Laser Scanning

Theory and practice

Martina Diaz
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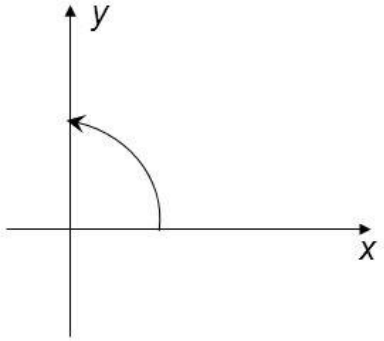
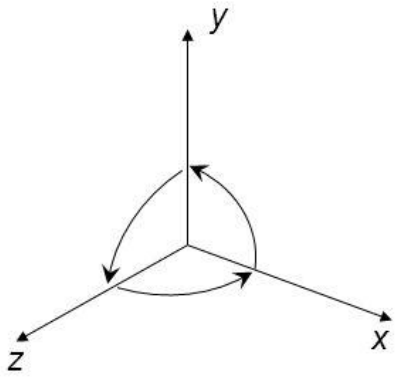
CONTENTS

Scanners : input devices





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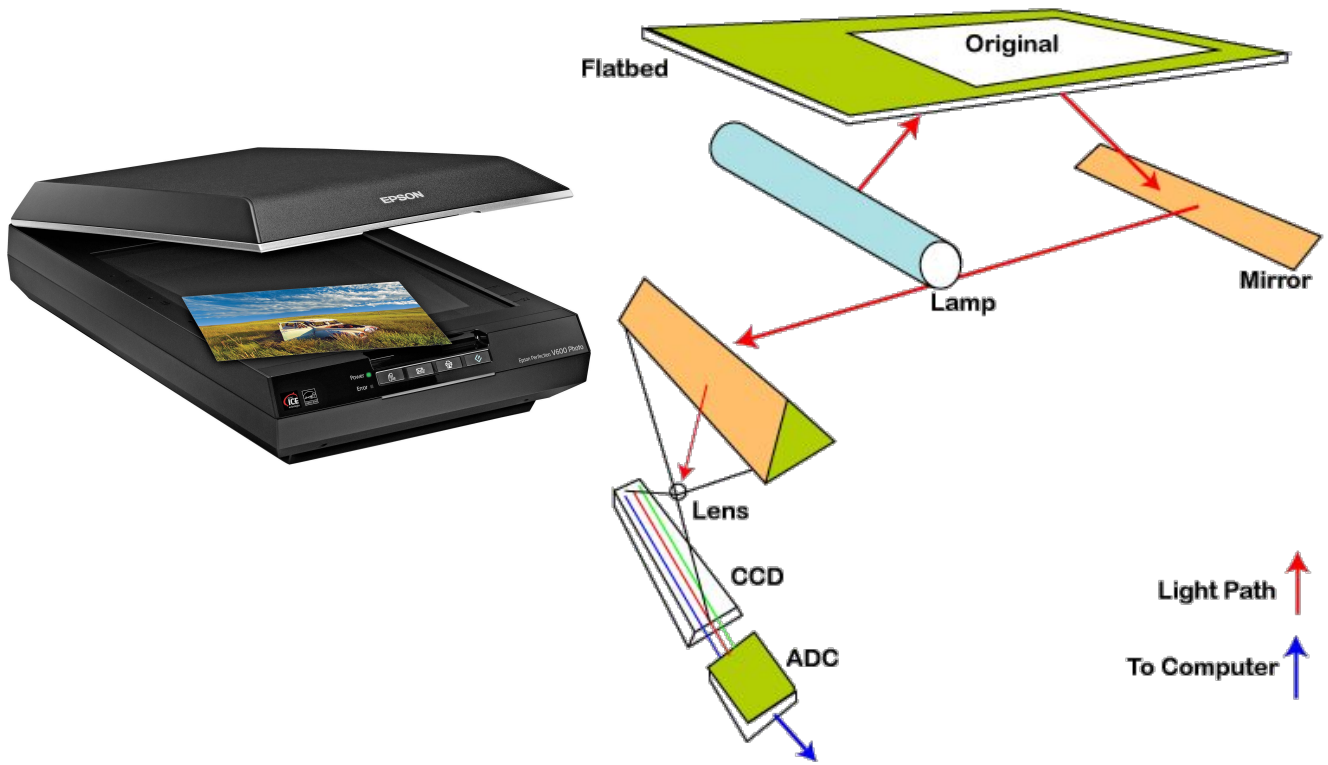
Scanners : input devices

Charge Couple Device (CCD)
is a device for the movement of electrical charge, usually from within the device to an area where the charge can be manipulated, for example conversion into a digital value

CCD converts light in electrical charge

Made up of thousands pixels

Makes the hard copy of the image into an electrical form that can be stored on the device (laptop/hard disk/…)



Scanners : input devices

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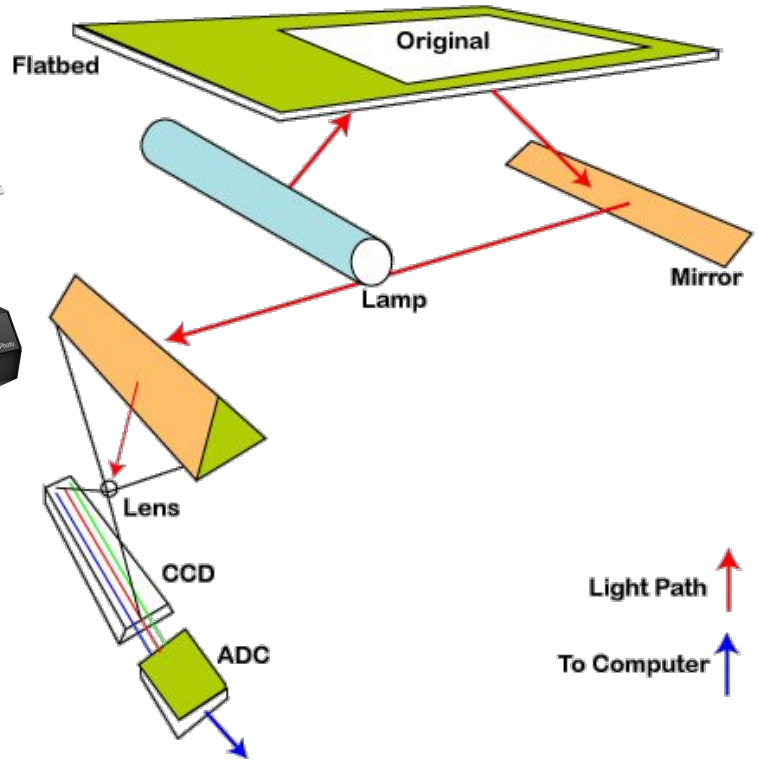
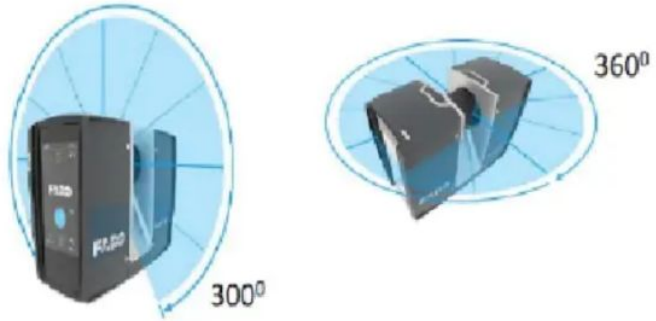


Scanners : input devices

3D scanner technologies

- Laser
- White lights
- X-rays
- Ultrasound



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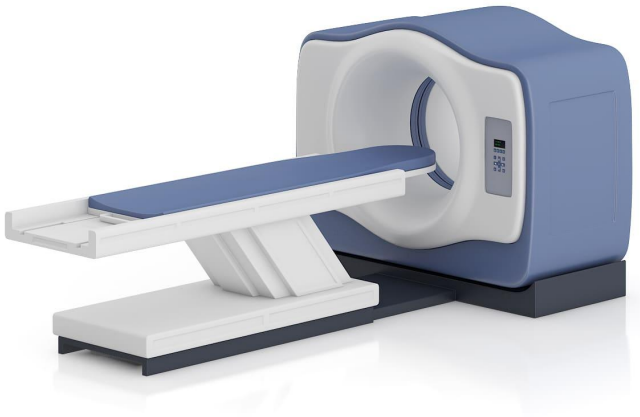
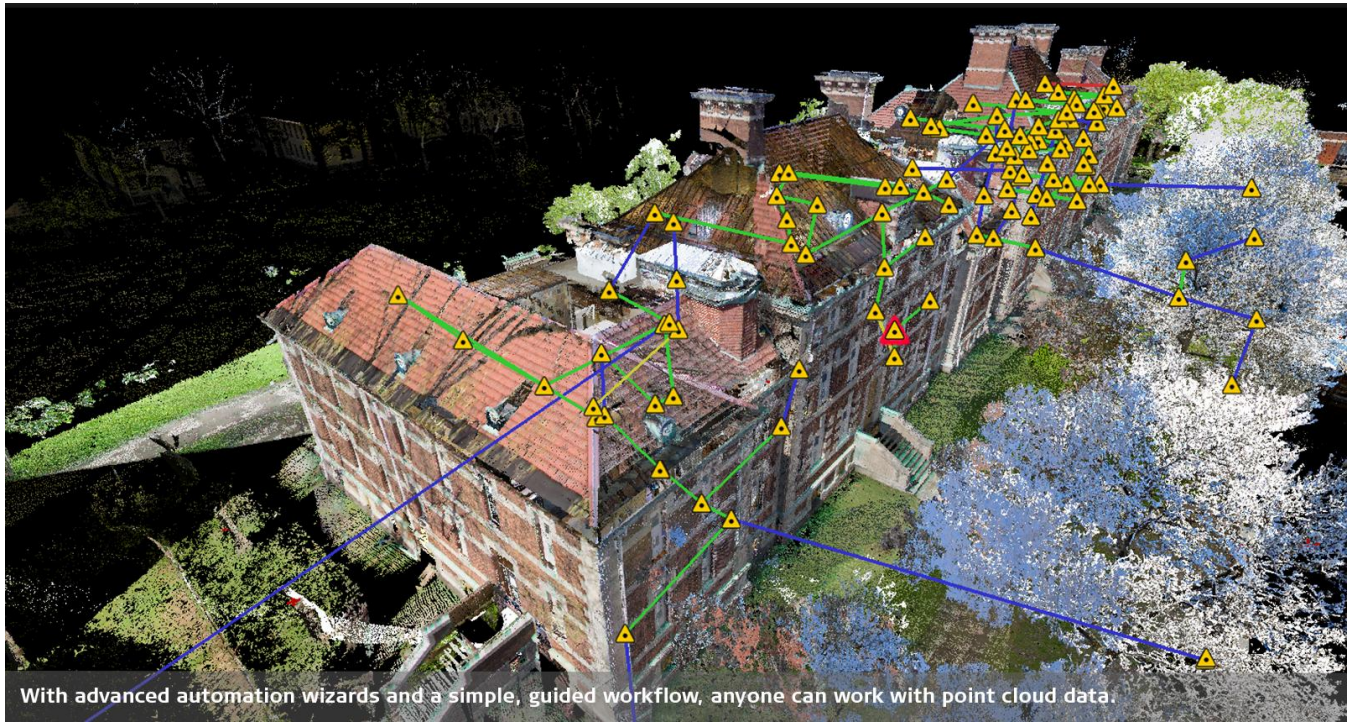


https://www.youtube.com/watch?v=1lDO1UevAJI

What is 3D scanning?



