ENY-C2005 Geoinformation in Environmental Modeling

Lecture 4b: Laser scanning

Petri Rönnholm

Aalto University

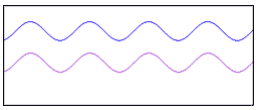
Learning objectives

- To recognize applications of laser scanning
- To understand principles of laser scanning
- To know laser scanning instruments
- To understand processing of laser scanning data

Principles of laser scanning

LASER

- LASER = "Light Amplification by Stimulated Emission of Radiation"
- Laser light is well structured while, for example, plumb lights produce light waves randomly.
- Laser light is coherent, which means light waves are in “the same phase” compared to each other



- Laser light contains, typically, only one wavelength from the light spectrum. Normal light contains wide range of wavelengths from the spectrum. (Multispectral laser light will come to laser scanners in near future)
- In addition, laser light is highly directional (with narrow beam width).

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Laser scanning

- Laser scanners produce 3D point clouds
- Laser scanning can be done from either aerial or terrestrial perspectives.
- Airborne laser scanning is most suitable for collecting data from large areas for making maps
- Terrestrial laser scanners are more suitable for 3D documenting of individual targets
- Terrestrial measurements can be static or mobile
- Vehicle-based (car, boat, etc.) mobile mapping is becoming popular to collect data fast from the terrestrial perspective

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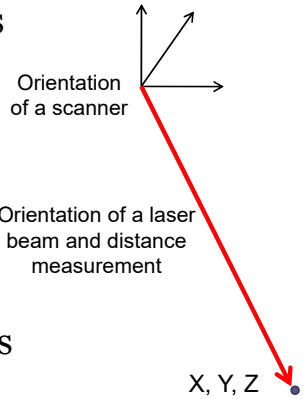
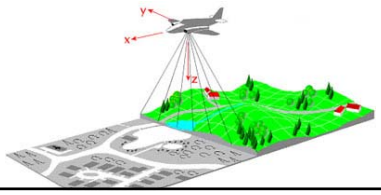
Measuring principle of laser scanning

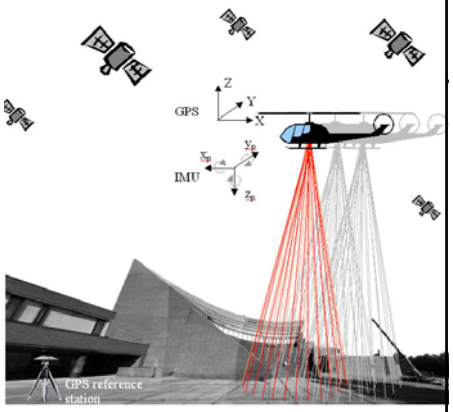
- Laser scanners measure distances (range finder)
- In addition, we need to know
  - Location of the device
  - Attitude of the device
  - Outgoing angles of distance measurements
- 3D points are computed using this information



Location and attitude

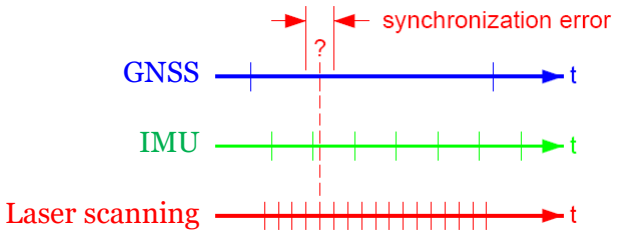
- Location and attitude of mobile systems must be measured with direct georeferencing sensors
  - Global Navigation Satellite System (GNSS) (location)
  - Inertial Measurement Unit (IMU) (location and attitude)
- GNSS require either a physical or virtual reference station in order to be accurate





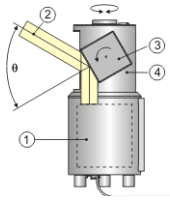
We have a synchronization problem

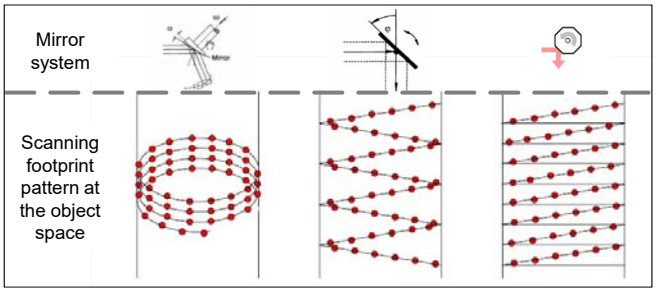
- Direct georeferencing sensors give observations with different frequencies
- The frequency of laser scanning measurements is much faster than georeferencing sensor observations
- The problem is solved with Kalman filter (we estimate observations at the common time)



