Remote Sensing (2)

Lecture No: 1

Laser Scanning

Agenda

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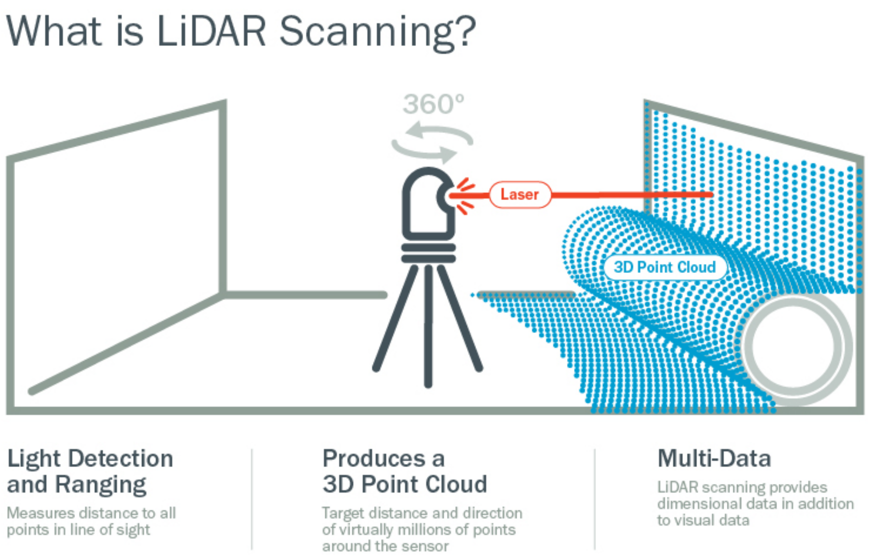
- Introduction
- Components of LiDAR System
- Basic Working Principle
- LiDAR Platforms
- Important Terms
- LiDAR QA and QC
- LiDAR Data Characteristics
- Applications
- Error Sources and Limitations
- LiDAR Resources

What is LiDAR?

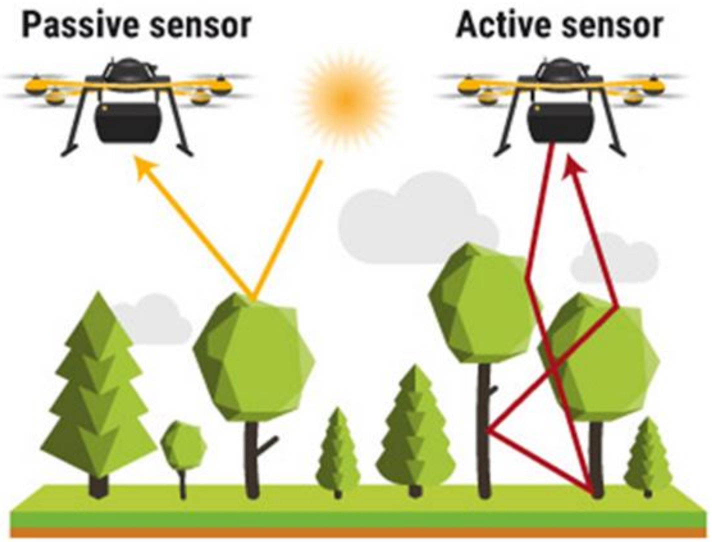
LiDAR (Light Detection and Ranging)

- It is an active remote sensing technique that measures distance by illuminating the target with a laser beam.
- LiDAR is not only replacing conventional sensors, but also creating new methods with unique properties that could not be achieved before



Why LiDAR?

- An active sensor, independent of sunlight, it can be used during day or night.
- It is used to generate precise and geo-referenced spatial information.
- Lasers produce a coherent light source.
- It reveals a high-density point cloud of the captured scene.