©Leica

Laser scanning is a process of capturing precise, three-dimensional information from a real-world object, a group of objects, or an environment, using a laser as a light source

- Downloading the model as point clouds
- Point clouds automatically converted it into a triangulated mesh

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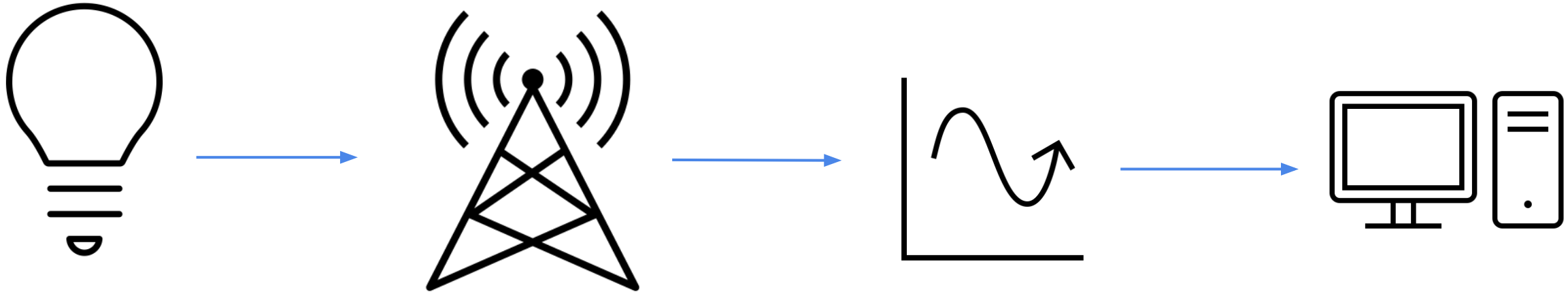
Data acquisition system - DAS

DAS principles:
Acquisition
Analysis
Presentation of the information



physical phenomenon/entity

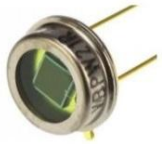
sensor

Signal acquisition

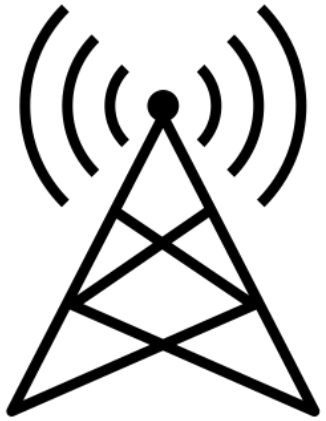
Data Processing

Temperature Sensor

Data acquisition system - DAS



Light Sensor



Humidity Sensor

Metal Sensor

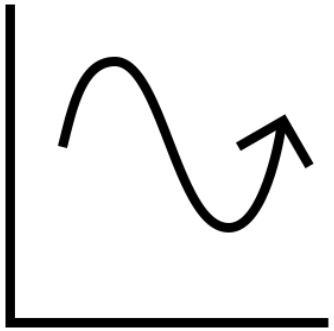
Proximity Sensor

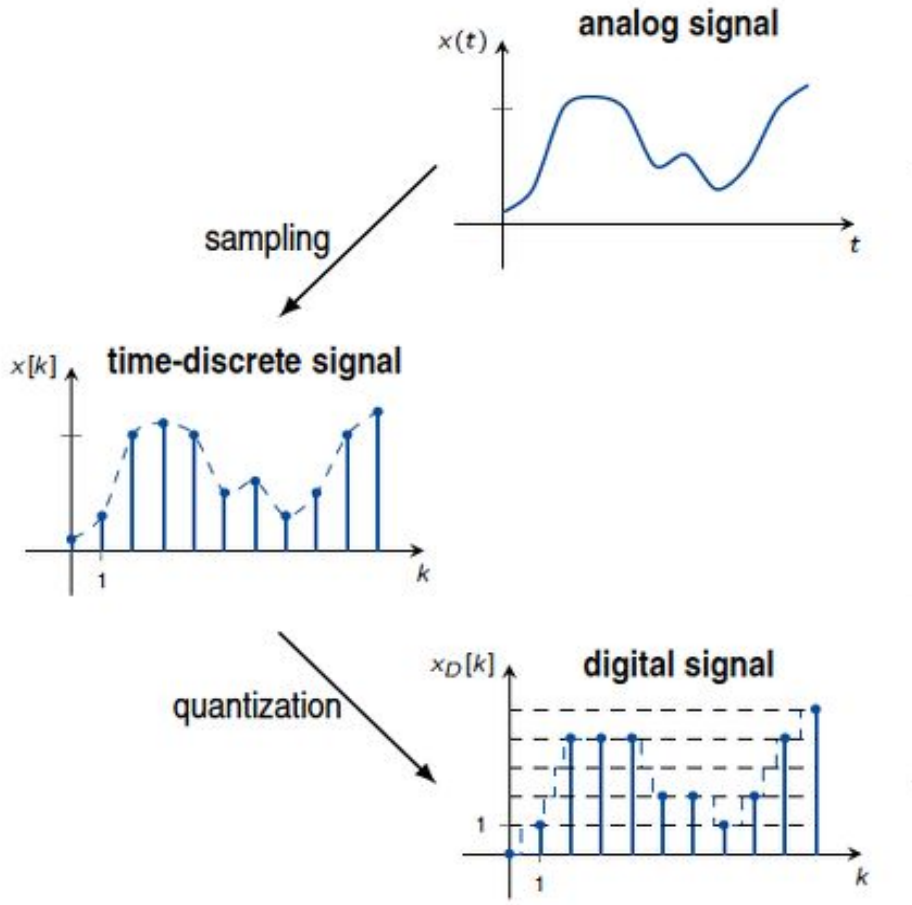
Color Sensor

A sensor has the role of converter of a physical phenomena (can be light, sound, temperature, etc.) into a signal measurable through its occurrence.

Phenomena	Transducers/Sensors	Electrical Characteristics
Temperature	Thermocouples, resistive temperature devices (RTDs), thermistors	Low voltage output, nonlinear Low resistance, nonlinear
Light	Vacuum tube, photo sensors	Current loop output if current type (typical 4 to 20 mA)
Sound	Microphone	Charge output, powered converter
Force and pressure	Strain gages, piezoelectric transducers	Low resistance, low sensitivity, nonlinear
Position and displacement	Potentiometers, linear voltage differential transformer (LVDT), optical encoder	LVDTs: Inductive, requires demodulation
Vibration	Accelerometer	Charge output, powered converter
pH	pH electrodes	

Data acquisition system - DAS





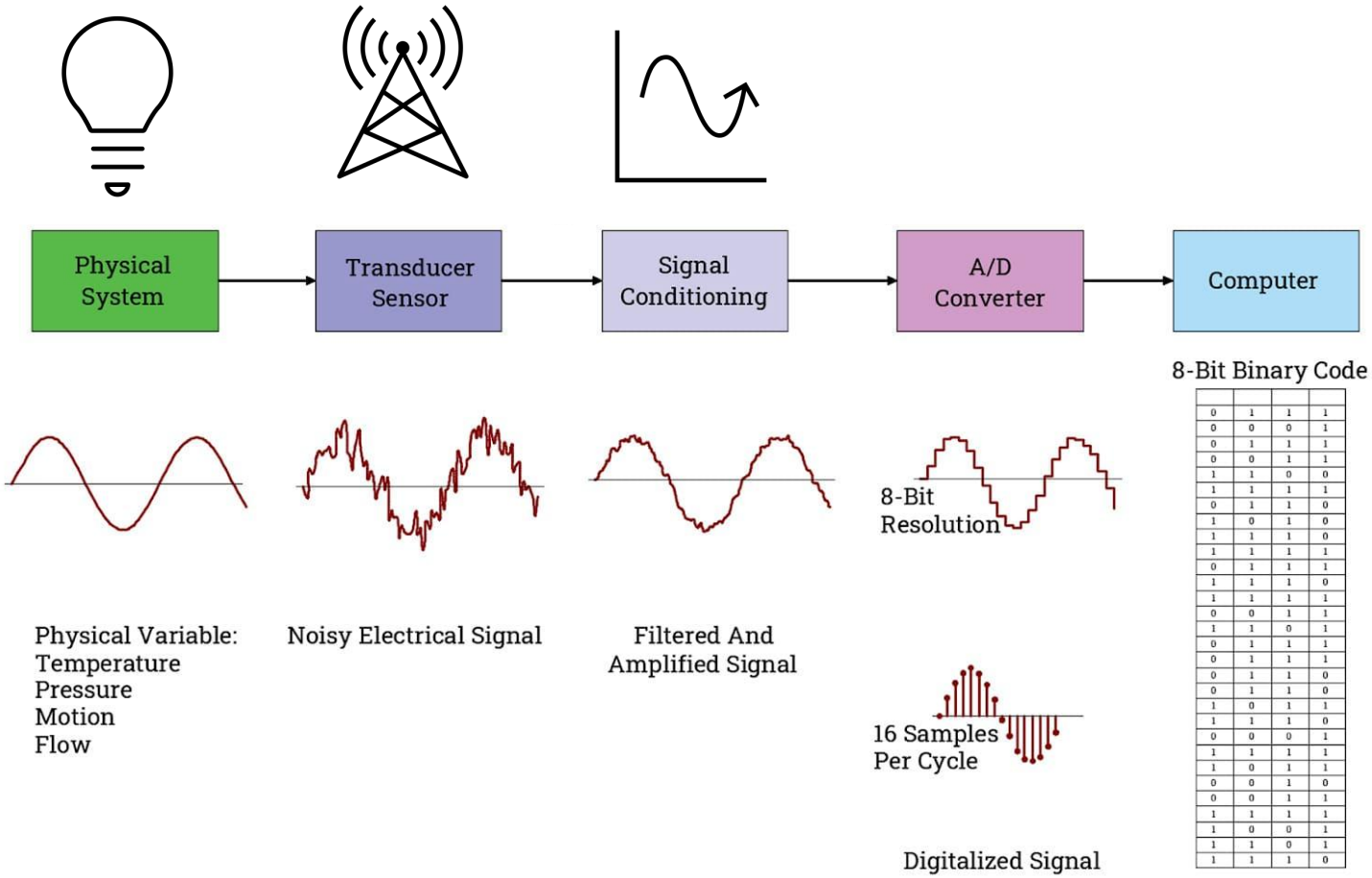
©https://www.bcstvalve.com/what-are-analog-and-digital-signal/

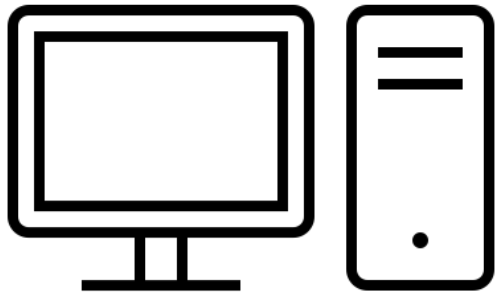
Analog signal
Continuous and time varying
Usually in the form of sine wave
Continues values to represent the data
Potential affection by noise
Use more power
Temperatures, pressure, flow, …
Resistors, inductors, … in analog circuit

Digital signal
Binary form, 2 or more states
Usually in the form of square wave
Discrete values to represent the data
Immune from noise
Use less power
Motor start, trip, …
Transistors, microcontroller, … in digital circuit

Data acquisition system - DAS

3 R(s) of DAS
- Resolution
- Range
- Rate





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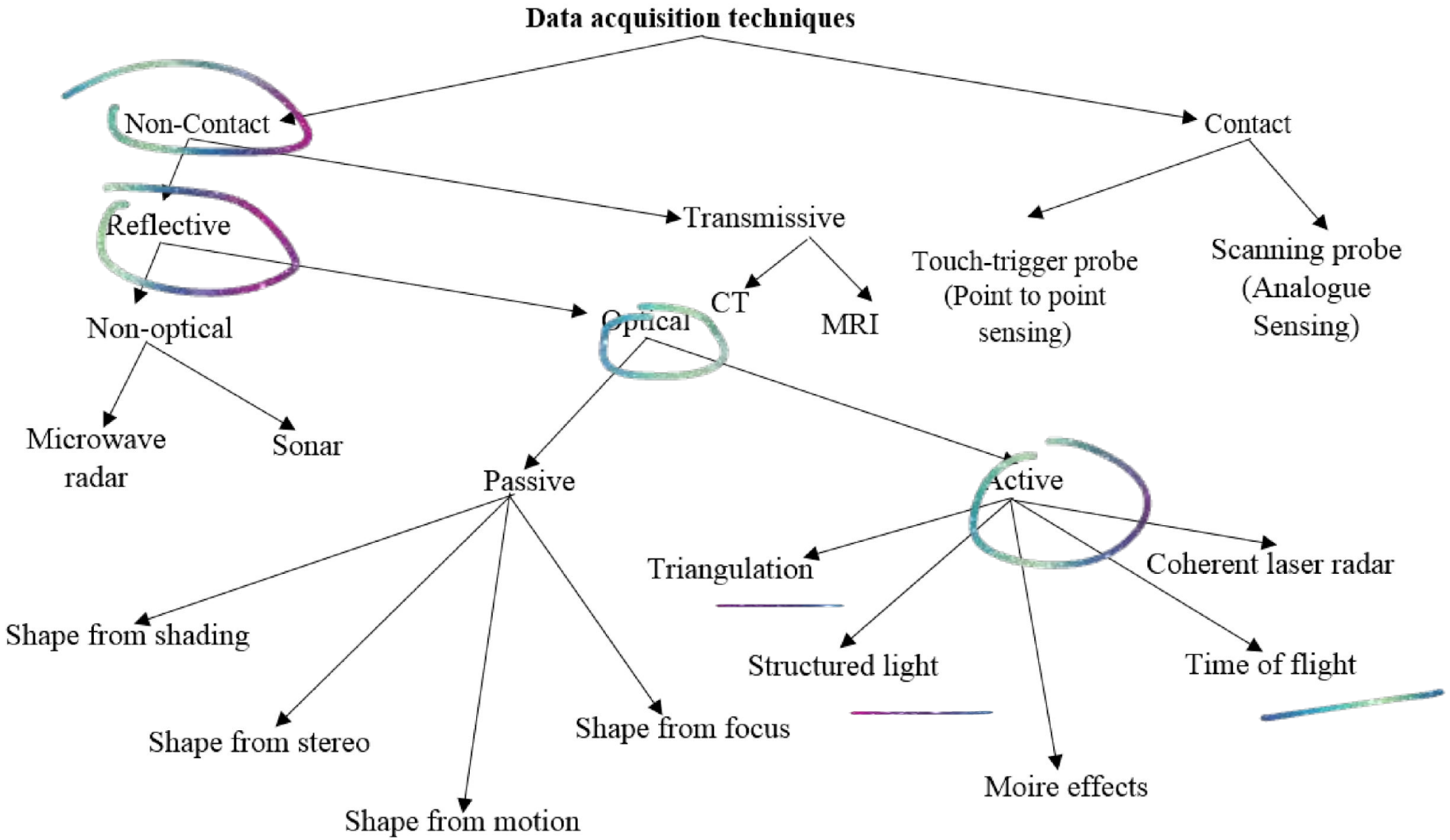
Data acquisition system - DAS



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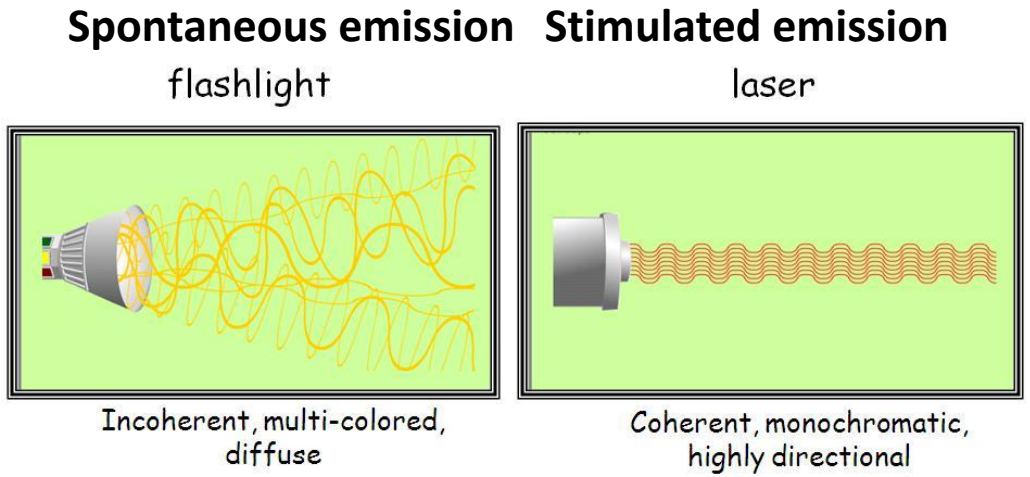
Laser : a device that utilises the natural oscillations of atoms or molecules between energy levels for generating a beam of coherent electromagnetic radiation usually in the ultraviolet, visible, or infrared regions of the spectrum
(Merriam-Webster)

Laser = Light Amplification by Stimulated Emission of Radiation



The laser is an equipment able to transform energy from a primary form (electrical, optical, chemical, thermal or nuclear) in a beam of monochromatic, coherent electromagnetic radiation of high intensity: the laser light.