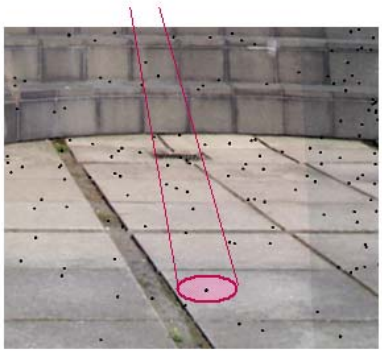
Outgoing angle of a laser beam

- Typically changed by
  - Rotating mirror
  - Rotating device





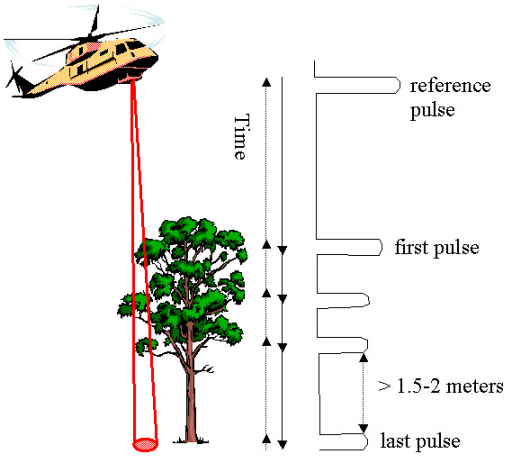
Laser beam



- A footprint of a laser beam is not an infinitely small dot at the target, but laser illuminates an area. (diameter of 0.1-3.8 m in airborne systems)

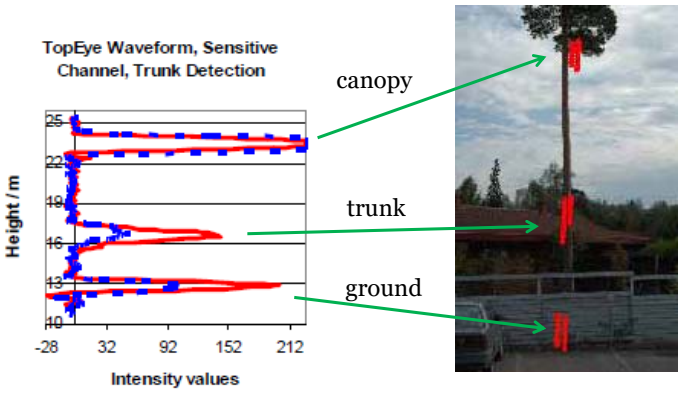
Laserpulses and echoes

- Echo, in this case, is considered to be a returning light pulse
  - first pulse (echo)
  - last pulse (echo)
  - full waveform



Full waveform

- The full waveform of two laser pulses

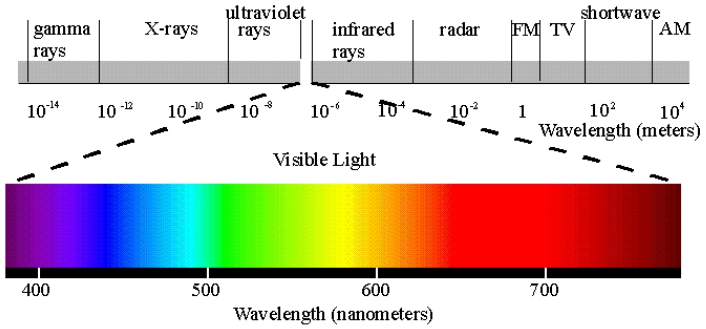


Wavelength of laser

1 μm = 0.001 mm

1 nm = 0.001 μm

- Typically varies between 500 – 1550 nm depending on device and the final application for what it has been designed.