Discrete vs. Full Waveform LiDAR

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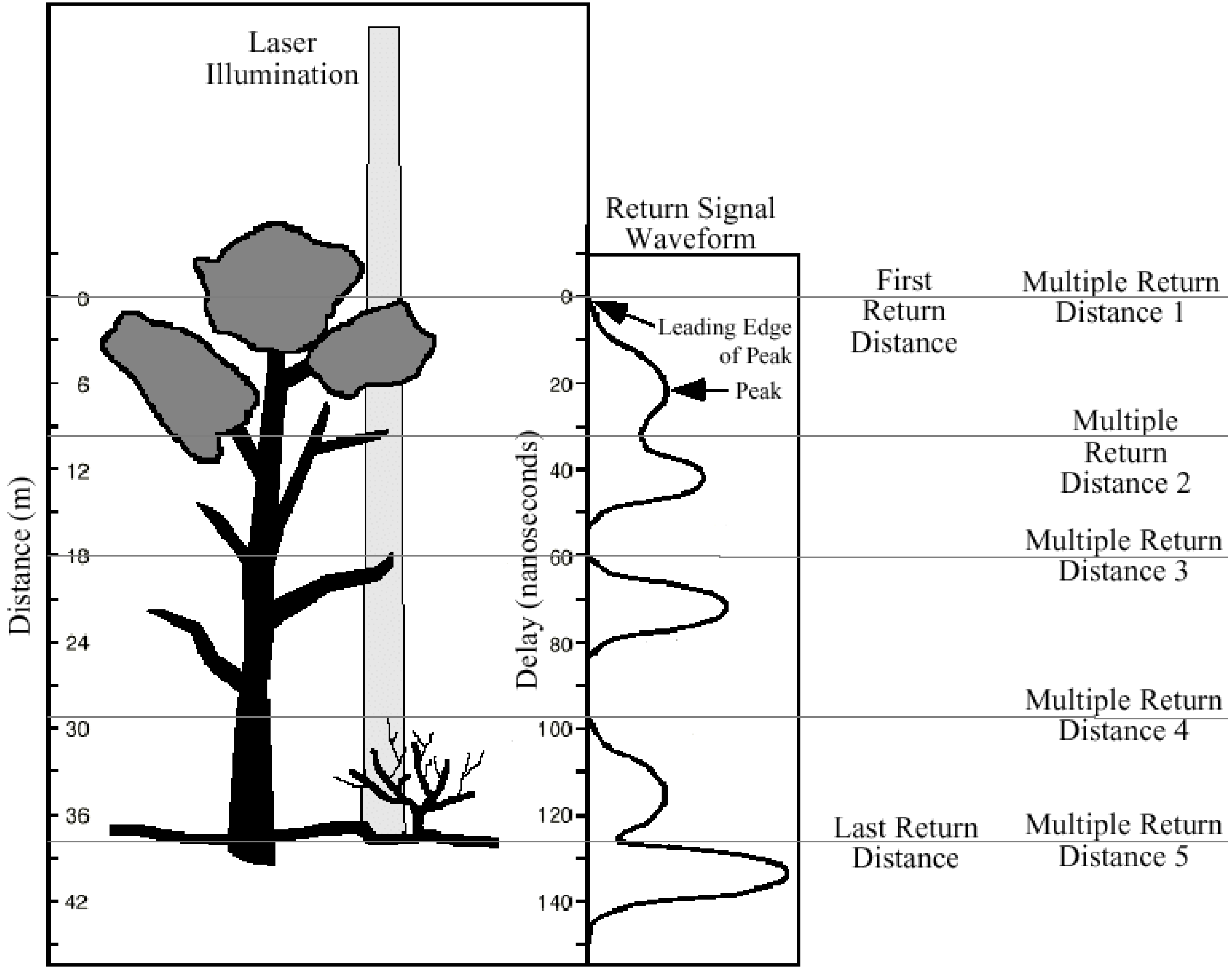
- A waveform or distribution of light energy is what returns to the LiDAR sensor. However, this return may be recorded in two different ways.
- A Discrete Return LiDAR System records individual (discrete) points for the peaks in the waveform curve. Discrete return LiDAR systems identify peaks and record a point at each peak location in the waveform curve. These discrete or individual points are called returns. A discrete system may record 1-4 (and sometimes more) returns from each laser pulse.
- A Full Waveform LiDAR System records a distribution of returned light energy. Full waveform LiDAR data are thus more complex to process however they can often capture more information compared to discrete return LiDAR systems.

Discrete vs. Full Waveform LiDAR



LiDAR Vs Photogrammetry

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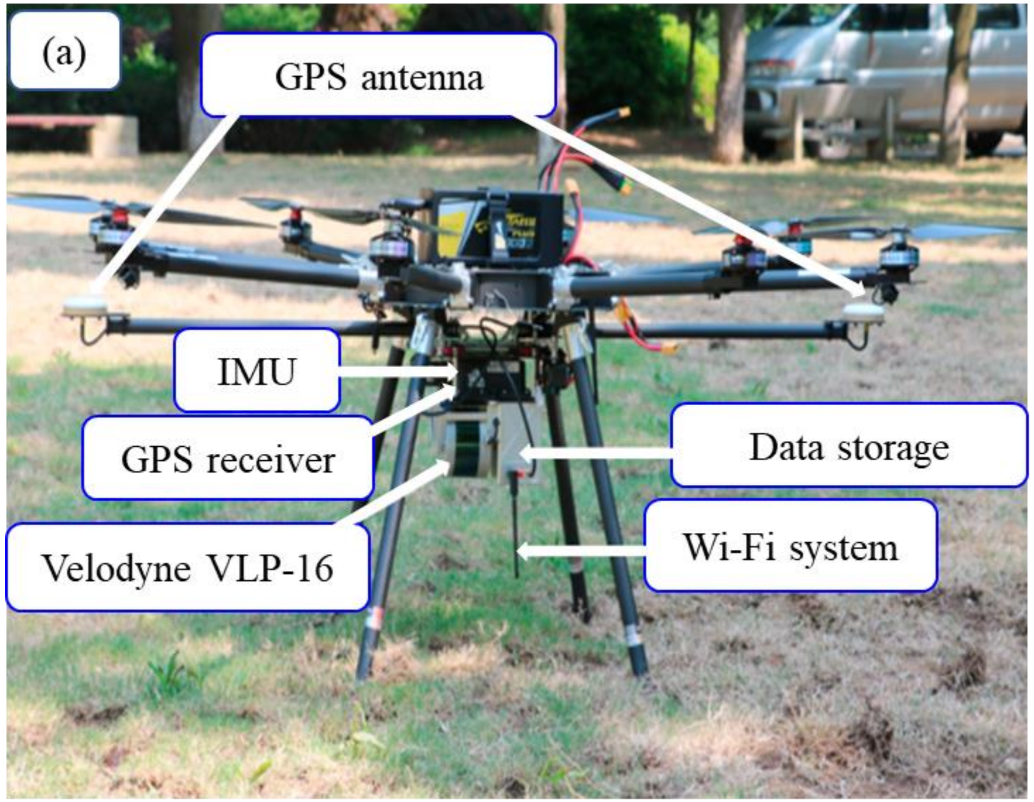
LiDAR	Photogrammetric
Day or night data acquisition	Day time collection only
Direct acquisition of 3D collection	Complicated and sometimes unreliable procedures
Vertical accuracy is better than planimetric*	Planimetric accuracy is better than vertical*
Point cloud difficult to derive semantic information; however, intensity values can be used to produce a visually rich image like product (example of an intensity image)	Rich in semantic information
Canopy Penetration enables imaging lower layers	No penetration

