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LiDAR Fundamentals

Hainner Aparicio & Viet Nguyen
Faculty of Forest and Environment
University for Sustainable Development
Eberswalde, Germany

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Introduction

Over the past few decades, remote sensing has been one of the most appealing research areas (Guimarães et al., 2020). It offers a number of methods and sensors for measuring various Earth properties utilizing energy that is reflected or emitted at a specific time or period (Roy et al., 2017). Monitoring forest ecosystems is one of the specific applications where remote sensing has been heavily used, especially in National Forest Inventory (NFI) programs to improve estimations (Barrett et al., 2016). Because of their highly dynamic processes, forest ecosystems are crucial for collecting reliable and up-to-date data (Goodbody et al., 2019).

Introduction

Essentially, there are two types of sensors that can be utilized in remote sensing: passive and active. Passive sensors detect natural radiation that is emitted or reflected by objects (Guimarães et al., 2020). Some popular passive sensors include RGB, multispectral, hyperspectral, and thermal (Shakhatreh et al., 2019). The majority of these sensors function in the visible, infrared, and thermal infrared ranges of the electromagnetic spectrum (Pádua et al., 2017).

Introduction

On the other hand, active sensors provide the energy to detect objects on their own. They emit radiation toward the objects, which in turn reflects the radiation back to the sensor to detect and measure (Guimarães et al., 2020). Among the most popular active sensors used in remote sensing are laser altimeters, Light Detection and Ranging (LiDAR), radar, and ranging instruments (Turner et al., 2003).

This tutorial provides an introduction to LiDAR remote sensing technology. A recommended material for the topic is The Basics of LiDAR - Light Detection and Ranging - Remote Sensing from The National Ecological Observatory Network (NEON).

Content

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What is LiDAR?

- Acronym for Light detecting and ranging
- An active remote sensing technology that measures the distance to, or other properties of a target by illuminating the target with light.
- LiDAR uses blue, infrared, or near-infrared light to image physical features with very high resolution.

Source: Robert J. McGaughey, 2018, FUSION Version 3.80, FUSION/LDV: Software for LIDAR Data Analysis and Visualization

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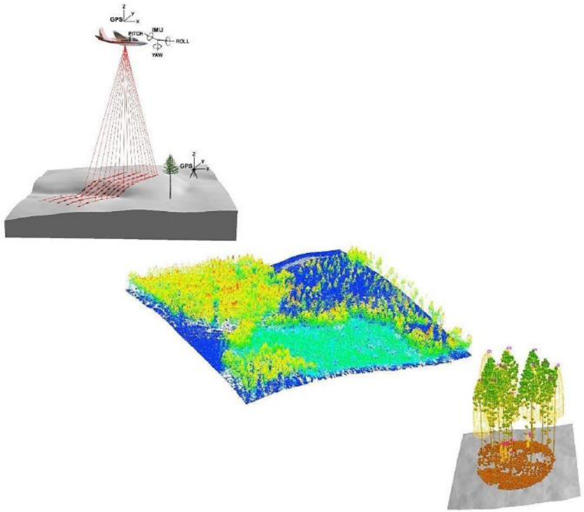
What is LiDAR?

- The time of laser beams from emission to return is used to compute a distance of the target from the sensor in a particular direction. X, Y, and Z coordinates of the target are then computed.



Source: Robert J. McGaughey, 2018, FUSION Version 3.80, FUSION/LDV: Software for LIDAR Data Analysis and Visualization

Advantages of LiDAR?

- Provide precise and directly geo-referenced spatial information
- Active sensor that works either during the day or at night
- Highest resolution of 3D imagery possible by remote sensing
- Increased accuracy of topographic mapping compared to traditional aerial photography
- Classification possibility of cloud points as different objects, e.g. vegetation, built-up area, ground, etc.

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Disadvantages of LiDAR?

- Calibration of data to GPS/ground control points, accuracy of IMU is crucial
- High cost, especially airborne scanning of large area
- Manually intensive, such as quality control or classification of points
- Very large datasets, which require large storage and processing power

LiDAR components

- A **sensor** to produce laser pulses
- An **ultra-accurate clock** to measure the return time for each beam as it travels between the sensor and targets.