Laser

Monochromatic

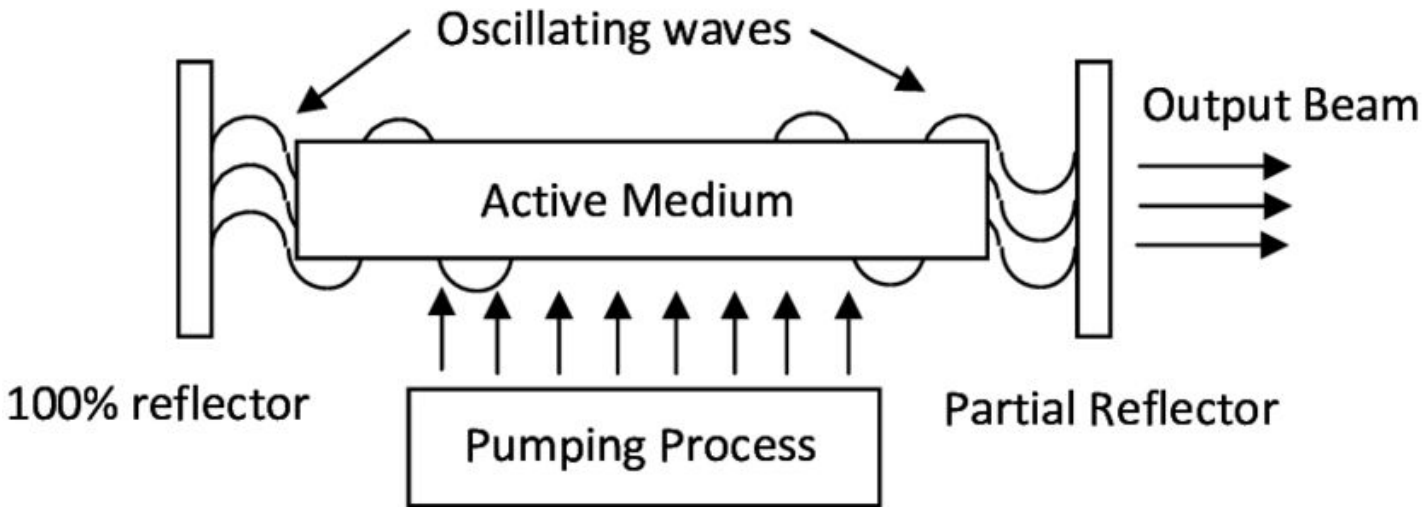
Concentrate in a narrow range of wavelengths (one specific colour).

Coherent

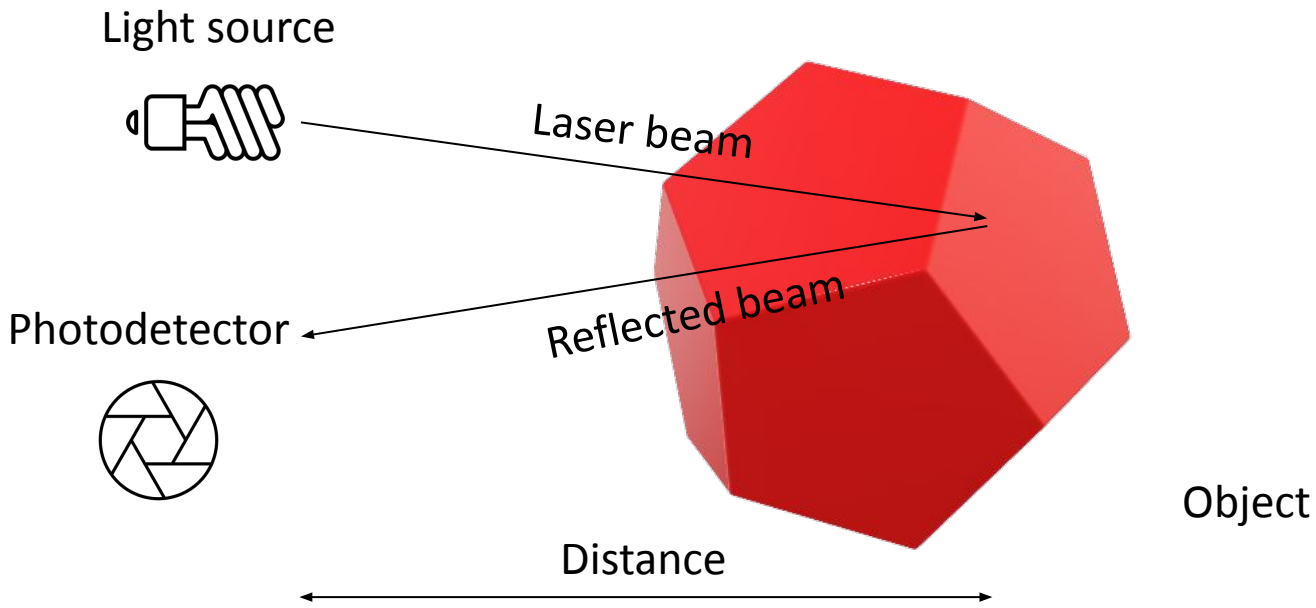
All the emitted photons bear a constant phase relationship with each other in both time and phase

Directional

A very tight beam which is very strong and concentrated.

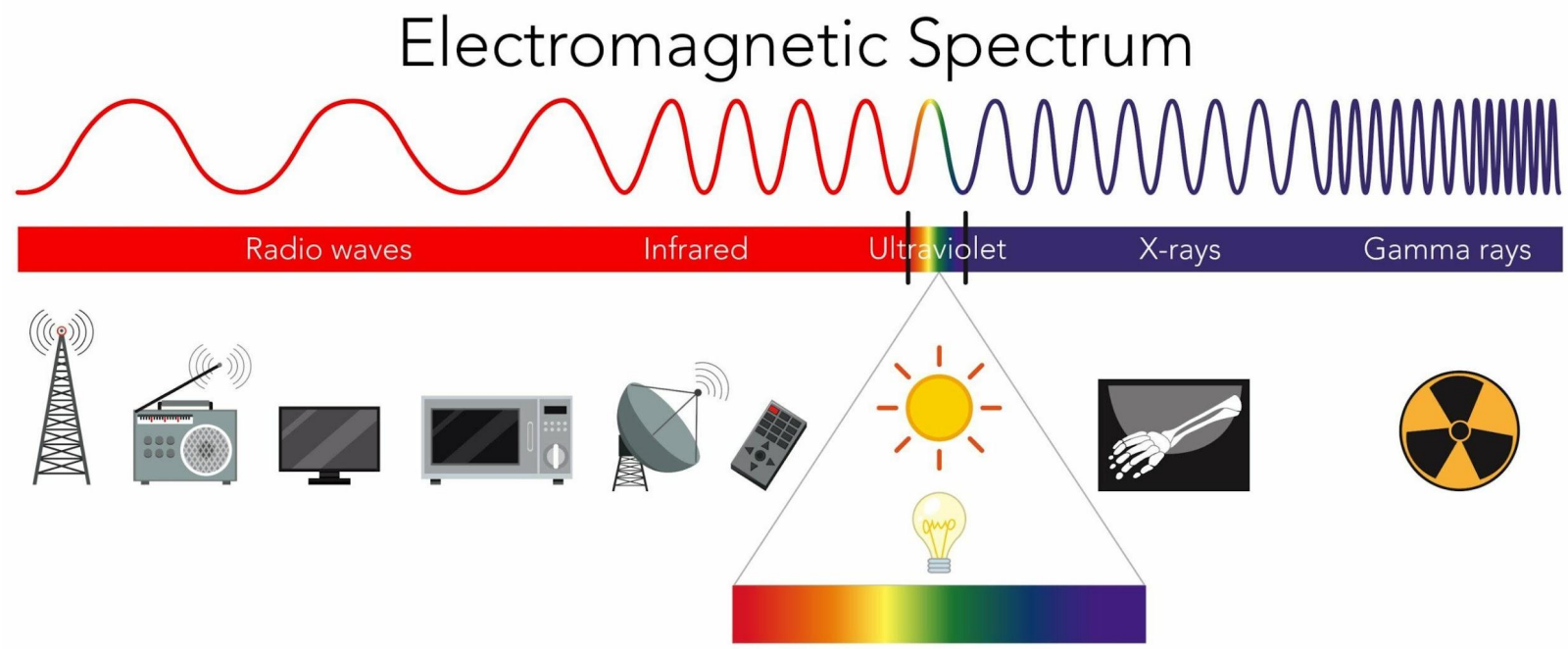


Laser


Light source
Laser beam
Photodetector
Reflected beam
Object
Distance

Laser radiation

ultraviolet (200-400 nm)
visible (400-700 nm)
infrared light (>700 nm)

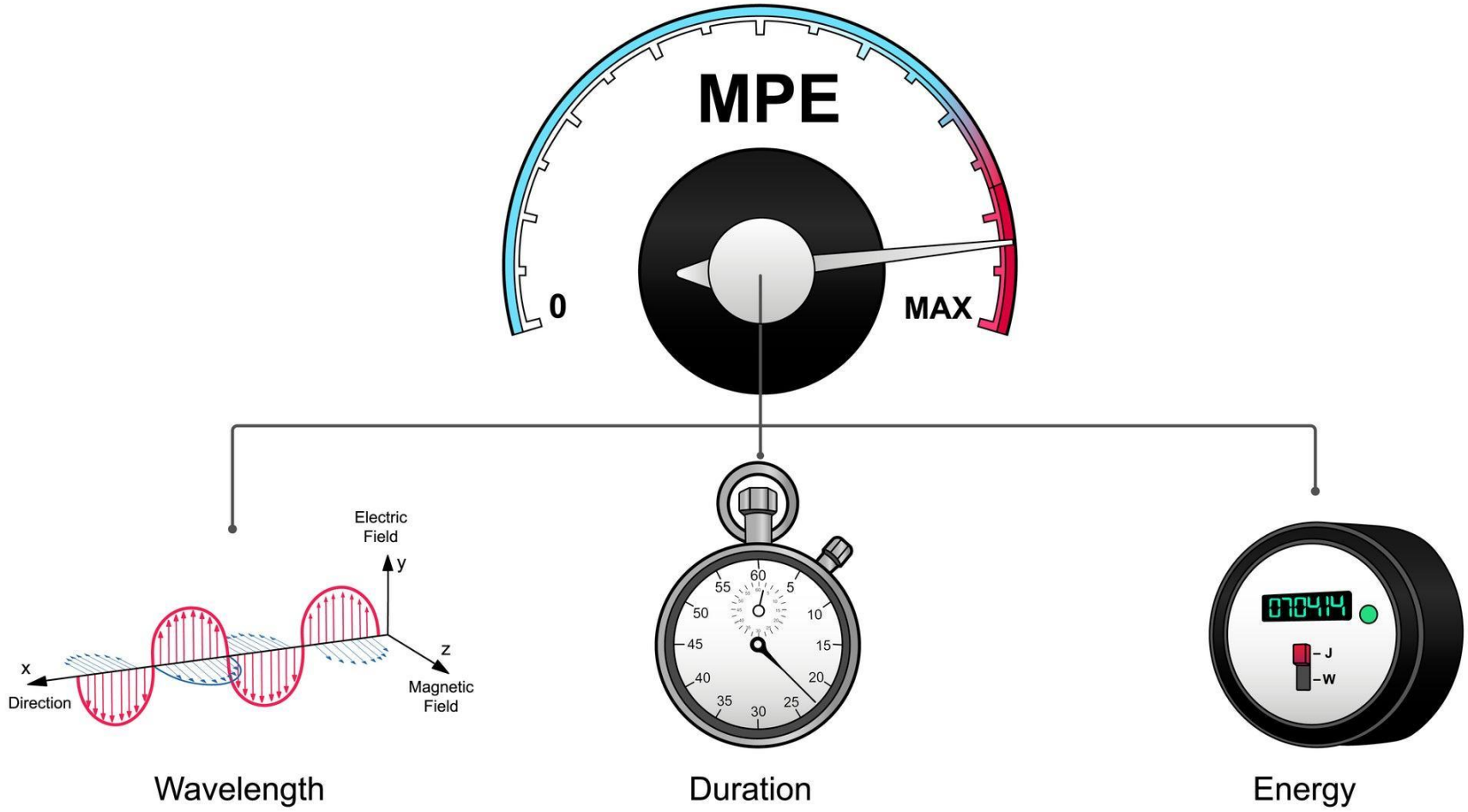


©https://online-learning-college.com/knowledge-hub/gcses/gcse-physics-help/electromagnetic-spectrum/

