

KIG-C1010 Introduction to geoinformatics

Lecture 6b: Laser scanning

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Learning objectives

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

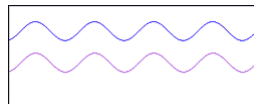
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Principles of laser scanning

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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

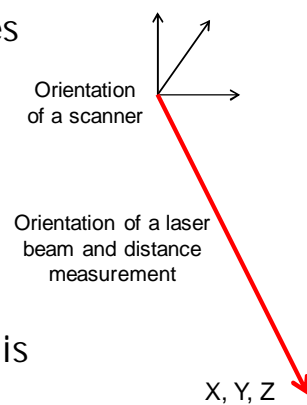
- Laser scanners produce 3D point clouds
- Laser scanning can be done from either aerial or terrestrial perspectives.
- Airborne laser scanning is most suitable for collecting data from large areas for making maps
- Terrestrial laser scanners are more suitable for 3D documenting of individual targets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



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Measuring principle of laser scanning

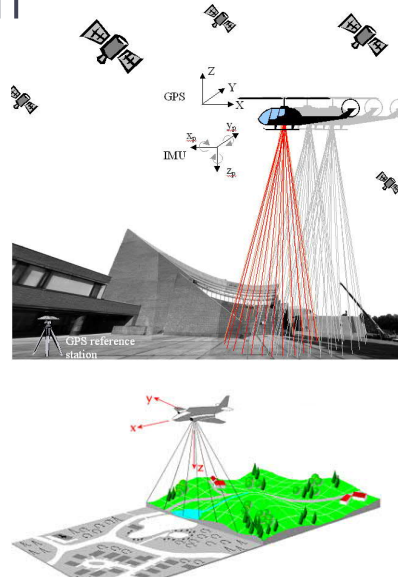
- Laser scanners measure distances (range finder)
- In addition, we need to know
 - Location of the device
 - Rotation of the device
 - Outgoing angles of distance measurements
- 3D points are computed using this information



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Location and rotation

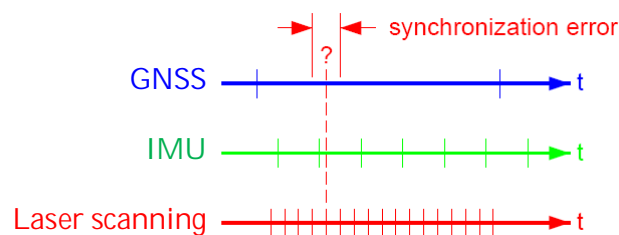
- Location and rotation of mobile systems must be measured with direct georeferencing sensors
 - Global Navigation Satellite System (GNSS) (location)
 - Inertial Measurement Unit (IMU) (location and attitude)
- GNSS require either a physical or virtual reference station in order to be accurate



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We have a synchronization problem

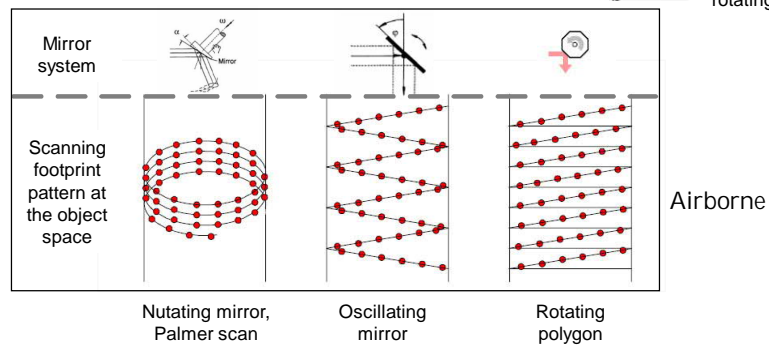
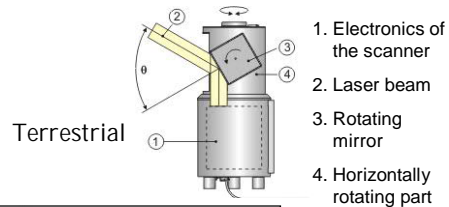
- Direct georeferencing sensors give observations with different frequencies
- The frequency of laser scanning measurements is much faster than georeferencing sensor observations
- The problem is solved with the Kalman filter (we estimate observations at the common time)



