# Laser scanning

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# LiDAR, Terrestial laser scanning

**LiDAR** – Light Detection and Ranging

**Terrestrial laser scanning (TLS)**

- **ground-based, active imaging method** that rapidly acquires accurate, dense 3D point clouds of large object surfaces by laser rangefinding (Lichti, 2011)
- **contact-free measuring devices** which run usually at fixed positions. Multiple scans are taken for covering the area of interest.

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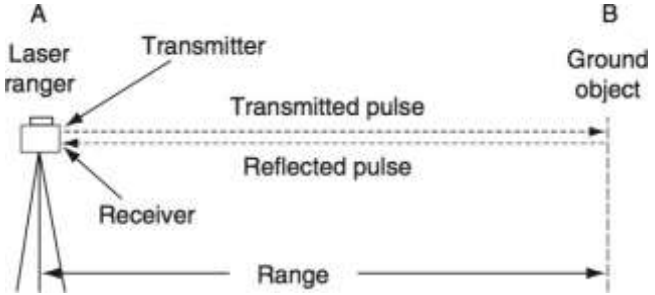
# Most common laser scanners

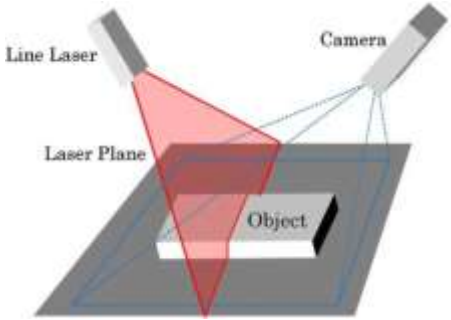
**TOF (time-of-flight)**

- Measures traveling time of a laser pulse (**pulse-based scanner**)
- Solves traveling time from the phase difference of modulated light (**phase shift scanner**)

**(Active) Triangulation**

- e.g. Structured light systems



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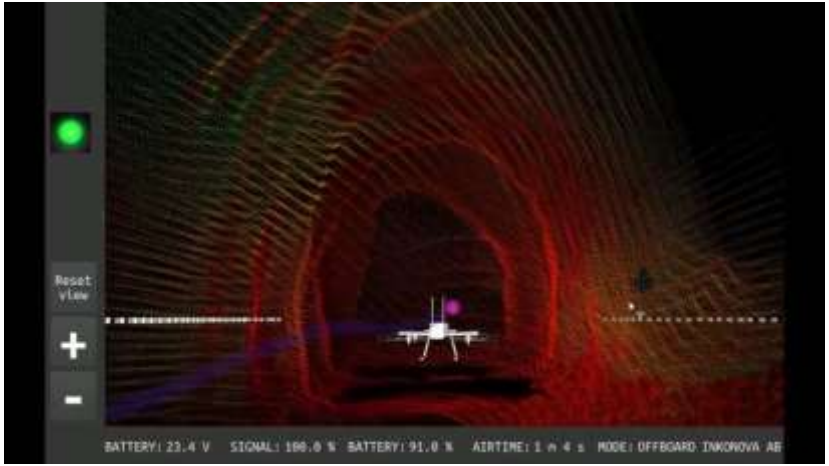
# Mobile laser scanning

**Mobile laser scanning (MLS)**

**Simultaneous localisation and mapping (SLAM) -** complex algorithms that map an unknown environment

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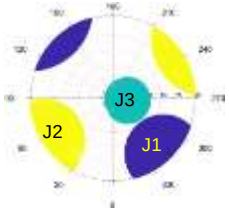
# Other types of active imaging systems

- Structured-light systems
- Range cameras / FLASH Lidar

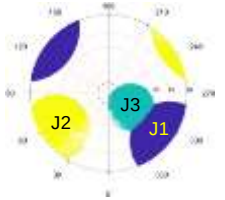
Artec LEO

LiDAR sensor location on Apple iPhone Pro 12 (left) and iPad Pro 2020 devices

Torkan et al. 2022




**DSLR**




**iPhone LiDAR**



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# Manufacturers: examples

- Zoller+Fröhlich, www.zf-laser.com
- Leica, www.leica-geosystems.com
- RIEGL, www.riegl.com
- Trimble, www.trimble.com
- I-SiTE 3D, www.maptek.com
- FARO, www.faro.com
- VisImage, www.vis.ca (body scanner)
- Polhemus, www.polhemus.com (hand-held)
- Artec3D, www.artec3d.com
- Velodyne, velodynelidar.com
- Quanergy, quanergy.com
- Ouster, ouster.com