THE LASER LIGHT IS NOT ALWAYS CONTINUOUS, BUT CAN BE EMITTED IN THE FORM OF SHORT PULSES. CONSEQUENTLY, THE PEAK POWER CAN BE EXTREMELY HIGH

Types of lasers: MPE

Maximum Permisible Exposure



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Types of lasers: AEL

The Accessible Emission Limit passable
maximum accessible emission level
permitted within a particular class

CLASSES

AEL = MPE * area of LA

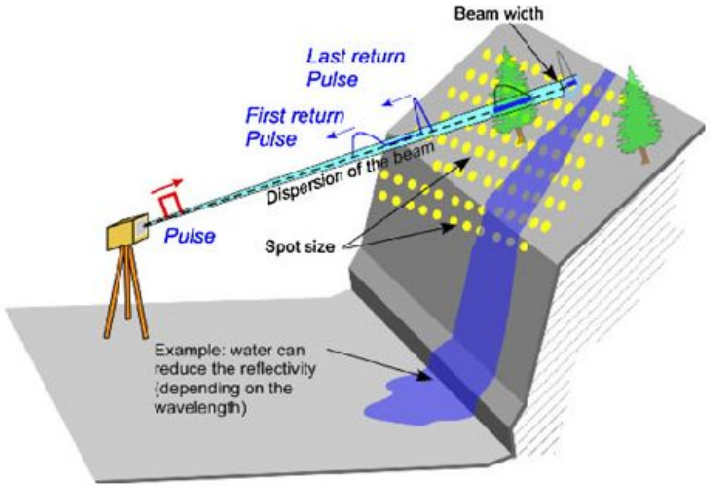
is a parameter that describes the levels of radiation from a laser system, and identify different categories according to the classes of hazard

BREAK 15 MIN

Types of LASER SCANNER

TLS

Terrestrial Laser scanning



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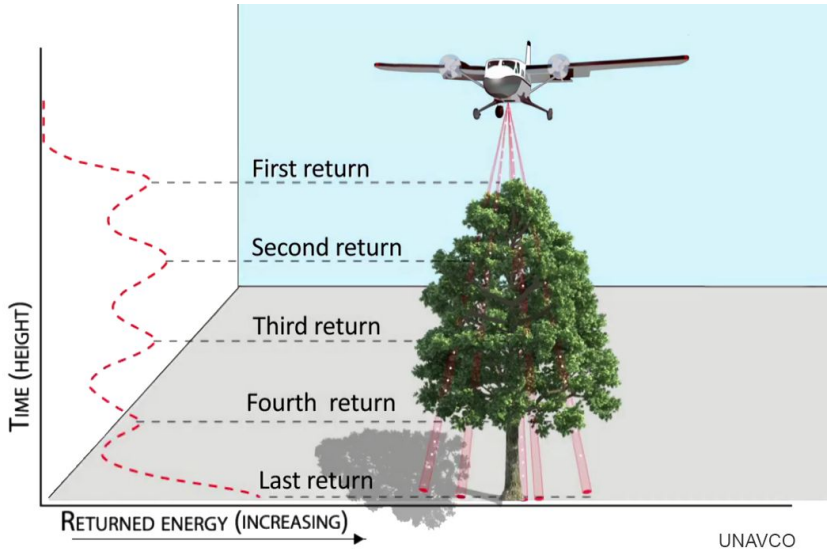
ALS

Aerial laser scanning



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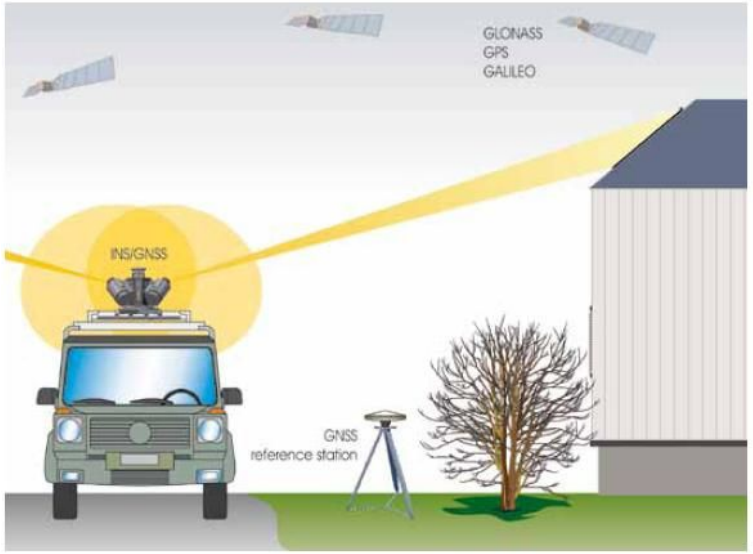
MLS

Mobile laser scanning



©Wang et al 2012

LiDAR : Light Detection and Ranging

Basically, LiDAR is a remote sensing process which collects measurements used to create 3D models and maps of objects and environments

ALS
Components

$$Distance = \frac{Speed\ of\ Light\ x\ Time\ of\ Flight}{2}$$

Ground elevation = (LiDAR system altitude) - Distance

Laser ranging unit

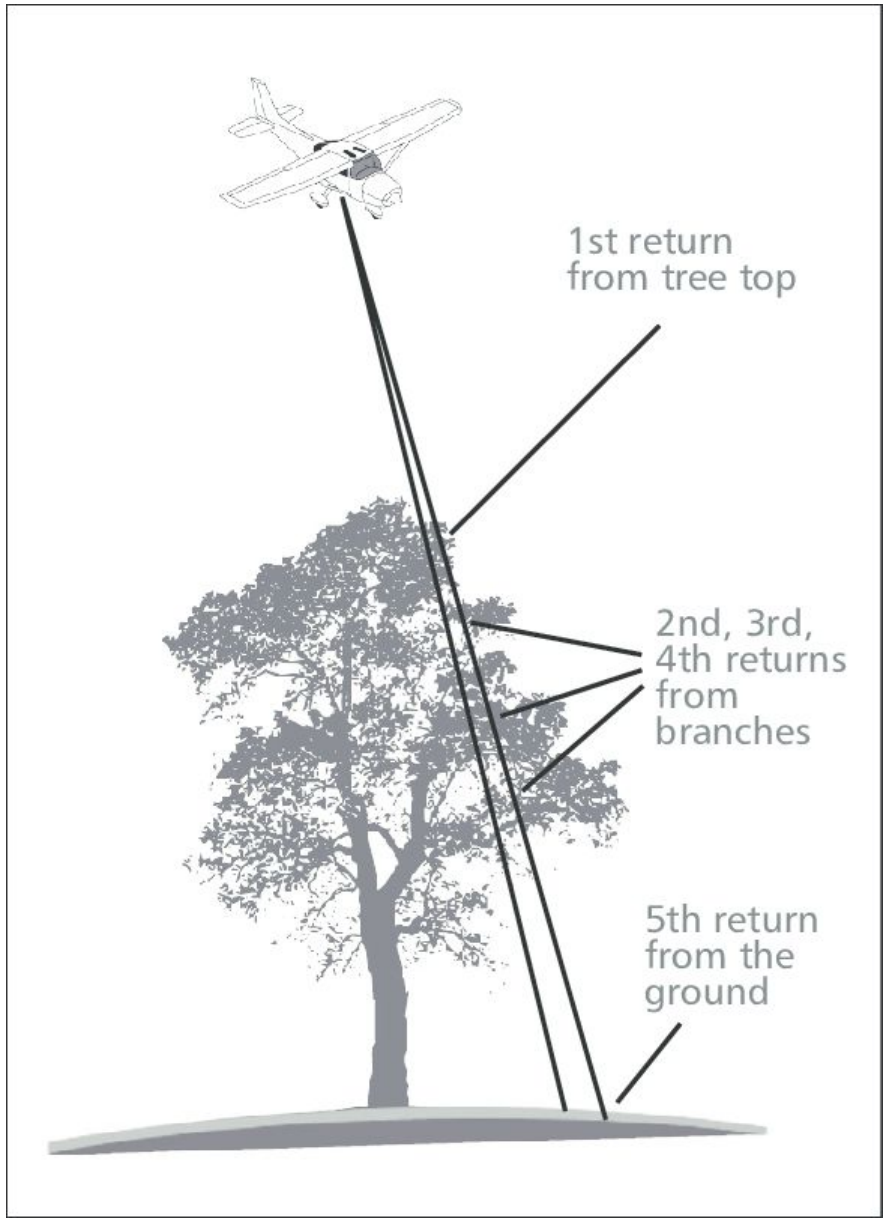
Optical scanning mechanism

Data recording unit

Position detector

Imaging device

https://opentopography.org/lidar_basics



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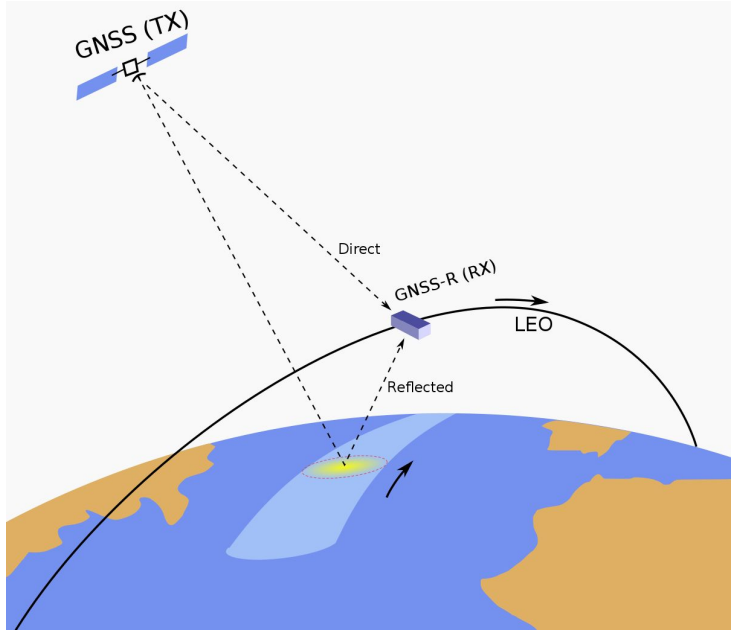
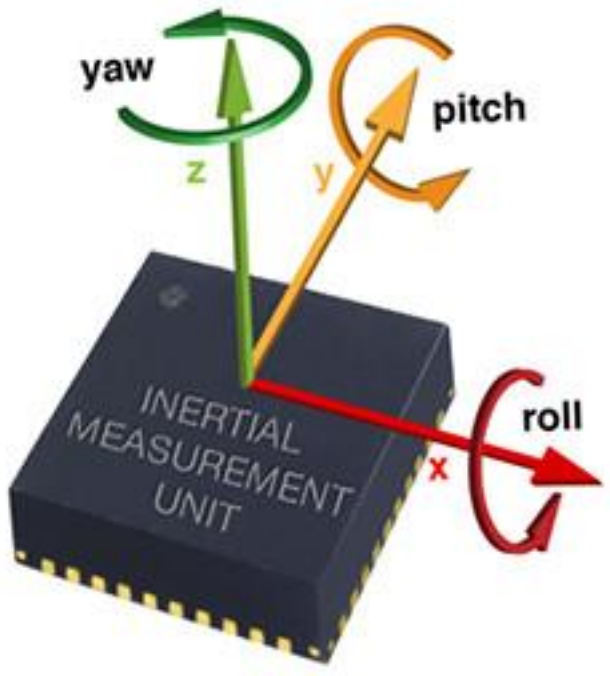
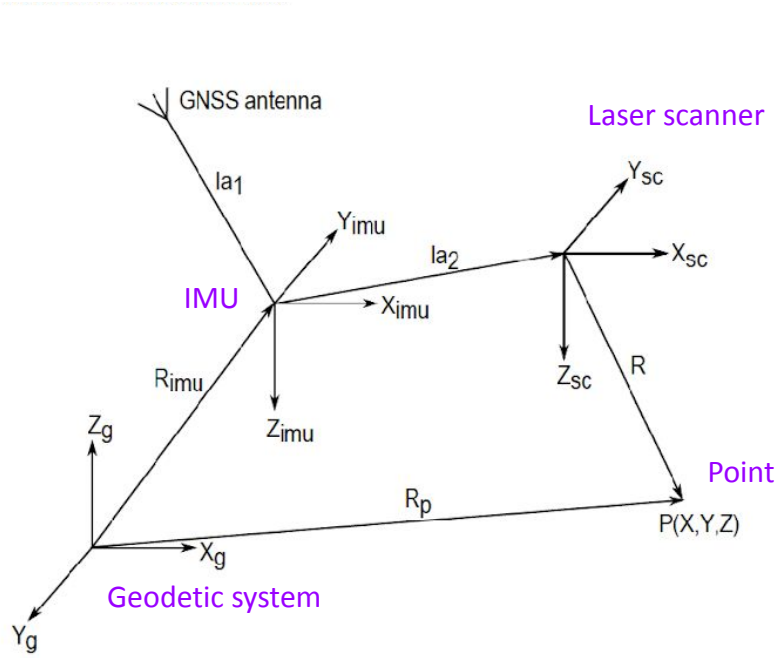
ALS
IMU : Inertial Measurements Unit