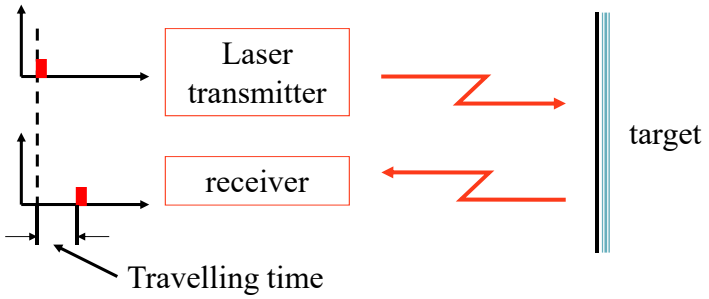


Laser scanner types

- Time-of-flight (TOF) scanners (medium or long range)
  - Pulse-based laser scanners, airborne and terrestrial devices
  - Phase-based laser scanners (continuous-wave laser scanners), terrestrial devices
- Triangulation-based laser scanners (short range), terrestrial devices
- 3D range cameras (TOF), terrestrial and airborne devices

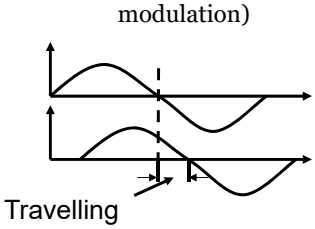
Pulse-based scanners

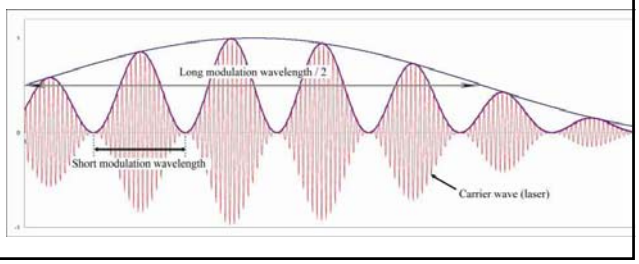
- Device sends a short light pulse and measures the time when reflected light beam returns



Phase-based scanners (continuous-wave scanners)

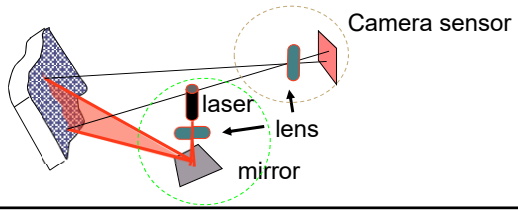
- A laser device is sending continuous-wave modulated (can be modulated several times) light and the time difference is solved from a phase shift
  - A laser beam is modulated, e.g., as a sinusoidal signal and is transmitted continuously
  - The phase difference between transmitted and received modulation is compared
  - The most usual method is to use the amplitude modulation (AM modulation)





Triangulation-based scanners

- A laser beam illuminates a target producing a line (the most usual implementation) or a point / points on the surface. This line or point is detected with a camera
- If the surface is a plane, the line is straight, otherwise it is a curve
- A laser line is moved over the target and each illuminated laser profile or point is recorded with the camera
- We need to know the relationship between a camera and a laser

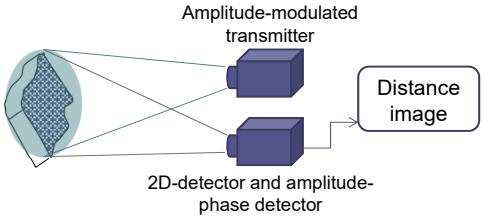


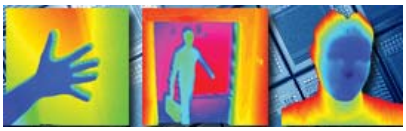
Laser scanners classified according to measuring distance

- Short-range accurate industrial laser scanners (usually triangulation-based)
  - Measuring distance 1-5 m, accuracy 0.05…1 mm
- Mid-range laser scanners (pulse or phase principle)
  - Measuring distance 1-120 m, accuracy 2…20 mm
- Long-range laser scanners (pulse or phase principle, mostly pulse-based)
  - Measuring distance 1-150…2500 m, accuracy 2…20 mm

3D range cameras (flash lidar)

- Light source illuminates the complete scene using modulated light (like a flash)
- Each sensor of the camera records the backscattered modulated light and the distance is computed from the phase difference between the transmitted and received signal
- Resolution and accuracy are relatively low
- Fast -> even 60 range images per second





Choosing a terrestrial laser scanner?