Components of LiDAR System

There are 4 main parts of an airborne LiDAR, that work together to produce

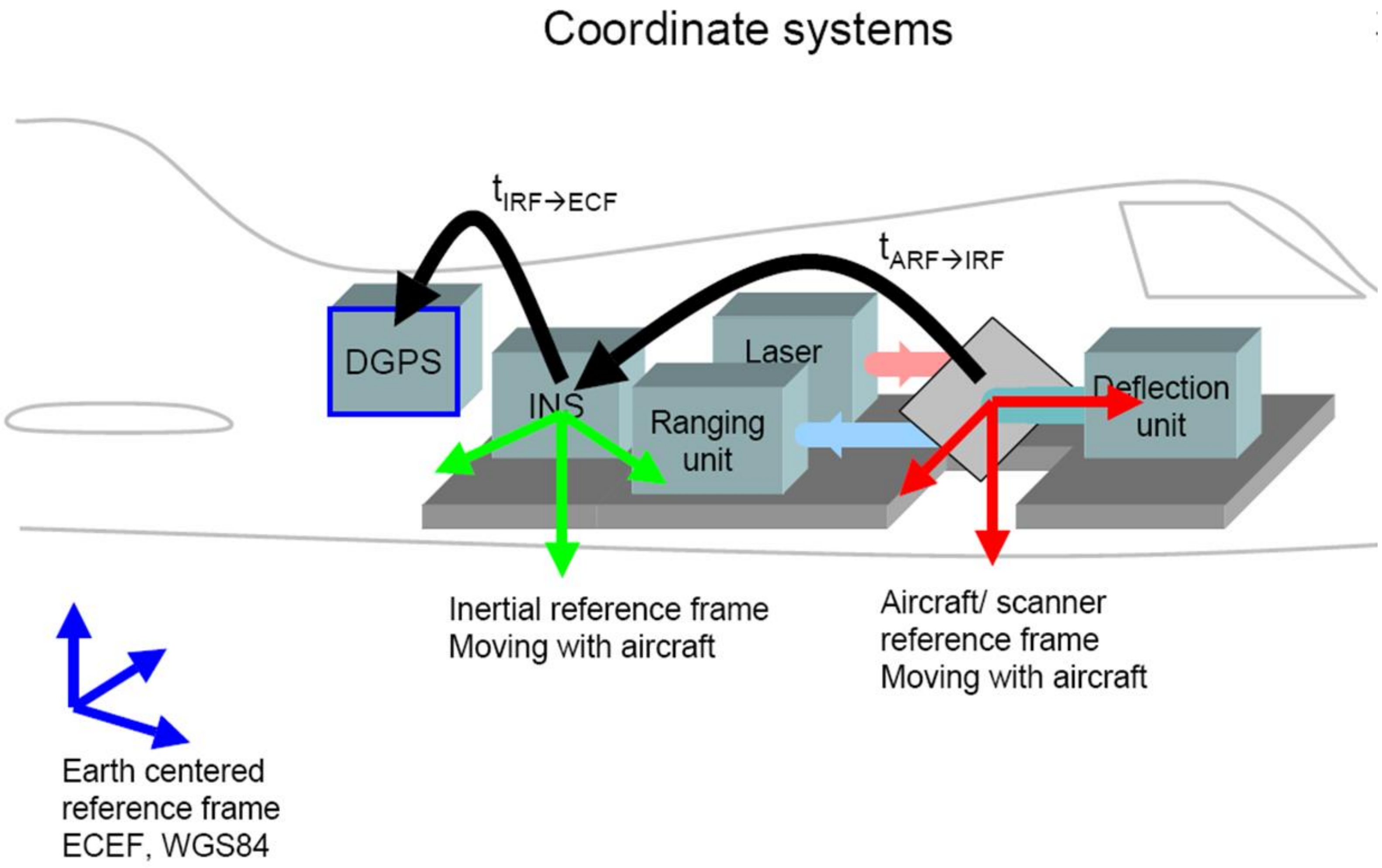
highly accurate, usable results:

- LiDAR Sensors: As the airplane or Drone travels, sensors scan the ground from side-to-side. The pulses are commonly in green or near-infrared bands.
- GPS Receivers: GPS receivers track the altitude and location of the airplane. These tracks are important for accurate terrain and elevation values.
- Inertial Measurement Units (IMU): As airplanes travel, IMUs tracks its tilt. LiDAR systems use tilt to accurately measure incident angle of the pulse.
- Data Recorders: As LiDAR scans the surface, a computer records all of the pulse returns. Then, these recordings get translated into elevation.