LiDAR components

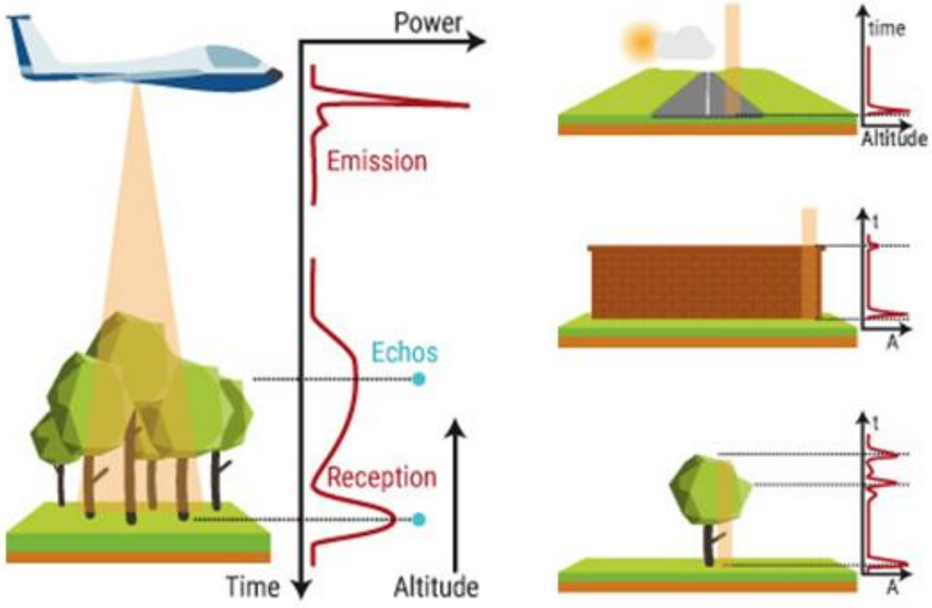
- The location of each laser return is achieved by precise kinematic positioning using **GNSS** and orientation characteristics received from an **Inertial Measurement Unit** (IMU). The IMU records the scanner's orientation characteristics, such as roll, pitch, and heading angles. As a result, the GNSS provides the laser source’s coordinates, while the IMU provides the pulse's direction.
- A **computer** to control interaction of all components.

LiDAR Principle

- Emission of a laser pulse
- Record of the backscattered signal
- Distance measurement (Time of travel x speed of light)
- Retrieving positions of targets from distance, scan angle, and position of sensor

$$d = \frac{Ct}{2}$$

d: distance between sensor and target
t: time between pulse emission and reception
C: speed of light (~ 3*10^8m/s)



Source: https://www.yellowscan-lidar.com

LiDAR platforms

- **Spaceborne laser scanning**

e.g. GLAS, GEDI (Ø 25-60 m)

- **Airborne laser scanning (ALS)**

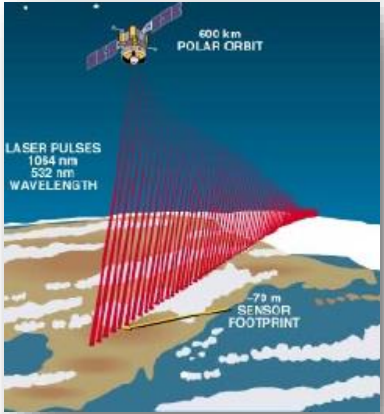
Large footprint,

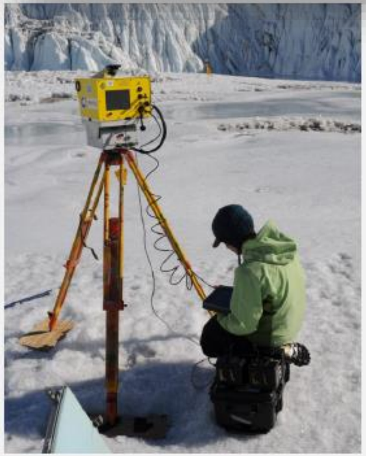
e.g. SLICER, LVIS (Ø 25 cm- 15 m)

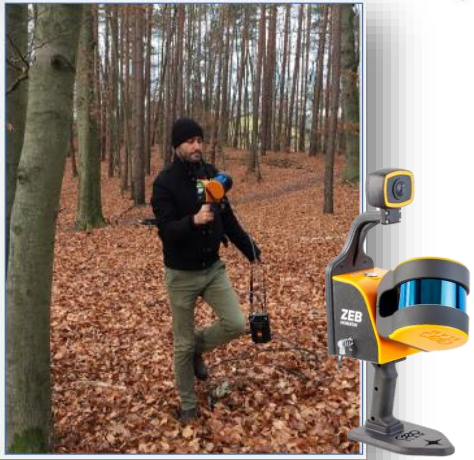
Small footprint,

e.g. CAO, G-LiHT(Ø 10-100 cm)