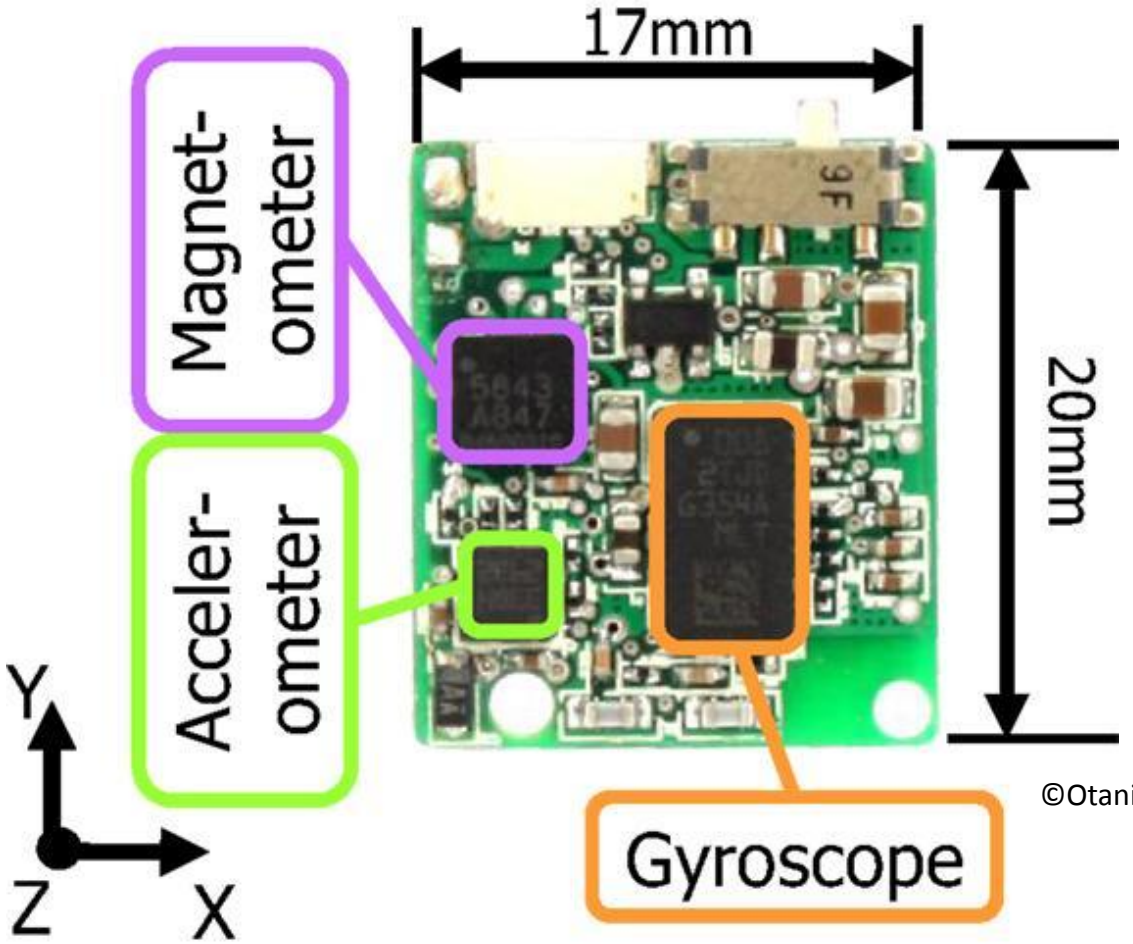




A device that senses and quantifies motion by measuring the forces of acceleration and changes in attitude in the pitch, roll, and yaw axes using accelerometers and gyroscopes

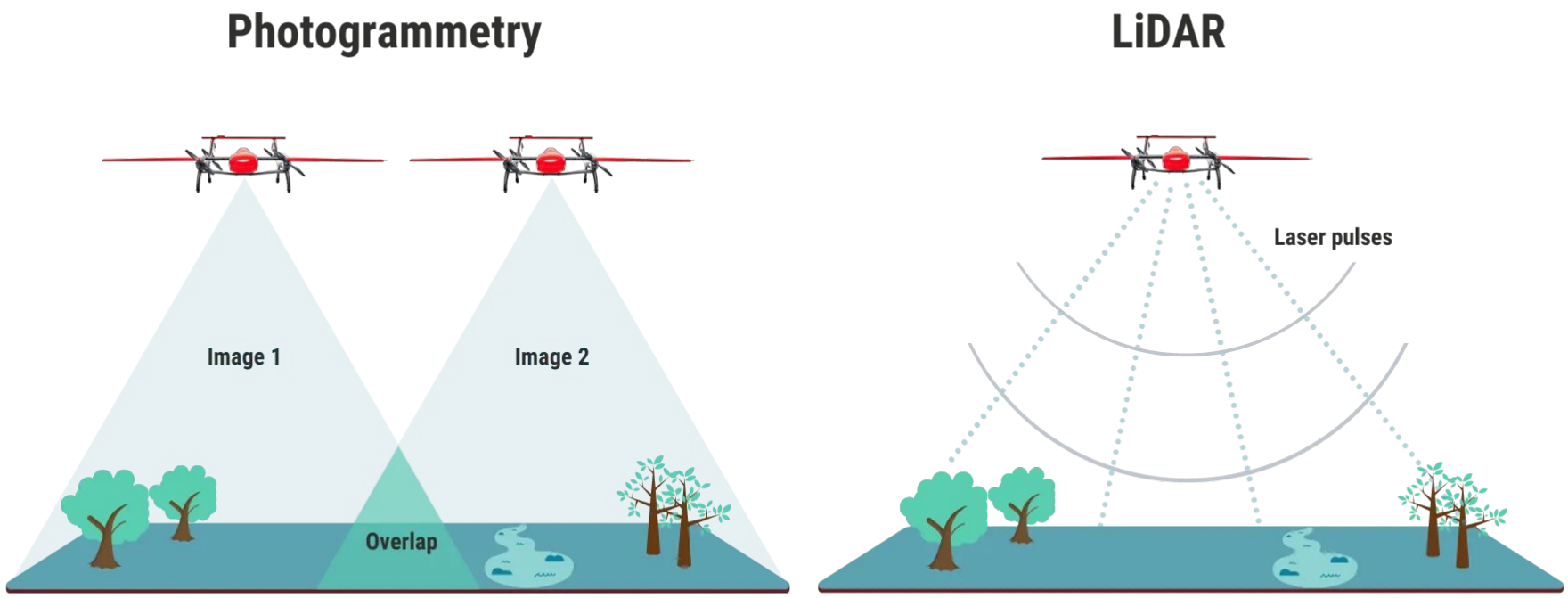
GNSS (Global Navigation Satellite System) – Satellite navigation systems including the United States' Global Positioning System (GPS), Russia's GLONASS, the European Union's Galileo, and China's BeiDou Navigation Satellite System