Components of LiDAR System

- Multi-sensor combination



Basic Working Principle

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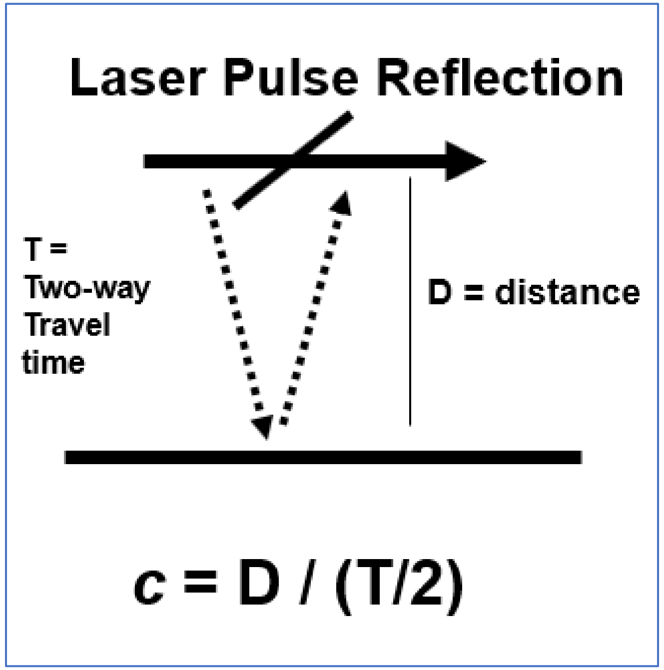
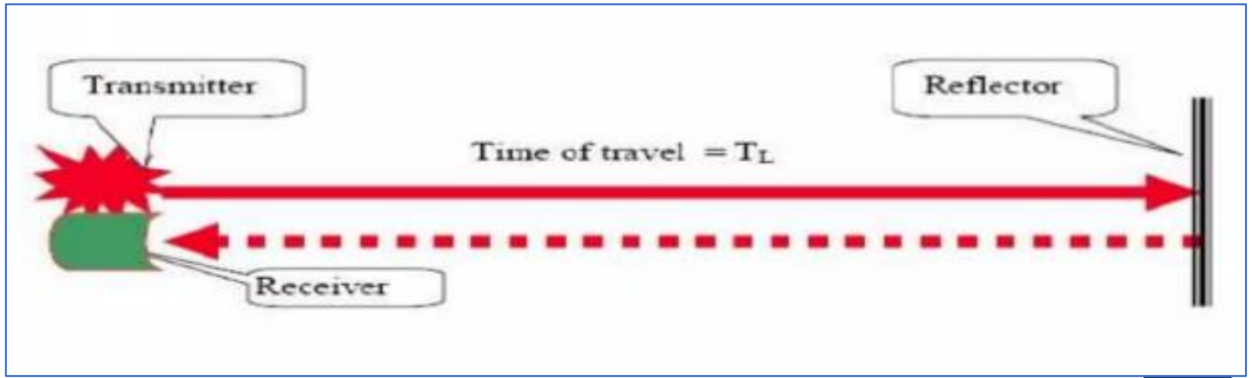
Each time the laser is pulsed:

- ➢ Laser generates an optical pulse
- ➢ Pulse is reflected off an object and returns to the system receiver
- ➢ High-speed counter measures the time of flight from the start pulse to the return pulse
- ➢ Time measurement is converted to a distance (the distance to the target and the position of the airplane is then used to determine the elevation and location)
- ➢ Multiple returns can be measured for each pulse
- ➢ Up to 200,000+ pulses/second
- ➢ Everything that can be seen from the aircraft is measured



