spot
- Processing
  - For any project, always good to go back to the data
  - What does the dataset look like ?
- More on taht in Lab 2
  - Downloading LAS data
  - LiDAR data properties and statistics in ArcGIS
  - Processing LiDAR data using LAStools