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# Scanning methodology

## Before

### Planning
- Equipment selection
- Scan parameters
- GNSS / total station
- Reference data
- Control measurements

### Calibration
- Scanner

## On-site

### Control measurements
- Targets
- Reference points

### GNSS base station

### TLS measurements
- Scan stations
- Reference targets

## Post-processing

### Processing raw data
- Scan data preprocessing
- Control meas. computation

### Georeferencing
- Target selection
- Computation

### Point cloud processing
- Filtering
- Projections
- Measurements

## Quality control



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# Error sources

- **Instrumental** (distance and angle measurement)
- **Object-related** (material, moisture, incidence)
- **Environmental** (atmosphere, disturbances)
- **Scanning methodology related** (operator, hardware, software, registration, scanning location…)



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# Instrumental errors

Example of scanner specs

- Laser footprint
  - **Beam size** at exit and beam divergence determine the laser footprint on target
  - Typically, 3 mm at exit + 0.25 mrad -> **footprint** 28 mm @100 m
- Ranging accuracy
  - TOF: How short is the emitted laser pulse and how accurately can the time be measured
  - E.g. 5 mm @ 100 m (1 standard deviation)

| | | |
|---|---|---|
| **SYSTEM ACCURACY** | | |
| Accuracy of single measurement * | | |
| Range accuracy | 1.2 mm + 10ppm over full range (120 m / 270 m mode)<br>3 mm + 10ppm over full range (570 m / >1 km mode) | |
| Angular accuracy | 8" horizontal; 8" vertical | |
| Target acquisition ** | 2mm standard deviation at 50m | |
| Dual-axis compensator | Liquid sensor with real-time onboard compensation, selectable on/off, resolution 1", dynamic range ±5', accuracy 1.5" | |
| **DISTANCE MEASUREMENT SYSTEM** | | |
| Type | Ultra-high speed time-of-flight enhanced by Waveform Digitising (WFD) technology | |
| Wavelength | 1550nm (invisible) / 658nm (visible) | |
| Laser class | 1 (in accordance with IEC 60825:2014) | |
| Beam divergence | < 0.23mrad (FWHM, full angle) | |
| Beam diameter at front window | ≤ 3.5mm (FWHM) | |
| Range and reflectivity | Minimum range 0.4 m | |
| | Maximum range mode | Reflectivity |
| | 120 m | 8% |
| | 270 m | 34% |
| | 570 m | 60% |
| | >1 km | 80% |
| Scan rate | Up to 1'000'000 points per second | |
| Range noise * | 0.4mm rms at 10m<br>0.5mm rms at 50m | |



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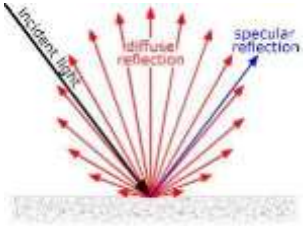
# Object related errors: material

Returning signal is influenced by the **reflective properties of the surface**…




- Very dark and very bright surfaces cause increased noise -> ranging errors
- Specular reflection -> no returning signal
- Multipath reflection -> on transparent material the laser beam is refracted and reflected

Effect of distance, wavelength, moisture and rock type tested in laboratory (Rosnell, 2017) @ 8 m distance

- Errors caused by **moisture** up to **20 mm**
- Error caused by **rock type** up to **4 mm**

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# Environmental errors

## Temperature

- Sun is increasing surface temperature unevenly -> Hot surfaces may increase the noise in ranging
- e.g. frozen ground is melting under the tripod

## Atmosphere

- Dust, fog, rain, smoke… anything that hinders the travel of light
- Air temperature, pressure and humidity influence the index of refraction and the speed of light
  - A difference in temperature of **10°C** or in air pressure of 35 mbar -> **distance error of 1 mm/100 m**
  - Elevation difference: the temperature decreases 0.65°C/100 m and air pressure decreases 10 mbar/100 m. At **2000 m** elevation the atmospheric parameters may lead up to **8 mm distance error at 100 m.**



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# Methodology – operator has the strongest influence on:

- Scanner selection
- Scan station locations
- Scanner parameters
- Reference target types and locations
- Measuring the targets




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