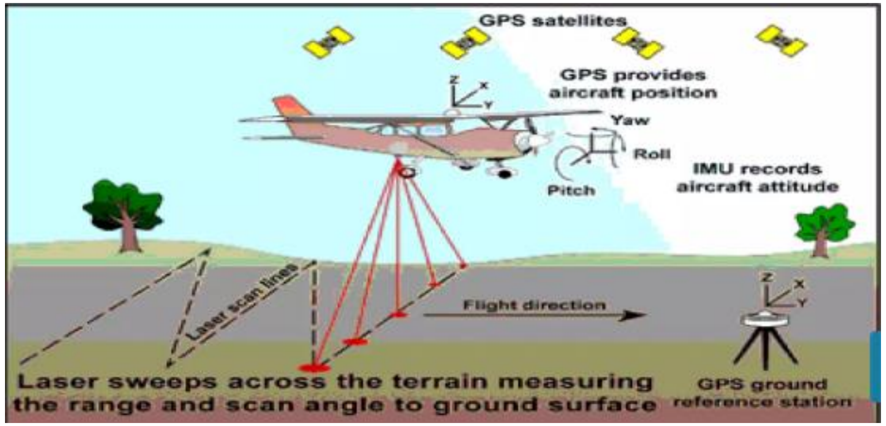


- https://youtu.be/EYbhNSUnIdU

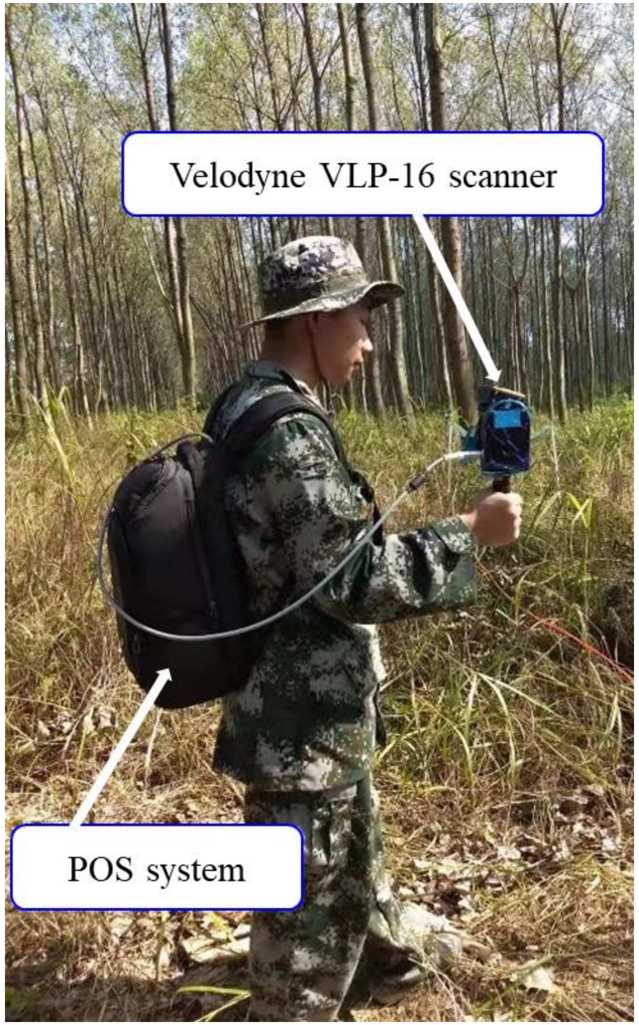
LiDAR Platforms

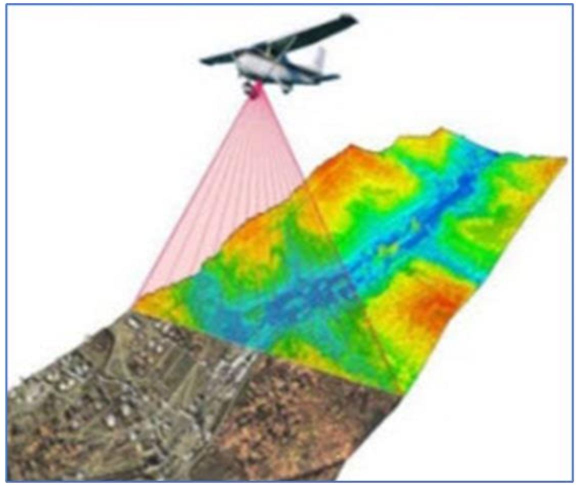
LiDAR platforms include:

- ➢ Airborne LiDAR
  - high level of detail (LoD)
  - Relatively large scale
  - Mostly used for topography.
- ➢ Satellite (spaceborne) LiDAR
  - Large-scale coverage but less LoD
- ➢ Terrestrial LiDAR
  - Highest point density (LoD)
  - Urban mapping, 3D modeling
  - Deformation of bridges

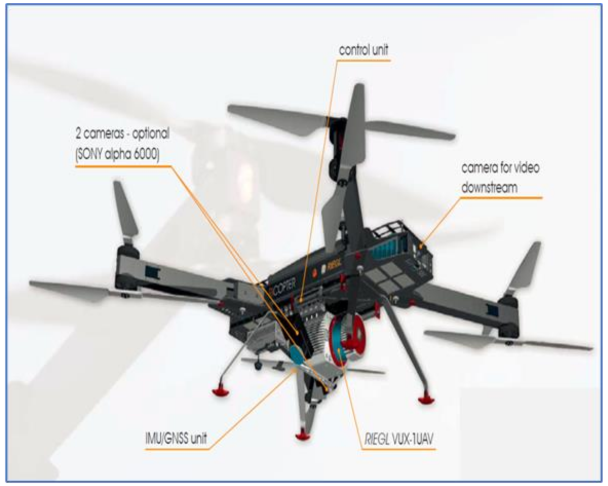


Types of LiDAR





Airborne Laser Scanning (ALS)



UAV Laser Scanner (ULS)

Terrestrial Laser Scanner (TLS)

Backpack Laser Scanner (BLS)

Mobile Laser Scanner (MLS)

Handheld Laser Scanner (HLS)