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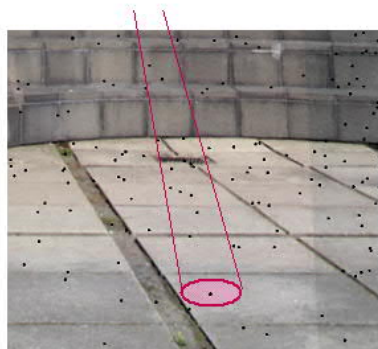
Outgoing angle of a laser beam

- Typically changed by
 - Rotating mirror
 - Rotating device



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Laser beam

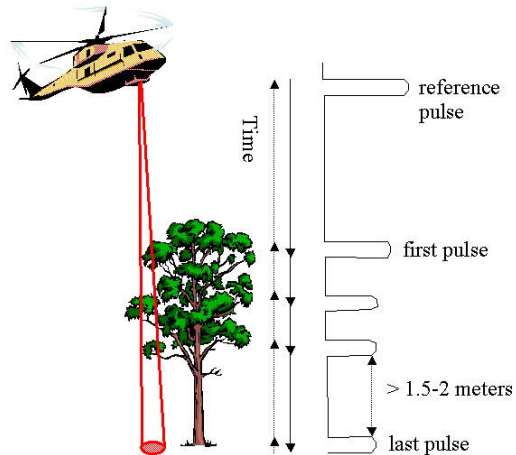


- A footprint of a laser beam is not an infinitely small dot at the target, but laser illuminates an area. (diameter of 0.1-3.8 m in airborne systems)

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Laserpulses and echoes

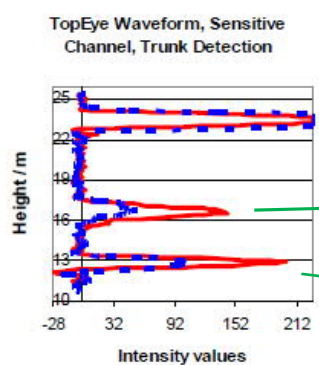
- Echo, in this case, is considered to be a returning light pulse
 - first pulse (echo)
 - last pulse (echo)
 - full waveform



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Full waveform

- The full waveform of two laser pulses



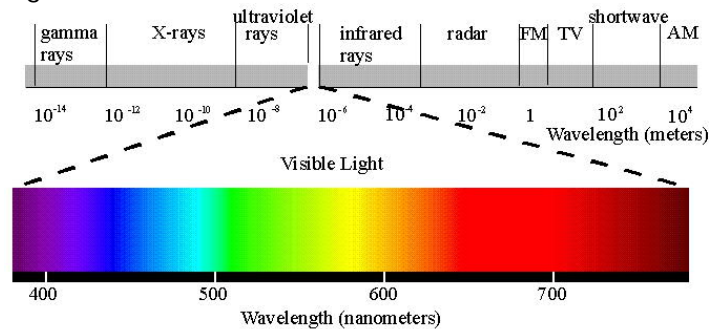
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The wavelength of a laser

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.



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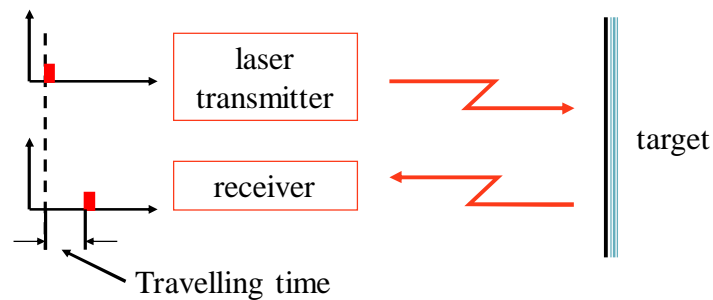
Laser scanner types

- Time-of-flight (TOF) scanners (medium or long range)
 - Pulse-based laser scanners, airborne, mobile and terrestrial devices (direct time-of-flight scanners)
 - Phase-shift laser scanners (other names: continuous-wave or phase-based laser scanners), terrestrial and mobile devices
- Triangulation-based laser scanners (short range), terrestrial devices
- 3D range cameras (TOF), terrestrial, mobile- and airborne devices