- Depends on the application
  - Point density
  - Measuring speed
  - Measuring range
  - Wavelength
  - Measuring accuracy
  - Is full-waveform needed?
- There is no such laser scanner that is optimal in all measuring cases

Mobile mapping

- Multi-sensor surveying from a moving vehicle that integrates various navigation and data acquisition sensors on a rigid, moving platform for the remote mapping of surrounding objects

Images © FGI

Hardware for mobile mapping

- Navigation system
- Laser scanners
  - Most laser scanners are applicable to mobile mapping (2D/3D scanners)
- Cameras
- Other electro-optical sensors
  - Spectrometer
  - Thermal camera
  - Range camera/flash lidar
  - Radar
  - Etc.

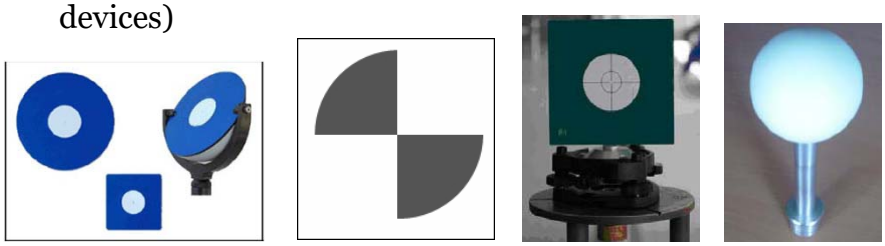
Laser scanners mounted in Unmanned Aerial Vehicles (UAV)

- Usually, only the lightest laser scanners can be lifted
- Limited flight time
- Low-cost flying
- Availability
- Regulations may prevent flights

Images © FGI

Registration and georeferencing of laser scanning point clouds

- 2D or 3D reference targets (usually, a geodetic ground survey is needed)
- Clearly distinguishable natural features
  - can be used for the registration of separate laser scans
- Leveling on the known ground control point (terrestrial devices)



Targets for the registration of terrestrial laser scans

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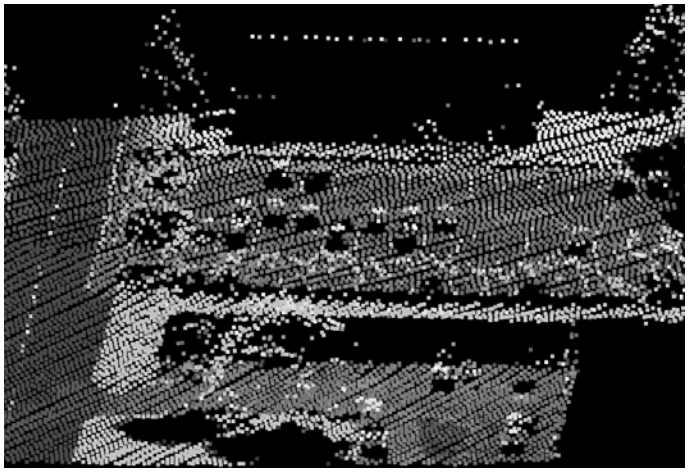
Visualization of laser points: intensity



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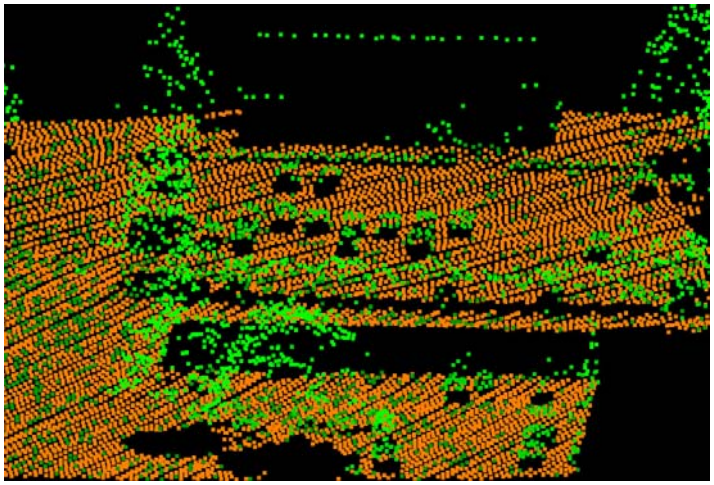
Visualization of laser points: classification