Information in Urban Scene

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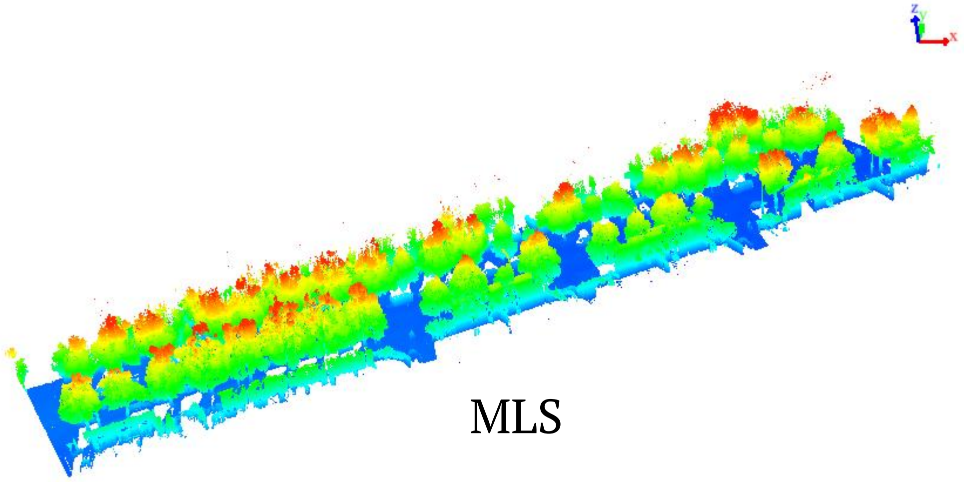
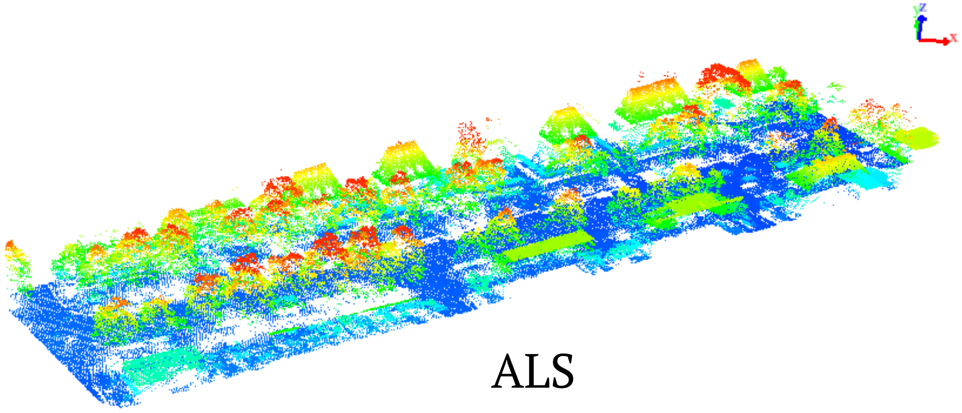
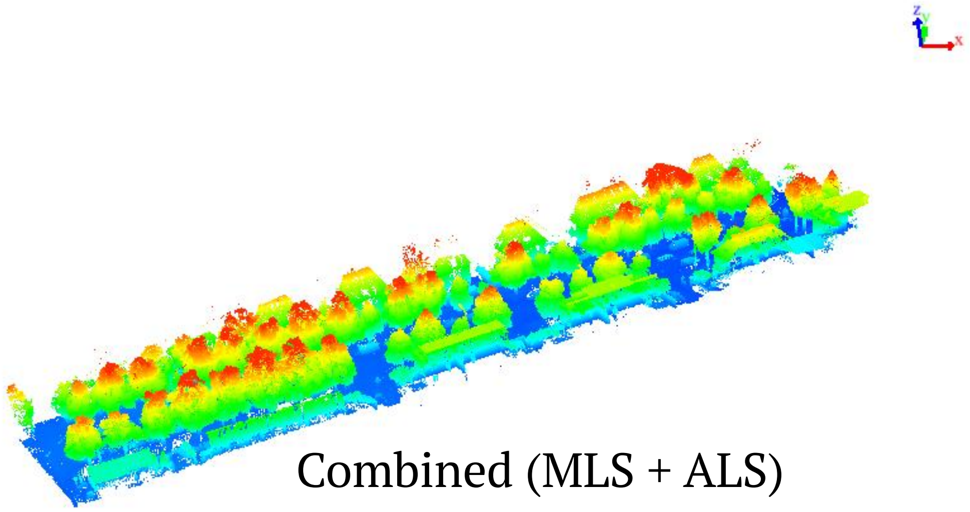