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Pulse-based scanners

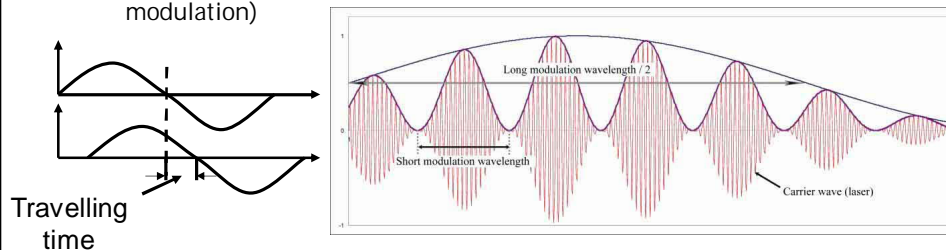
- A device sends a short light pulse and measures the time when reflected light beam returns



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Phase-shift scanners (continuous-wave or phase-based scanners)

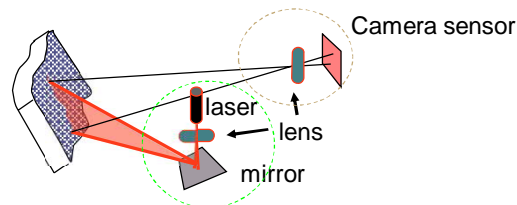
- A laser device is sending continuous-wave modulated (can be modulated to waves of different lengths) light and the time difference is solved from a phase shift
 - A laser beam is modulated, e.g., as a sinusoidal signal and is transmitted continuously
 - The phase difference between transmitted and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



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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 orientation between a camera and a laser



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Laser scanners classified according to measuring distance

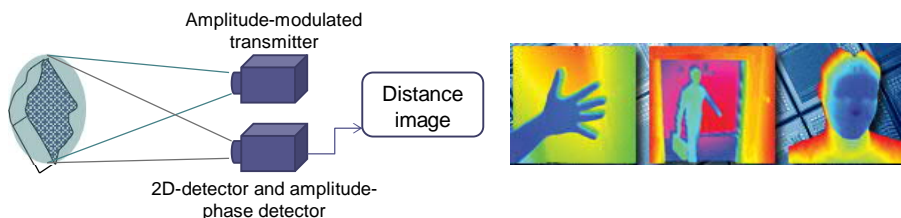
- Short-range accurate industrial laser scanners (usually triangulation-based)
 - Measuring distance 1-5 m, accuracy 0.05...1 mm
- Mid-range laser scanners (pulse or phase-shift principle)
 - Measuring distance 1-120 m, accuracy 2...20 mm
- Long-range laser scanners (pulse or phase principle, mostly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

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3D range cameras (flash lidar)



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



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Choosing a terrestrial laser scanner?

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

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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

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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.



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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



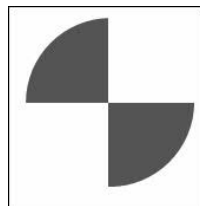
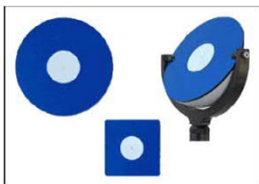
Images © FGI



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Registration and georeferencing of laser scanning point clouds

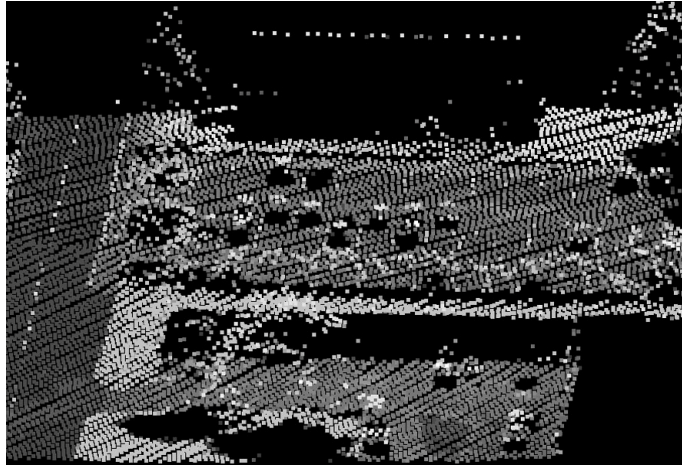
- 2D or 3D reference targets (usually, a geodetic ground survey is needed)
- Clearly distinguishable natural features
 - can be used for the registration of separate laser scans
- Leveling on the known ground control point (terrestrial devices)