ALS
IMU : Inertial Measurements Unit



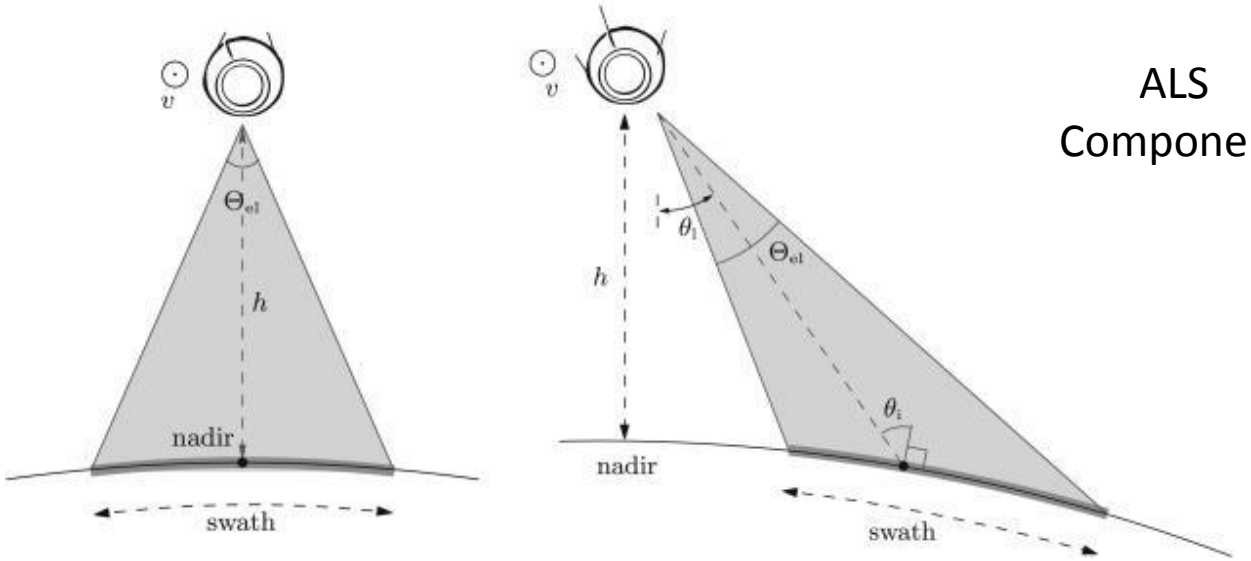
©Otani et al 2015

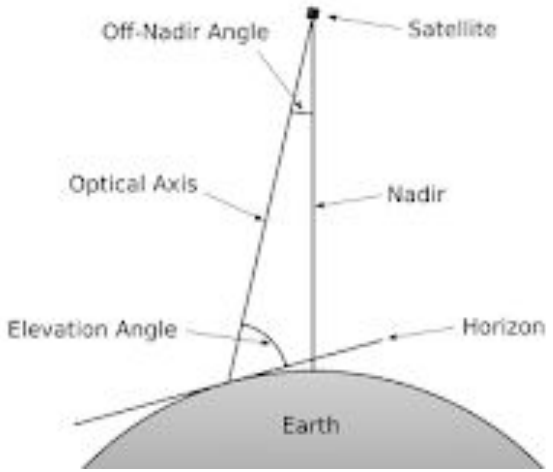
ALS
Vs
Photogrammtery

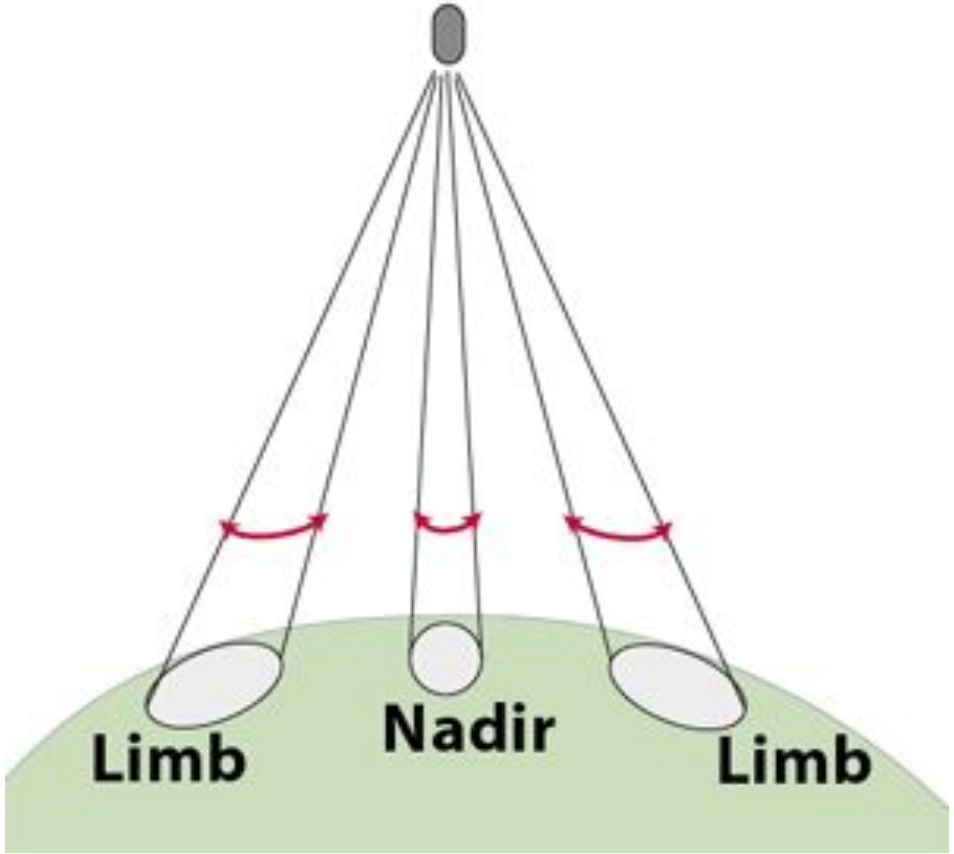


©RVS Land Surveyors

ALS
Component

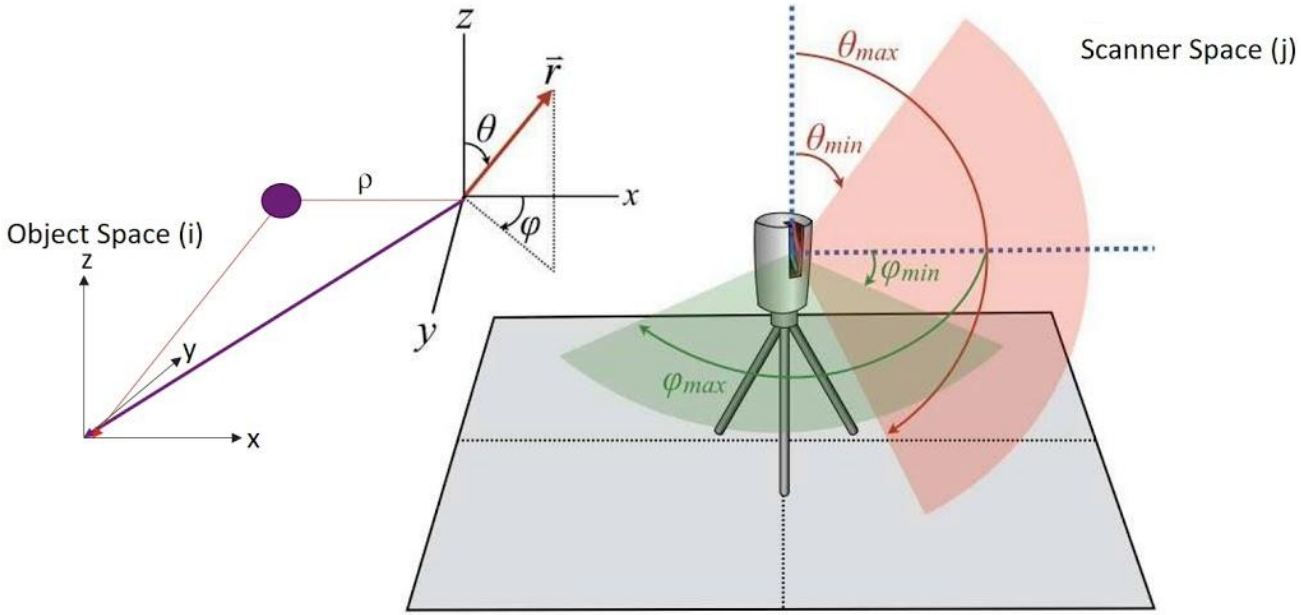






TLS
Coordinates

x,y,z,I



©Bailey, Ochoa 2018

There are different models of scanners active, all different in the way that the scanner receives and/or analyses the signal of the reflected radiation.

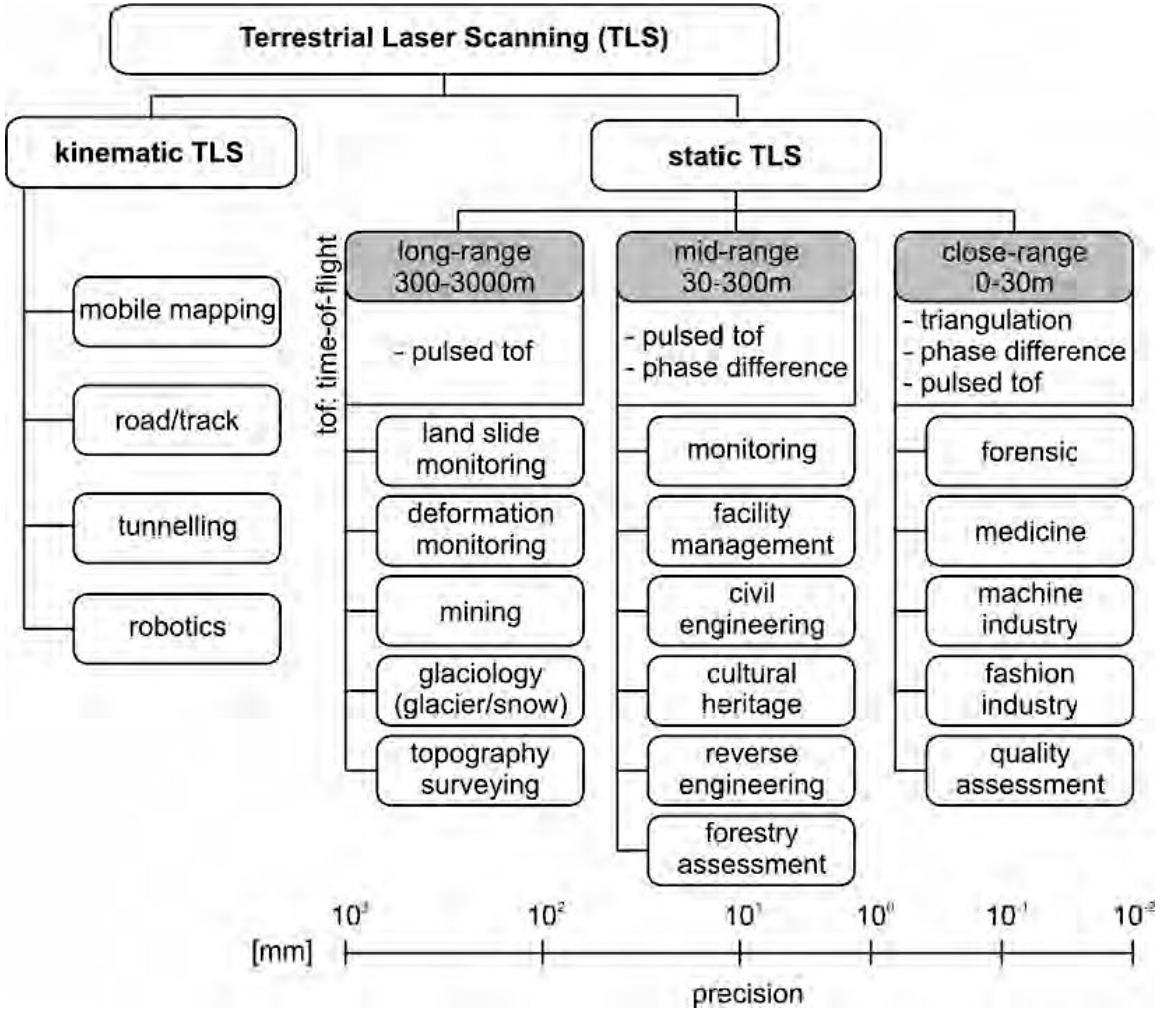
TLS & LiDAR
Types of range

- Long range (150-1000m): monitoring, city modelling, forest mapping, mining, …
- Medium range (1-150m): facility management, Industry, civil engineering, geology, architecture, cultural heritage, …
- Close range (0,5-2m) for detail and accuracy: reverse engineering, body scanning, medicine, police, …

Other parameters
(level of detail, capture of colour, scan speeds, mobility, size of data sets generated, etc.)

MLS

Mobile laser scanners



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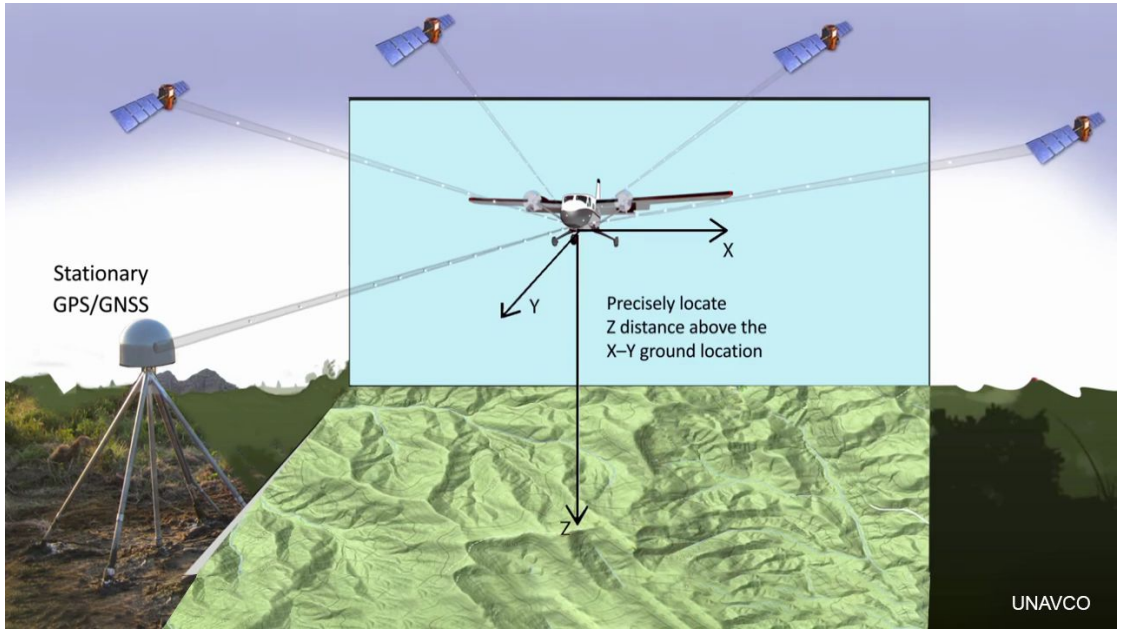
MLS

GNSS
outdoor

IMMS / SLAM
indoor



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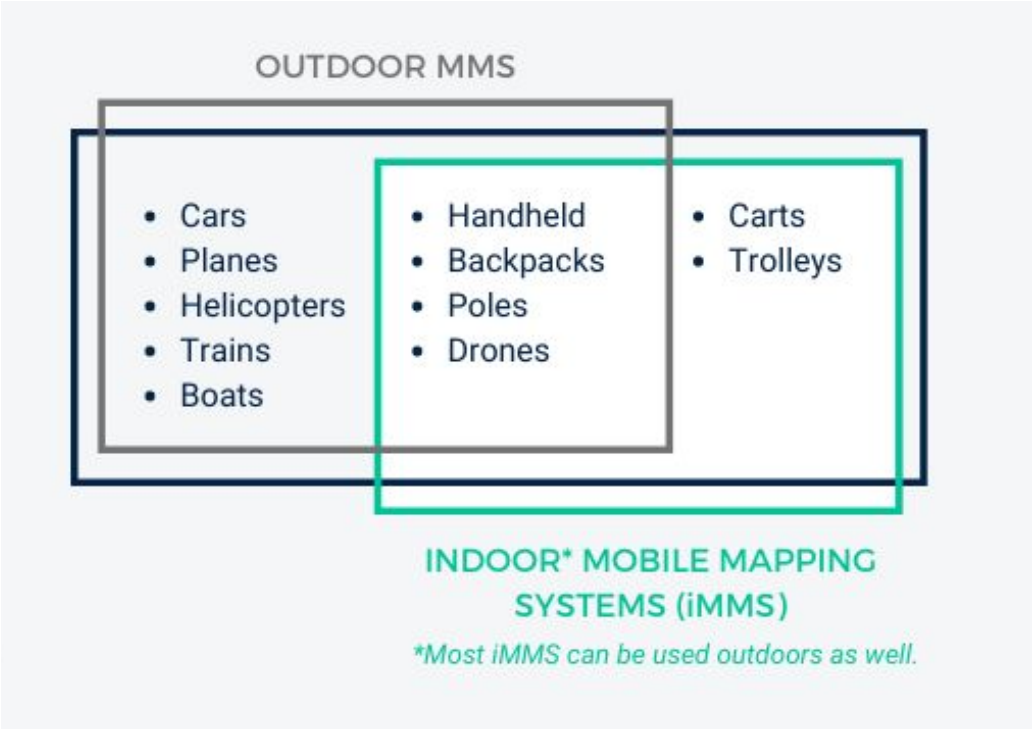
Global Navigation Satellite Systems

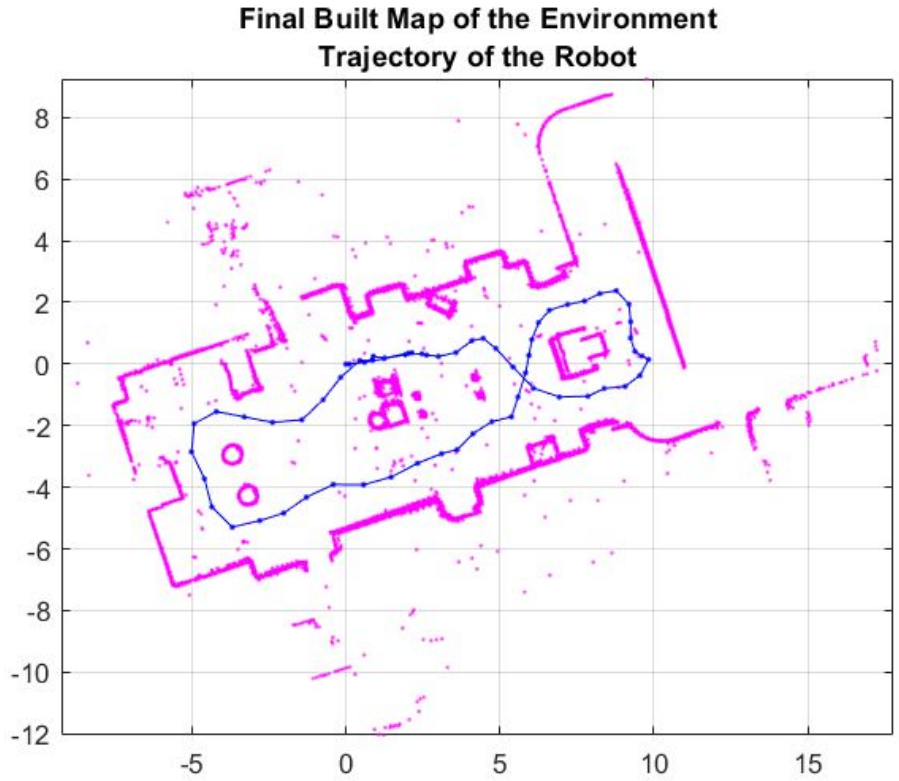


Indoor Mobile Mapping Systems

Simultaneous Localisation and Mapping

MLS
GNSS / SLAM

©NavVis



https://www.mathworks.com/help/nav/ug/implement-simultaneous-localization-and-mapping-with-lidar-scans.html