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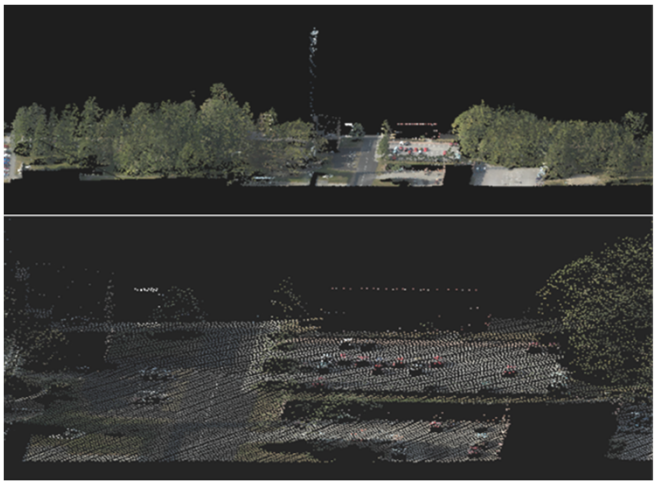
Visualization of laser points: RGB color from images



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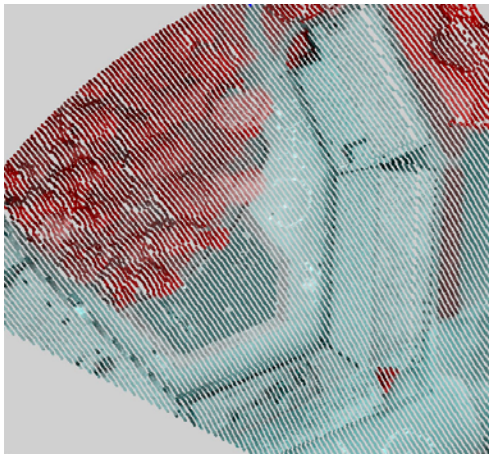
Visualization of laser points: other color combinations from multispectral images

False color composition:

R=Near Infrared
G=Red
B=Green



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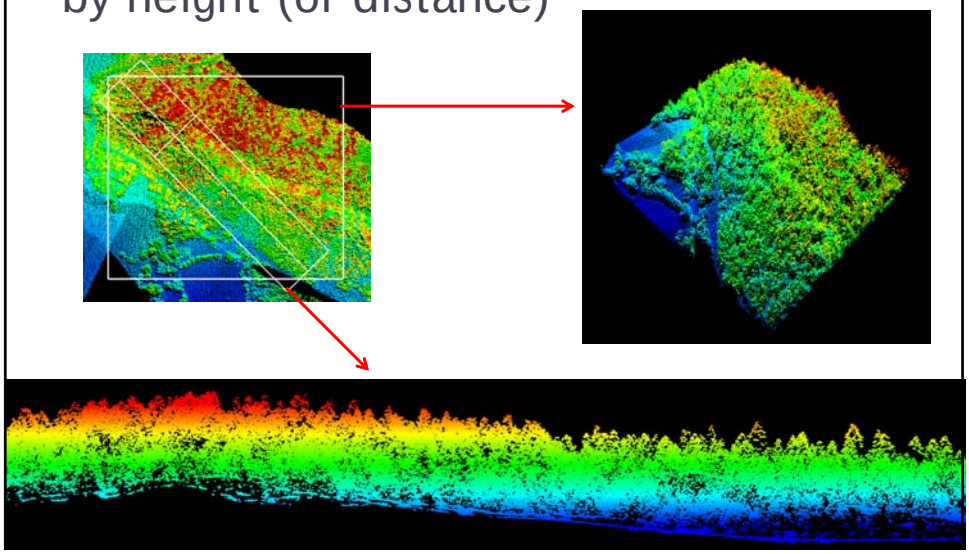
Visualization of laser points: colored by height (or distance)



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The virtualized Design Factory from the outside

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The virtualized Design Factory from the outside

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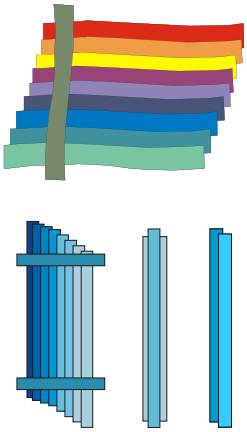
Terrestrial scans of the Undergraduate Centre

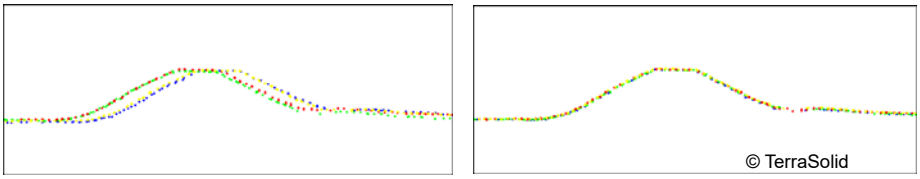
Airborne data collection

- The planning of a campaign is highly important
  - What is suitable point density?
  - Flying height?
  - The width of laser scanning strips?
  - How much overlap between adjacent laser scanning strips is enough?
  - The number of cross strips?
  - Timing?
    - Proper weather
    - Leafs-on or leafs-off?
  - How can we ensure quality?