Targets for the registration of terrestrial laser scans

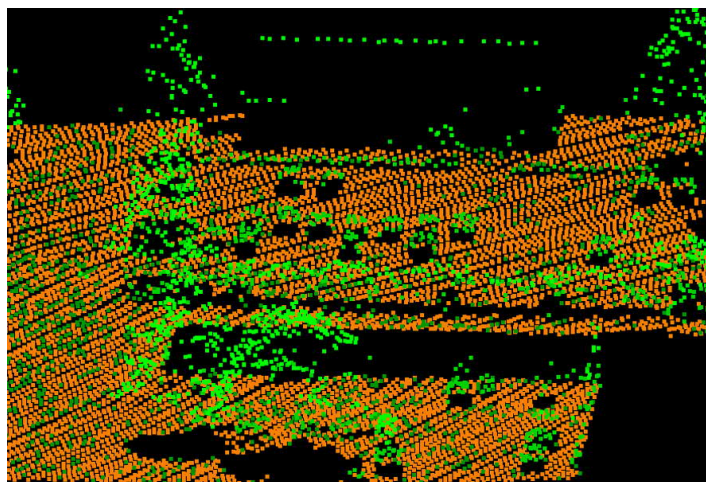
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Visualization of laser points: intensity



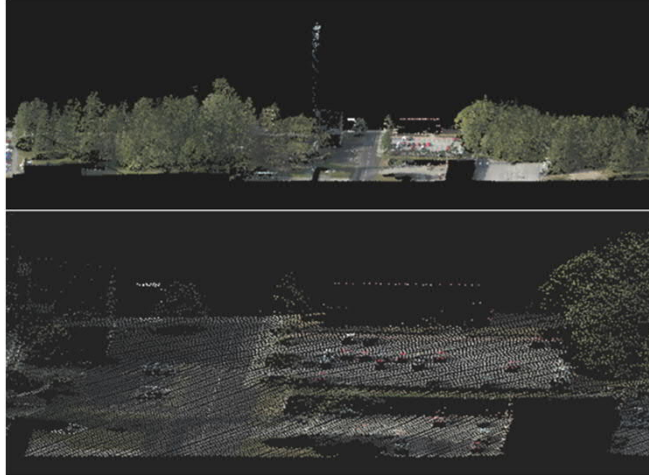
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Visualization of laser points: classification



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Visualization of laser points: RGB color from images

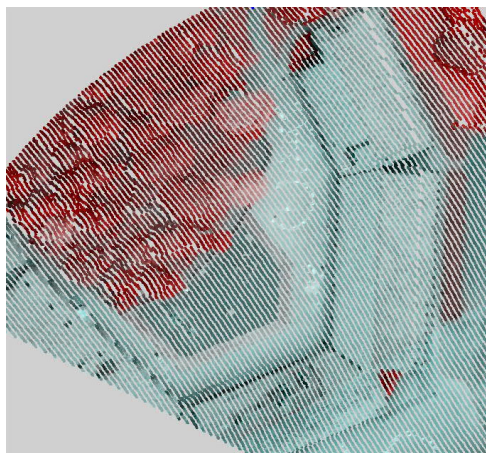


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Visualization of laser points: other color combinations from multispectral images

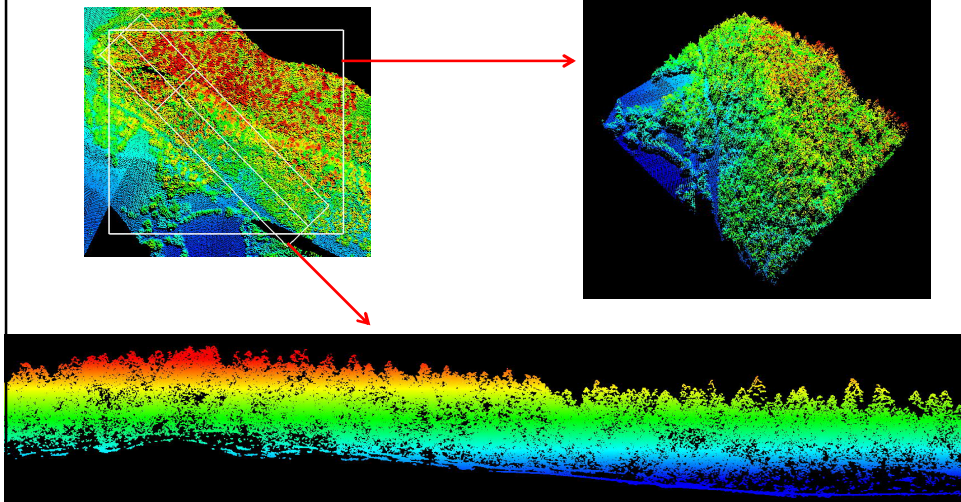
False color composition:

R=Near Infrared
G=Red
B=Green



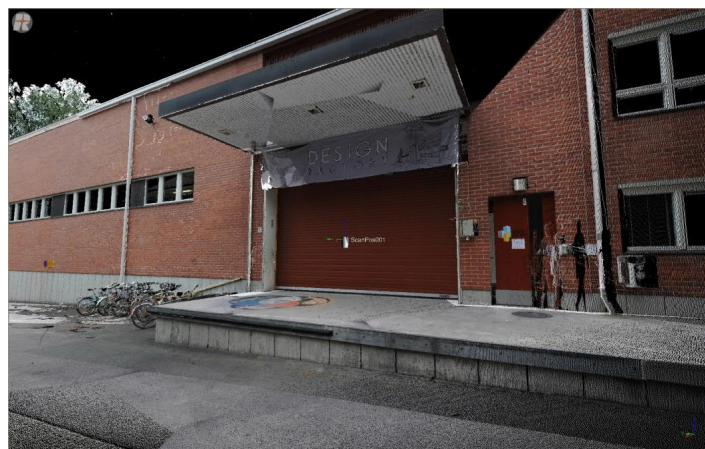
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Visualization of laser points: colored by height (or distance)



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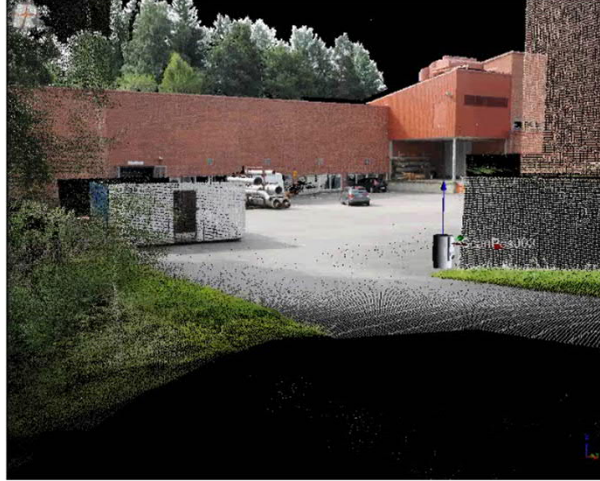
The virtualized Design Factory from the outside



© Nina Heiska

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The virtualized Design Factory from the outside



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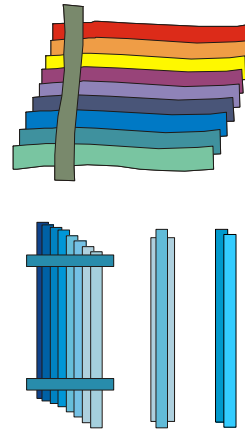
Terrestrial scans of the Undergraduate Centre



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Collecting airborne laser scanning data

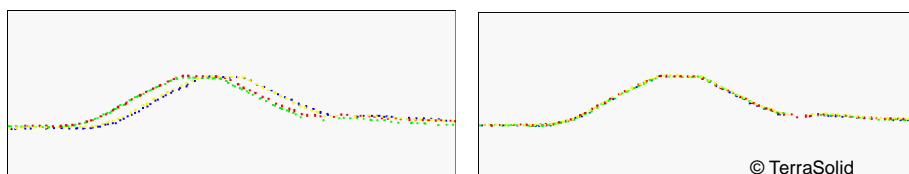
- The planning of a campaign is highly important
 - What is suitable point density?
 - Flying height?
 - The width of laser scanning strips?
 - How much overlap between adjacent laser scanning strips is enough?
 - The number of cross strips?
 - Timing?
 - Proper weather
 - Leafs-on or leafs-off?
 - How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