MLS

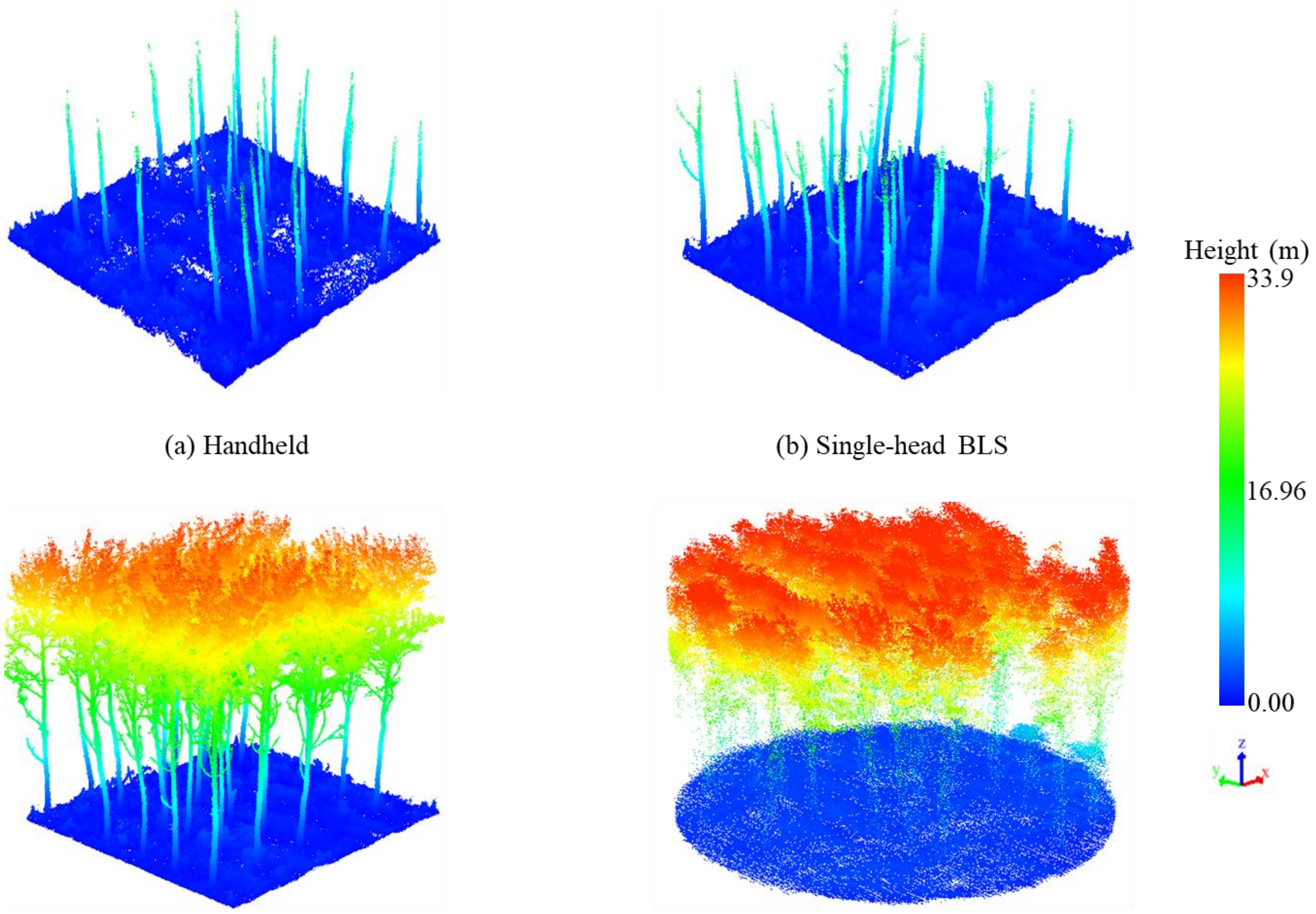


ALS



Combined (MLS + ALS)

Information in Forest Scene



(a) Handheld

(b) Single-head BLS

(c) Dual-head BLS

(d) ULS

Important Terms

Nominal Post Spacing (NPS)

- Average distance between adjacent LiDAR points (ft or m)

Point Density

- Number of LiDAR points per unit area (points per square meter)

Root Mean Square Error (RMSE)

- Statistical value equal to the square root of the average of the squares of the differences between known points and modeled points in the LiDAR surface

Accuracy

- 95% confidence interval of the data (vertical = RMSE x 1.96)

Laser Pulse Rate or Repetition Rate

- The speed at which the laser is pulsed during LiDAR collection. Maximum laser pulse rates on new sensors today generally range from between 150 kHz to 200 kHz (150,000 to 200,000 outgoing laser pulses per second).

Important Terms

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Scan Rate

- The speed at which the scanning mirror (that directs the laser pulses back and forth over the ground) is moved during LiDAR acquisition. Maximum scan rates on new sensors are generally around 100 Hz (100 times per second).

Field of View

- The angular swing of the mirror during acquisition. Typically the mirror moves in a perpendicular direction to the line of flight. The USGS V13 specifications call for a maximum FOV of 40 degrees (20 degrees each side of nadir), with a preferred maximum of 34 degrees.

Important Terms

Illuminated Footprint

- The diameter of the laser beam as it reaches the earth. The laser beam exits the sensor as a very narrow, highly focused beam but diverges slightly on its path from the sensor to the ground. The illuminated footprint increases with increased flying height, but is generally around 1 to 3 feet when using a fixed wing aircraft.

Swath Width

- The linear width of the laser coverage during acquisition, which varies with the flying height and FOV. Increased swath widths result in increased productivity and lower acquisition costs.

Along Track

- The direction in the line of the flight of the aircraft during acquisition.

Cross Track

- The direction perpendicular to the flight of the aircraft during.

LiDAR QA and QC

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Vertical Accuracy

Relatively easy to assess, often required

Normally look at various types of land cover… bare earth, urban, forest, brush, high grasses

Typically find a location with no abrupt changes in the ground surface (within 3 to 5 meters)

Determine precise 3D location with field techniques… then determine elevation from the LiDAR surface at that XY, subtract, and statistically summarize

Control at least 3x better than required accuracy

Fundamental, Supplemental, and Consolidated Accuracies

- –Fundamental – the accuracy in open terrain
- –Supplemental – the accuracy in other areas
- –Consolidated – the accuracy in all areas combined

LiDAR QA and QC

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Horizontal Accuracy

- More difficult to assess, not often required
- Possible to find identifiable objects in the intensity images… paint stripes, concrete-asphalt edges, etc.
- Building corners can be very useful; best to use multiple points on the building and intersect planes to determine the correct XY location

LiDAR Data Characteristics

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- **Raw return data are XYZ points**
- **High spatial resolution**

  - Laser footprint on ground ⩽ 0.50 meters
  - Typical density is 0.5 to 20+ pulses/m^2
  - 2 to 3 returns/pulse in forest areas
  - Surface/canopy models typically 1 to 5m grid

- **Large volume of data**

  - 5,000 to 60,000+ pulses/hectare
  - 10 to100+ thousands of returns/hectare
  - 0.4 to 5.4+ MB/hectare

LiDAR File Formats

- Whether it is collected as discrete points or full waveform, most often LiDAR data are available as discrete points. A collection of discrete return LiDAR points is known as a LiDAR point cloud.
- The commonly used file format to store LIDAR point cloud data is called .las which is a format supported by the American Society of Photogrammetry and Remote Sensing (ASPRS).
- Recently, the .laz format has been developed by Martin Isenberg of LasTools. The differences is that .laz is a highly compressed version of .las.
- Data products derived from LiDAR point cloud data are often raster files that may be in GeoTIFF (.tif) formats.