- **Terrestrial laser scanning (TLS)**
- **Personal laser scanning (PLS)**







	Spaceborne (e.g. GEDI or GLAS)	Airborne (e.g. ALS, LVIS)	Terrestrial (TLS)	Personal (PLS/WLS)
Altitude	400 km – 600 km	1 km – 20 km	1 m	1 m
Footprint	25 m – 60 m	25 cm – 15 m	1 cm - 10 cm	< 1cm
Vertical accuracy	15 cm – 10 m	50 cm – 1m	1 cm - 10 cm	< 1 cm

Source: www.winmol.thuenen.de

LiDAR data structure

The .las-file format:
Table containing one return per row
.laz is a compressed version of .las

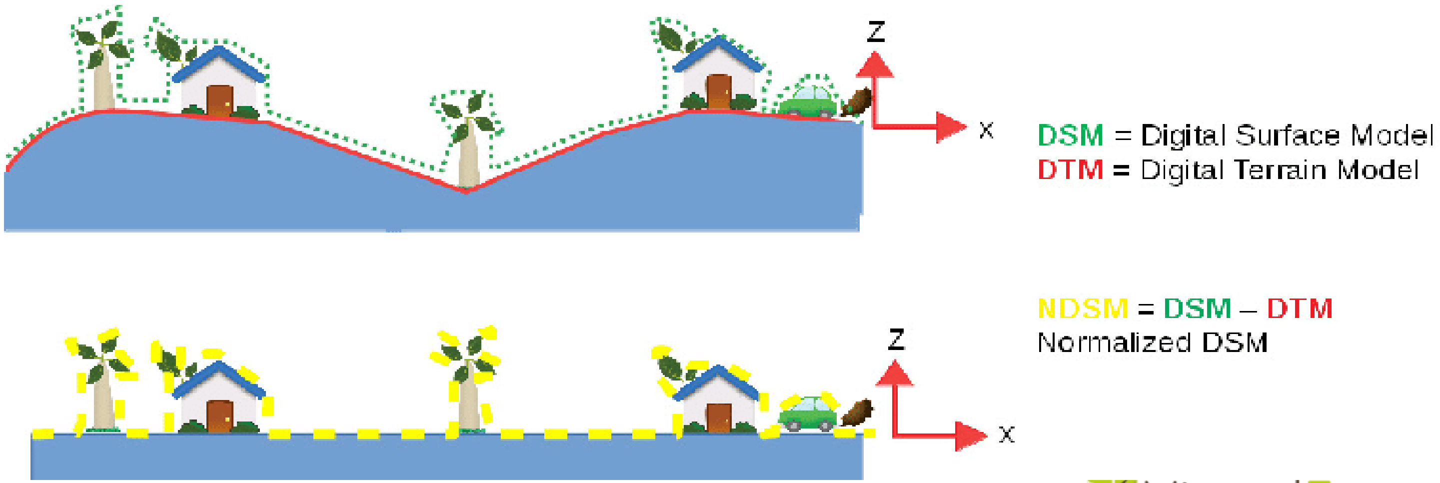
Classification:
1. = Never classified
2. = Unassigned
3. = Ground
4. = Low Vegetation
5. = Medium Vegetation
6. = High Vegetation
7. = Building
8. = Low Point
9. = Reserved

X	Y	Z	Intensity	ReturnNumber	NumberOfReturns	ScanDirectionFlag
625987.9	1012004	0.000	0	2	2	0
625981.6	1012000	0.000	14	2	2	0
625984.0	1012002	0.000	1	2	2	0

EdgeofFlightLine	Classification	ScanAngleRank	UserData	PointSourceID	gpstime	R	G	B
0	2	0	0	31	147354.1	0	0	0
0	2	0	0	31	147354.0	0	0	0
0	2	0	0	31	147354.0	0	0	0