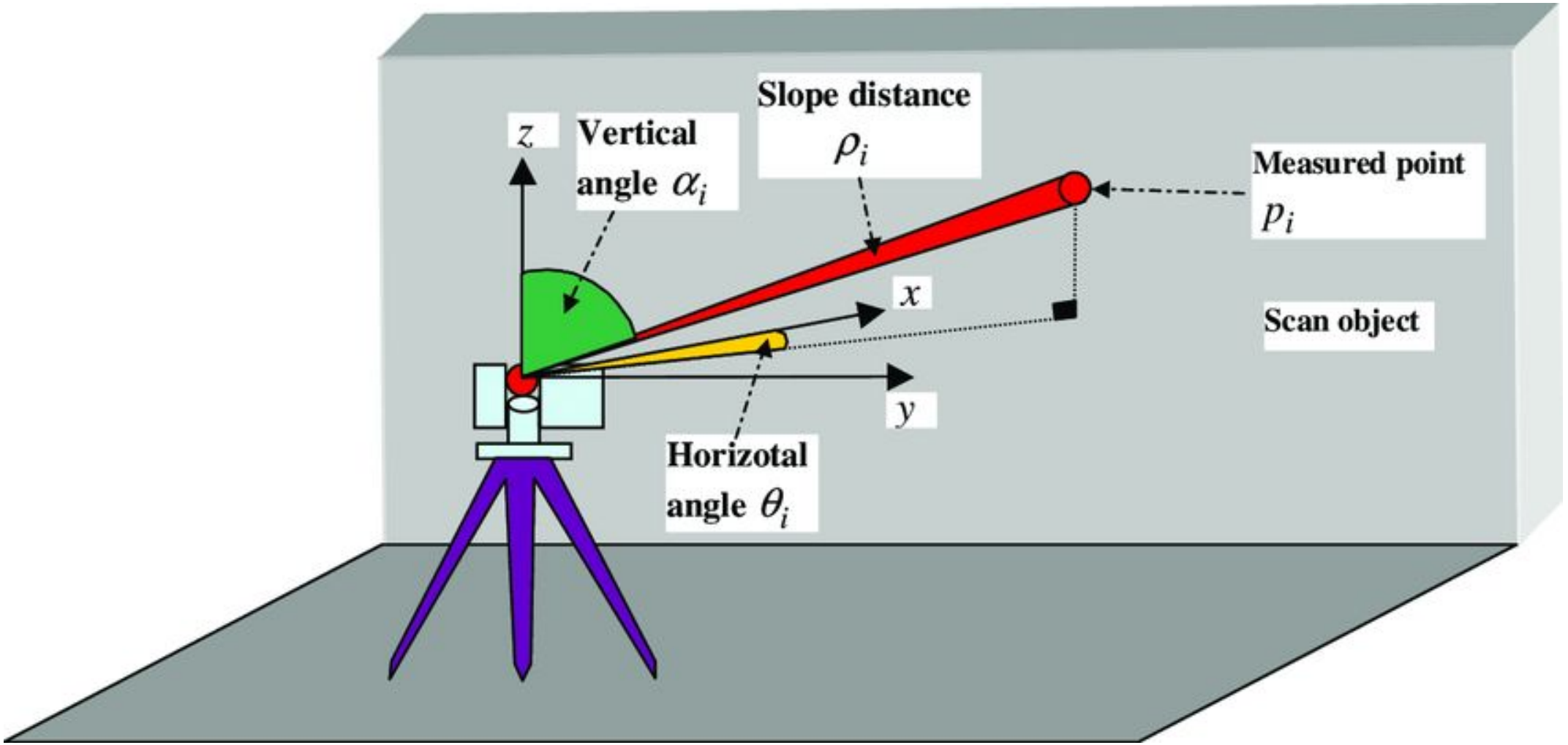
https://www.navvis.com/blog/how-slam-affects-the-accuracy-of-your-scan-and-how-to-improve-it

GNSS / SLAM

Terrestrial Laser Scanning	Mobile Laser Scanning	Airborne Laser Scanning
Scanning of streets/facades		House tops/streets
Control points required		Few control points required
High resolution		Medium resolution
Static	Cinematic	
Moderate speed	High speed	Very high speed
Quick availability	Need for driving permission (Pedestrian zone)	Need for flying permission

BREAK 15 MIN

Models of scanner



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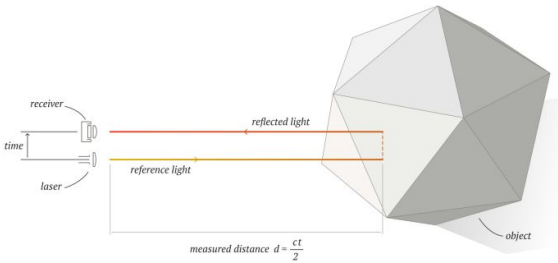
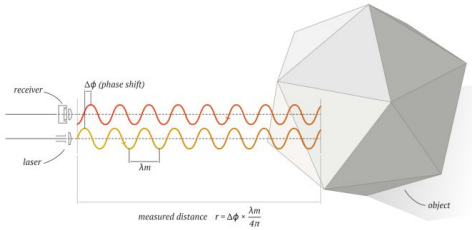
Models of scanner

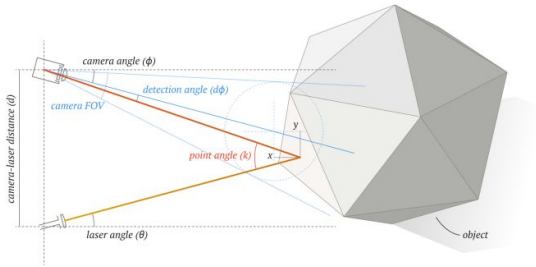
Time of flight / Pulse scanner



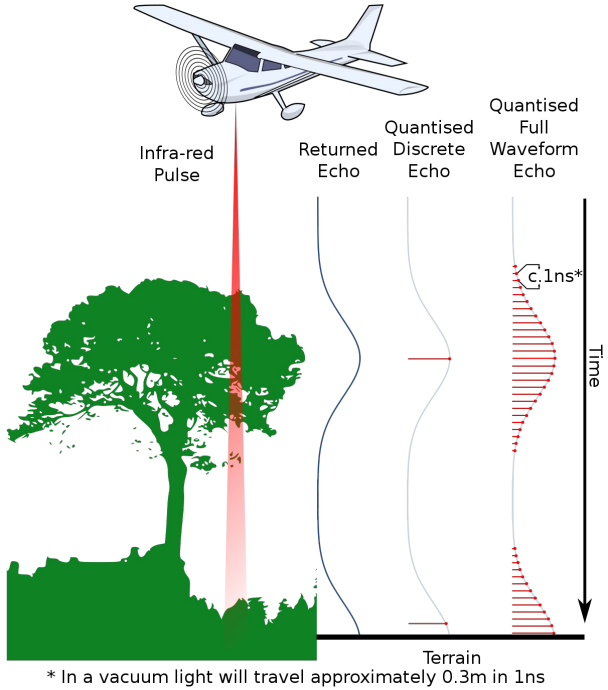
Phase shift scanner



Triangulation scanner



Full waveform



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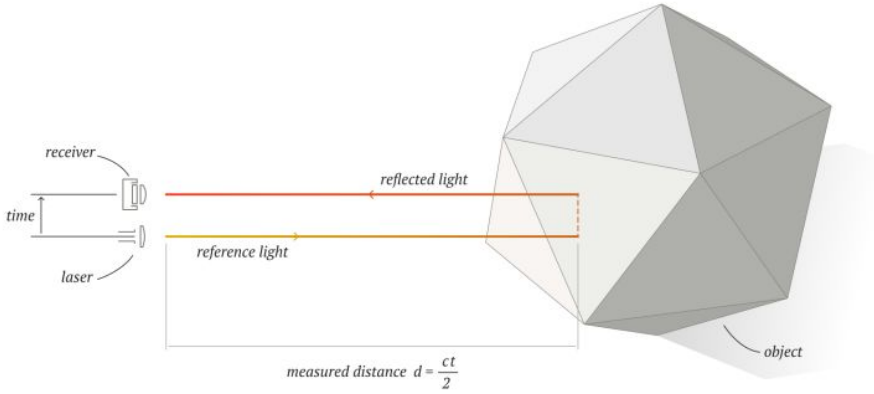
Models of scanner

Time of flight / Pulse scanner



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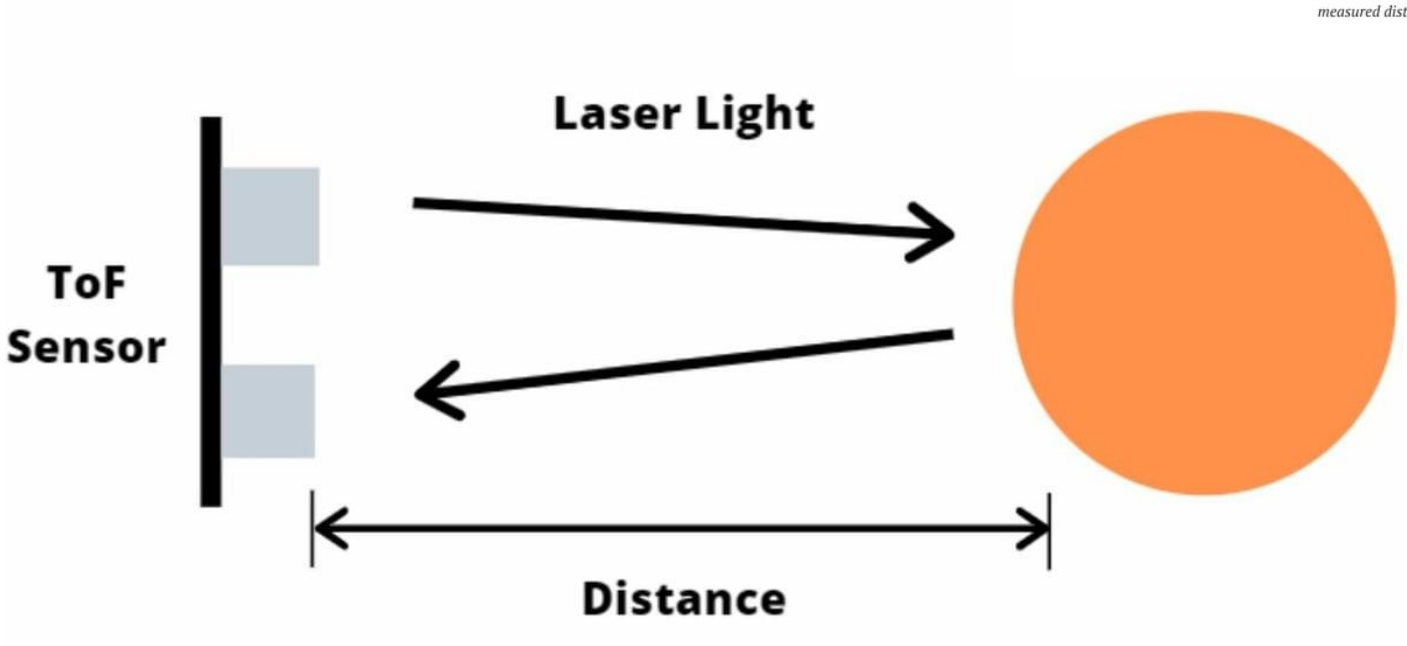
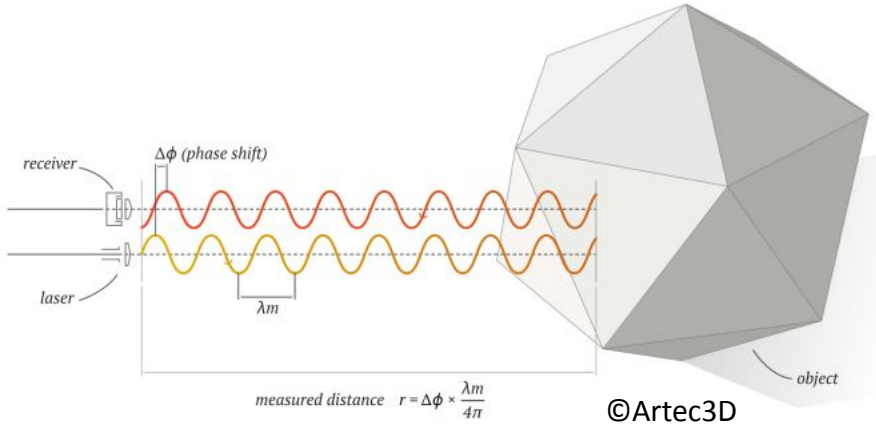