Applications

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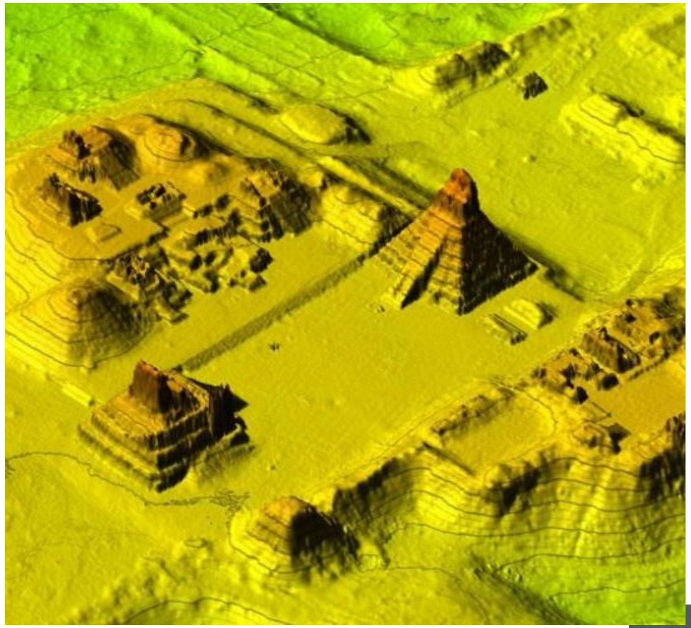
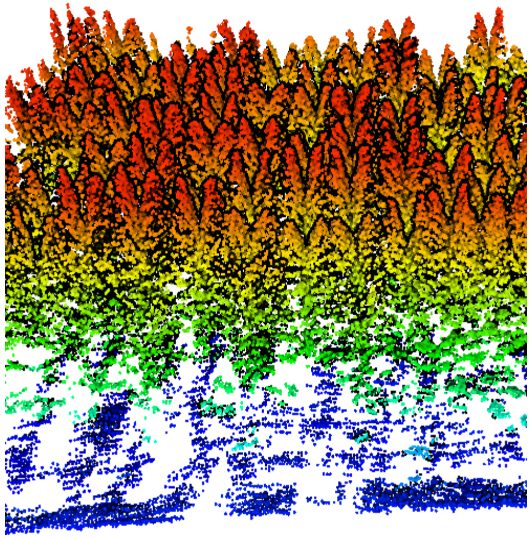
- Flooding
- Coastal erosion
- DTM
- Vegetation
- Forestry
- Urban mapping
- Archeology
- Indoor modeling
- ....

Archeology & Architecture

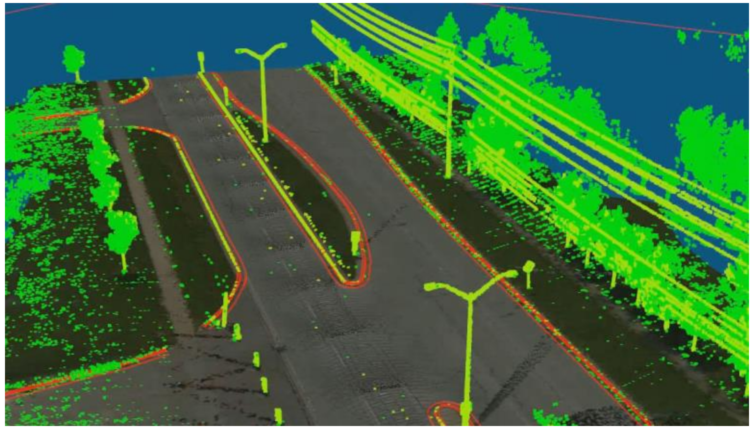


Forest Mapping & Management



3D City Modelling

Urban Mapping



Error Sources

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Random Errors

- Position noise will lead to similar noise in the derived point cloud. Moreover, the effect is independent of the system flying height and scan angle.
- Orientation noise (attitude or mirror angles) will affect the horizontal coordinates more than the vertical coordinates. In addition, the effect is dependent on the system flying height and scan angle.
- Range noise mainly affects the vertical component of the derived coordinates.

Error Sources

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Systematic Errors

- Error due to sensor position due to error in GPS, INS and GPS-INS integration.
- Error due to angles of laser travel as the laser instrument is not perfectly aligned with the aircraft's roll, pitch and yaw axis.
- There may be error in the laser range measured due to time measurement error, wrong atmospheric correction and ambiguities in target surface which results in range walk.
- The discrepancies caused by the bore-sighting offset and angular biases can be modelled by shifts and a rotation across the flight direction. Therefore, a six-parameter rigid-body transformation (three shifts and three rotations) can be used to express the relationship between conjugate features in overlapping strips.
- The discrepancies can be used for diagnosing the nature of the systematic errors in the system parameters.
- Error is also introduced in LiDAR data due to complexity in object space, e.g., sloping surfaces leads to more uncertainty in X, Y and Z coordinates.
- The divergence of laser results in a finite diameter footprint instead of a single point on the ground thus leading to uncertainty in coordinates.

Limitations

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- Laser measurements can be weakened by interacting with dust and vapor particles, which scatter the laser beam and the signal returning from the target
- Using last-pulse measurements can reduce or eliminate this interference
- Systems that are expected to work in such conditions regularly can be optimized for these environments

LiDAR Resources

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A list of some LiDAR data sources:

1. Open Topography http://www.opentopography.org
2. USGS Earth Explorer http://earthexplorer.usgs.gov
3. United States Interagency Elevation Inventory https://coast.noaa.gov/inventory/
4. National Oceanic and Atmospheric Administration (NOAA) Digital Coast https://www.coast.noaa.gov/dataviewer/#
5. Wikipedia LiDAR https://en.wikipedia.org/wiki/National_Lidar_Dataset_(United_States)
6. National Ecological Observatory Network—NEON http://www.neonscience.org/data-resources/get-data/airborne-data
7. LiDAR Data for the United Kingdom http://catalogue.ceda.ac.uk/list/?return_obj=ob&id=8049,8042,8051,8053