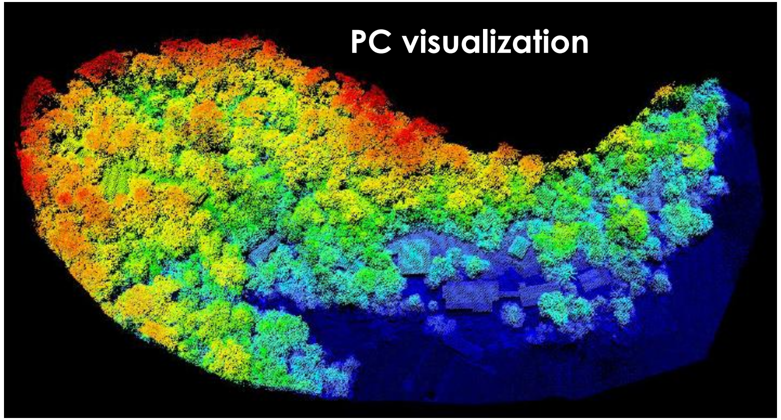
LiDAR important definitions

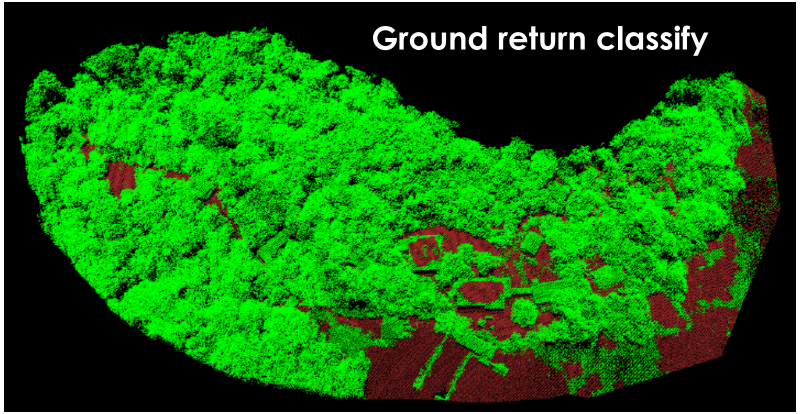
DEM = Digital elevation model
DTM = Digital terrain model
DSM = Digital surface model
nDSM= normalized digital surface model (= CHM in forests)