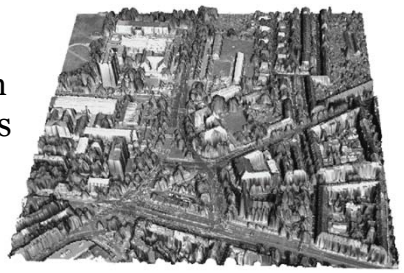
Quality control of airborne laser scanning data

- Data quality verification
  - Compare with known ground features
  - Compare overlapping scanning strips (specially with cross strips) and correct errors with strip adjustment
  - Check that data has no unwanted gaps



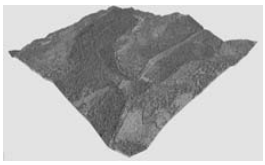
Post-processing of airborne laser data

- Data filtering and classification
  - Remove outliers
  - Remove points that belong into the class that is not relevant for your application
- Creation of elevation models
  - TIN
  - Grid
  - Contour lines
- Create object models (e.g. buildings, trees)



nDSM (normalized Digital Surface Model)

- nDSM=DSM-DTM (DSM=Digital surface model, DTM=Digital Terrain Model) the effect of terrain surface is eliminated



DSM

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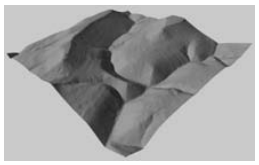

DTM

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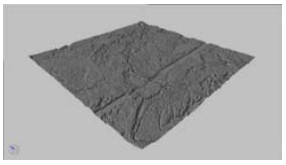


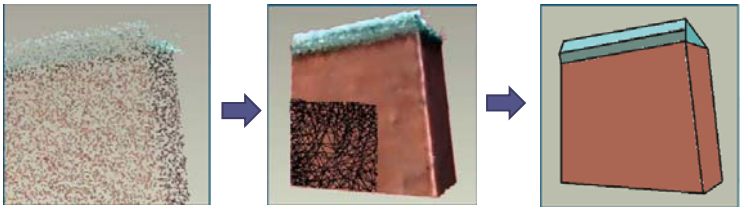
nDSM

Typical processing of terrestrial laser data

- Filtering
  - Noise
  - Outliers
- Registration
- Interpretation/classification
- Surface triangulation
- Feature extraction
- Model simplification
- Surface textures from images

From point clouds to CAD models

Processed point cloud



Point cloud *Surface model* *CAD model*

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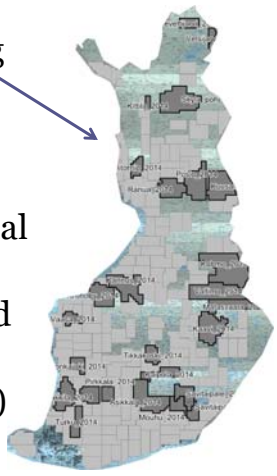
Where to get laser scanning data?

- National Land Survey of Finland
  - Open access airborne laser scanning data (0.5 points / m^2)
- Mapping companies
  - Finnish and international mapping companies (both aerial and terrestrial data)
- Consulting companies (both aerial and terrestrial data)
- Cities (both aerial and terrestrial data)



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How to become a professional in laser scanning – 4 steps?

1. Select Geoinformatics as the major
2. Select ”photogrammetry, laser scanning and remote sensing” courses from elective courses including, e.g., following courses
   - Digital Image Processing and Feature Extraction
   - Least-Squares Methods in Geosciences
   - Advanced Laser Scanning
   - Advanced Photogrammetry
   - Advanced Remote Sensing
3. Select a laser scanning topic in the course Project Work (10 op)
4. Select a laser scanning topic for your Master’s Thesis

Remember to

- Select the Bachelor's level course
  - Ympäristötiedon keruu (in Finnish)
- This course reveals more about laser scanning, photogrammetry, remote sensing and geodesy