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Quality control of airborne laser scanning data

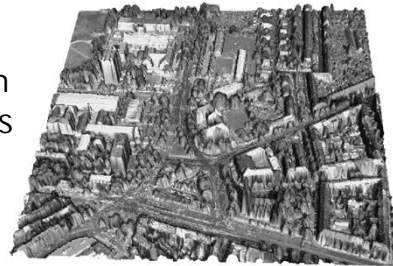
- Data quality verification
 - Compare with known ground features
 - Compare overlapping scanning strips (specially with cross strips) and correct errors with strip adjustment
 - Check that data has no unwanted gaps



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Post-processing of airborne laser data

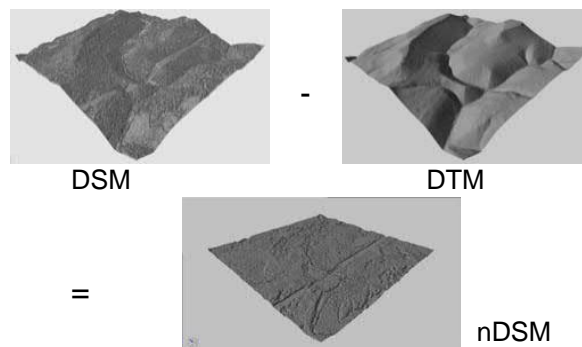
- Data filtering and classification
 - Remove outliers
 - Remove points that belong into the class that is not relevant for your application
- Creation of elevation models
 - TIN
 - Grid
 - Contour lines
- Create object models (e.g., buildings, trees)



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nDSM (normalized Digital Surface Model)

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



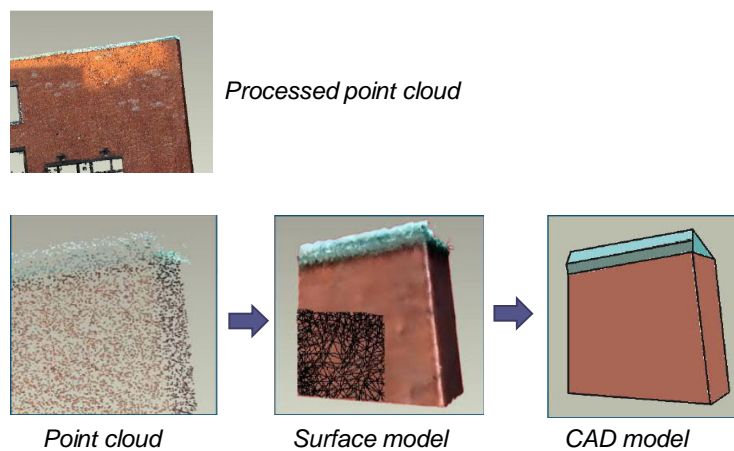
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Typical processing of terrestrial laser data

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

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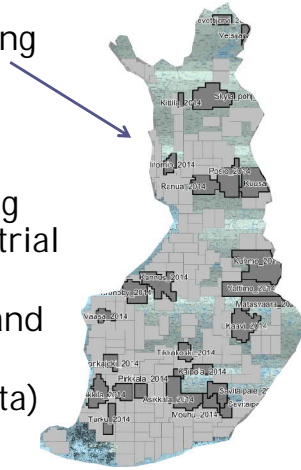
From point clouds to CAD models



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Where to get laser scanning data?

- National Land Survey of Finland
 - Open access airborne laser scanning data (0.5 points / m²)
 - Behind a license: 5 points /m²
- 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)



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

1. Come to Master's Programme in Geoinformatics
2. Select photogrammetric and laser scanning courses from elective courses including, e.g., following courses
 - Digital Image Processing and Feature Extraction
 - Advanced Laser Scanning
 - Advanced Photogrammetry
3. Select a laser scanning topic in the course GIS-E6010 Project Course (10 op)
4. Select a laser scanning topic for your Master's Thesis

During Bachelor's studies

- Select the GIS path
- Especially, the course KIG-C1040 Paikkatiedon keruu (in Finnish) reveals more about laser scanning, photogrammetry, remote sensing and geodesy
- There are topics about laser scanning for Bachelor's Thesis