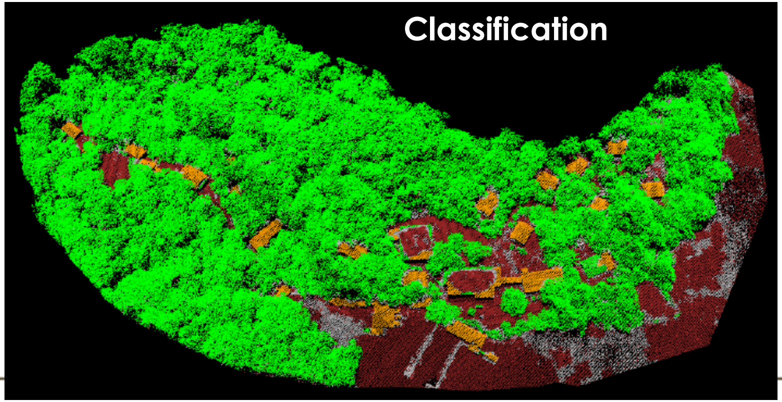


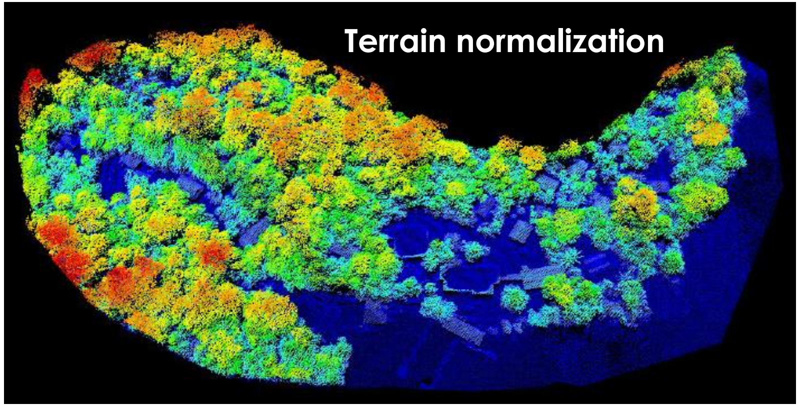
Source: *Contreras et al., 2020*

LiDAR important definitions



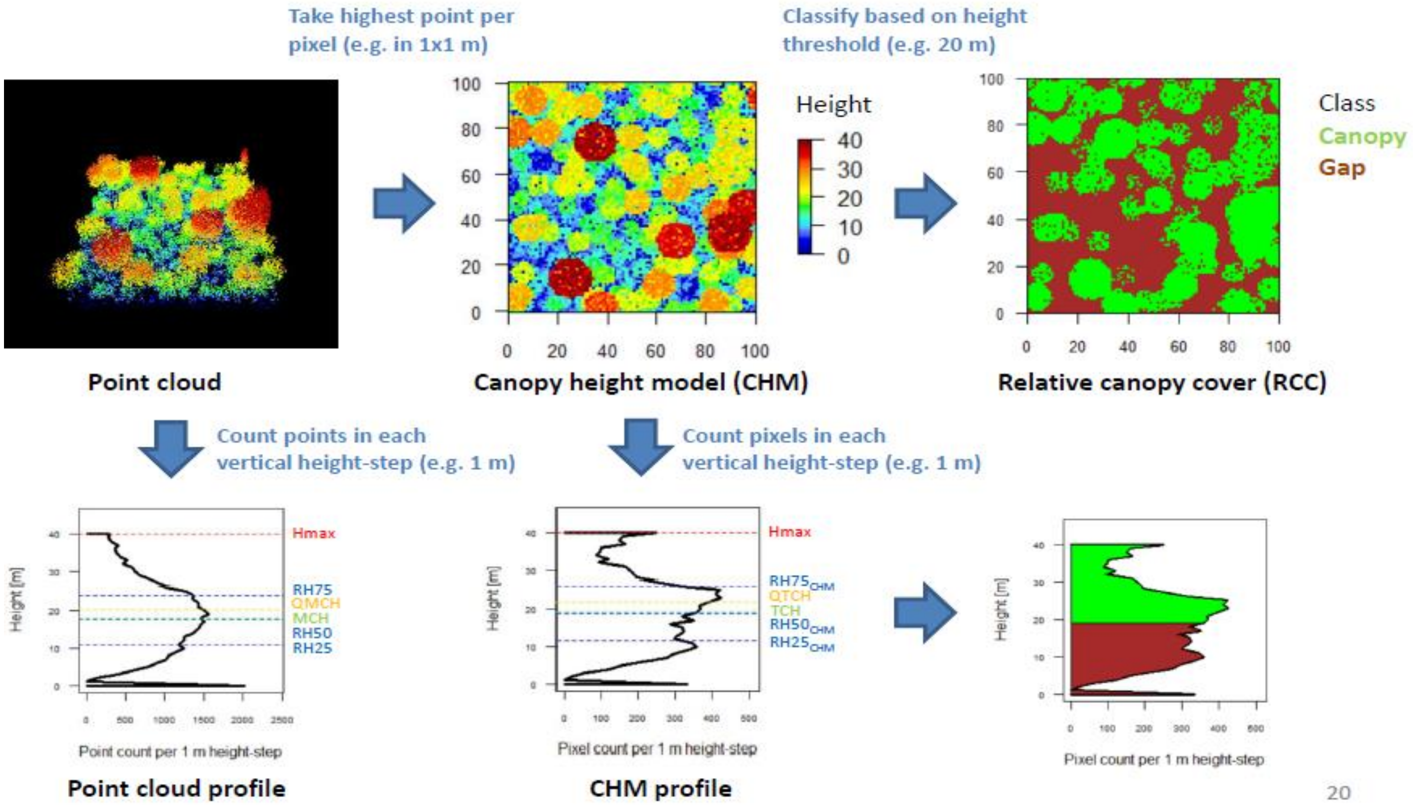






Source: Knapp, 2019

LiDAR metrics (related to forestry)



LiDAR processing software

WinPython:
Available from: http://winpython.github.io/

LAStools:
Available from: http://rapidlasso.com/lastools/

SAGA GIS:
Available from: http://www.saga-gis.org/en/index.html

FUSION Tools in QGIS 2.18
http://forsys.cfr.washington.edu/fusion/fusionlatest.html

R:
Available from: https://cran.r-project.org/

RStudio:
Available from: https://www.rstudio.com/

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¡Thank you for your reading!

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