$$D=(c.t)/2$$

Models of scanner

Phase shift scanner



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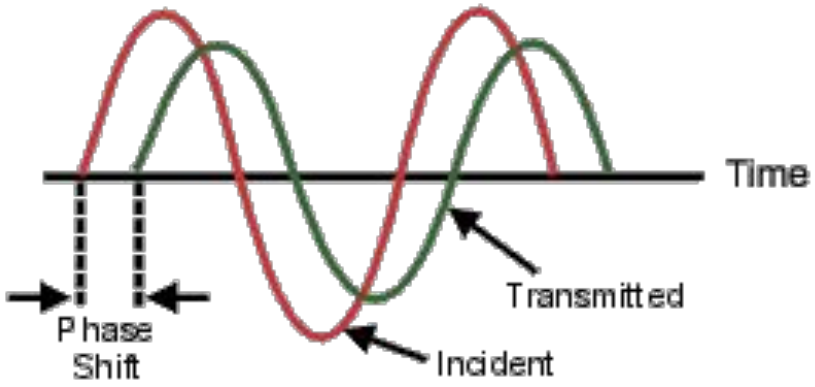
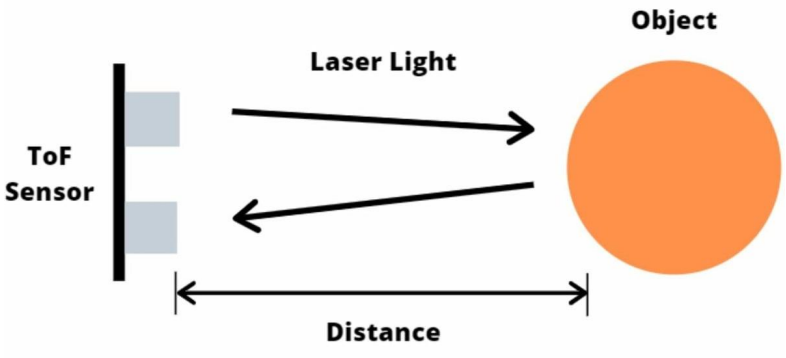
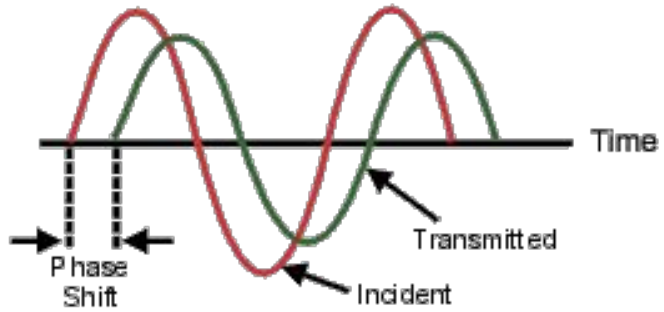


©https://rfmw.em.keysight.com/wireless/helpfiles/m9485a/tutorials/phase_meas.htm

$$t=\Delta\Phi/2\pi^{*}(fmodulated)$$

Models of scanner



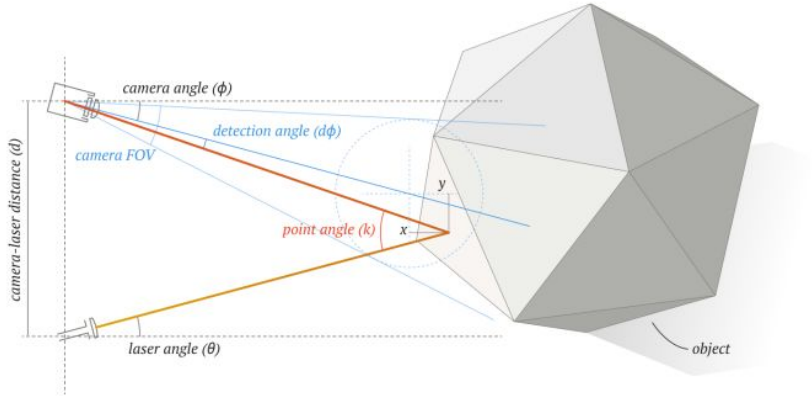


direct measurement of the ToF
long distances of up to 1,000 meters away
slowest data caption rates – between 100 and 1000 p/s
typical accuracy 4-10 mm
RGB caption option
Stationary scanners and ALS

indirect measurement of the ToF
shorter ranges up to 80/120 meters
Faster data acquisition – 10^6/s
Higher accuracy
RGB caption option
Stationary scanners and ALS

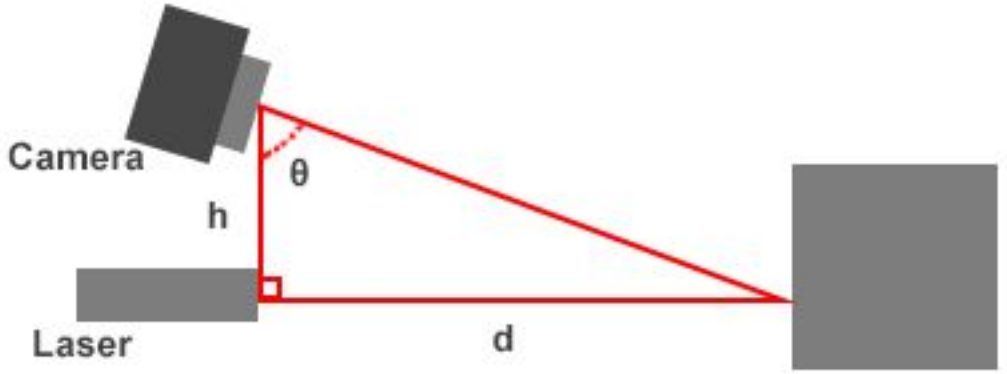
Models of scanner

Triangulation scanner



©Artec3D

shorter ranges <5 meters
RGB capture option
Small objects (1-300 cm)
Stationary scanners
Handheld scanners



h = distance between camera and laser (known)
θ = angle betwen laser and scanner (known)
d = distance between scanner and object (unknown)

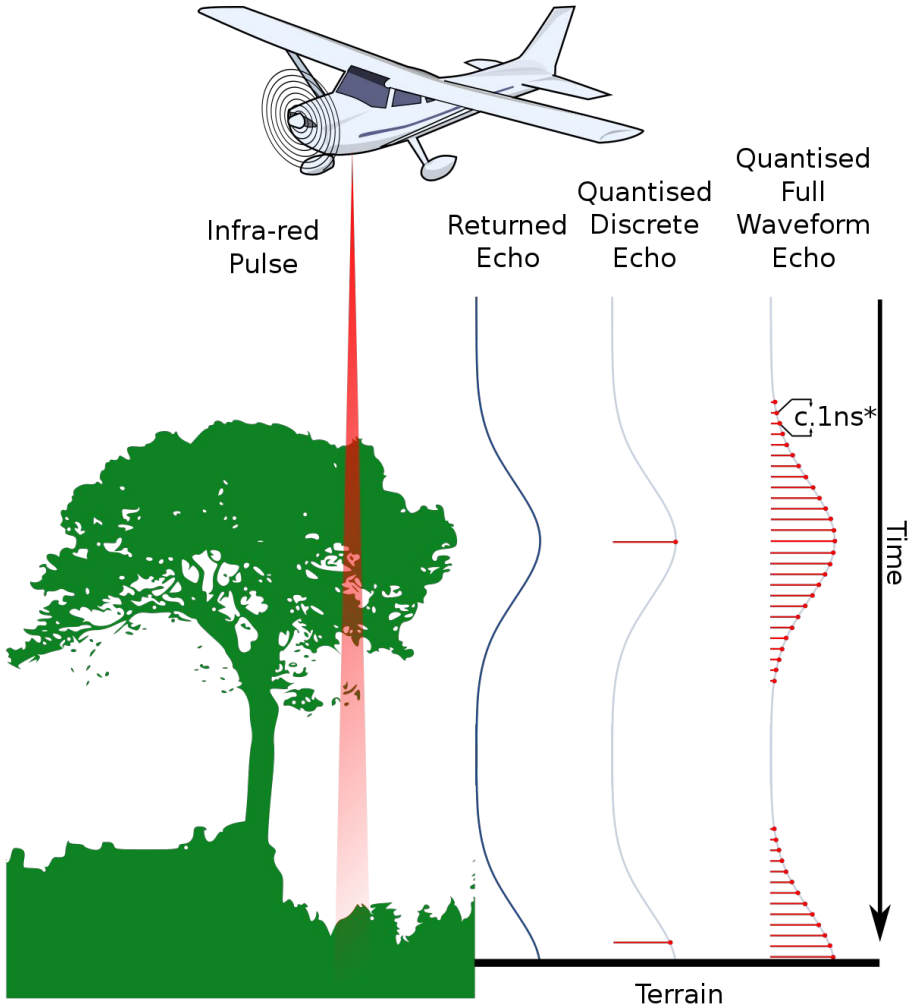
$$d = h * \tan(\theta)$$

©Bitfab

Models of scanner

Full waveform

X-rays
CT (computerized tomography)
Scan of interior and exterior
Airborne
Forestry applications



* In a vacuum light will travel approximately 0.3m in 1ns

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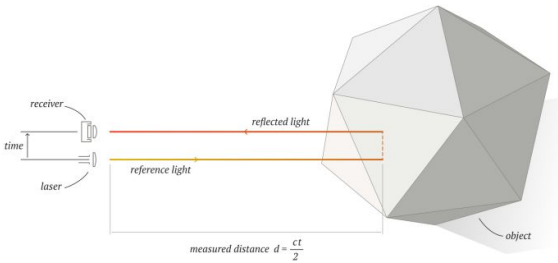
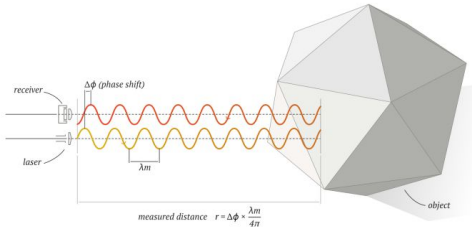
Models of scanner

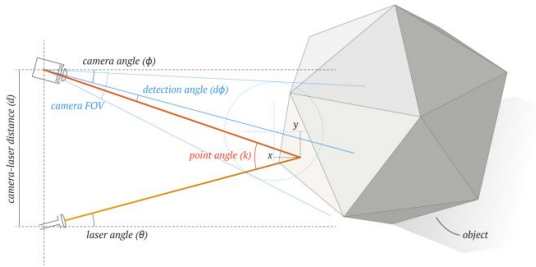
Time of flight / Pulse scanner



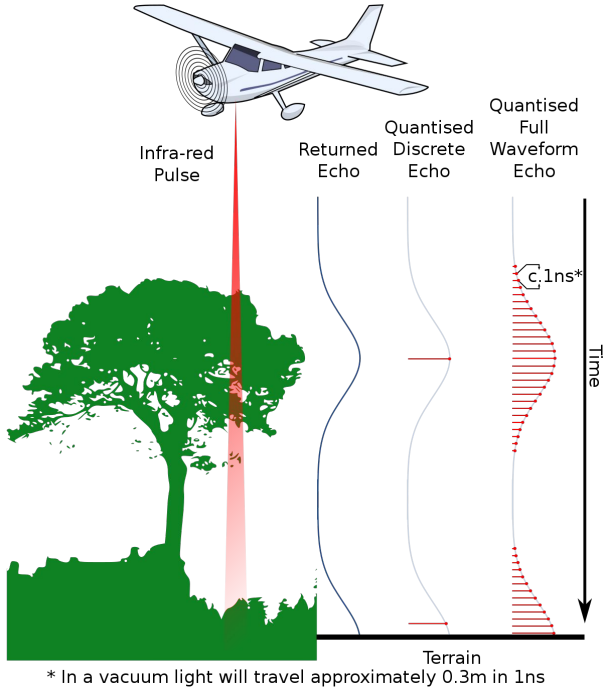
Phase shift scanner



Triangulation scanner



Full waveform



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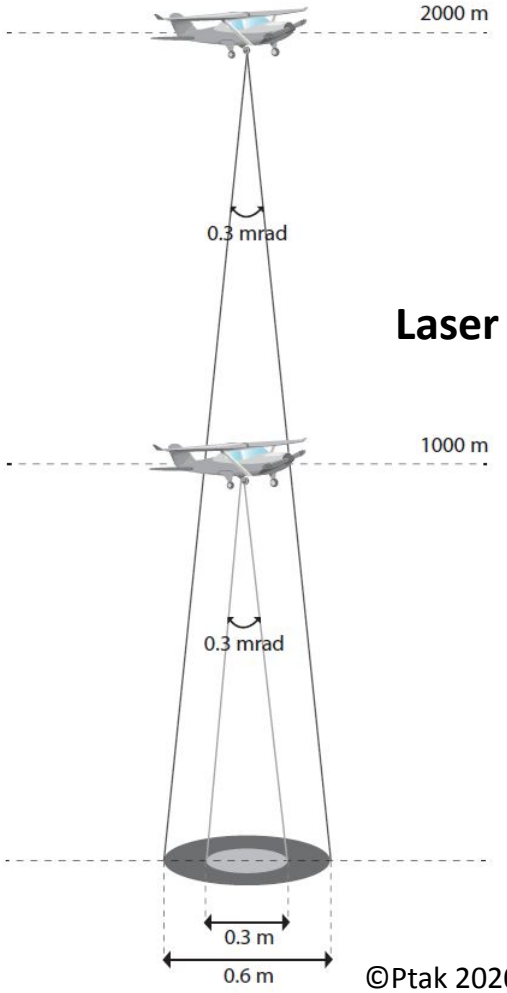
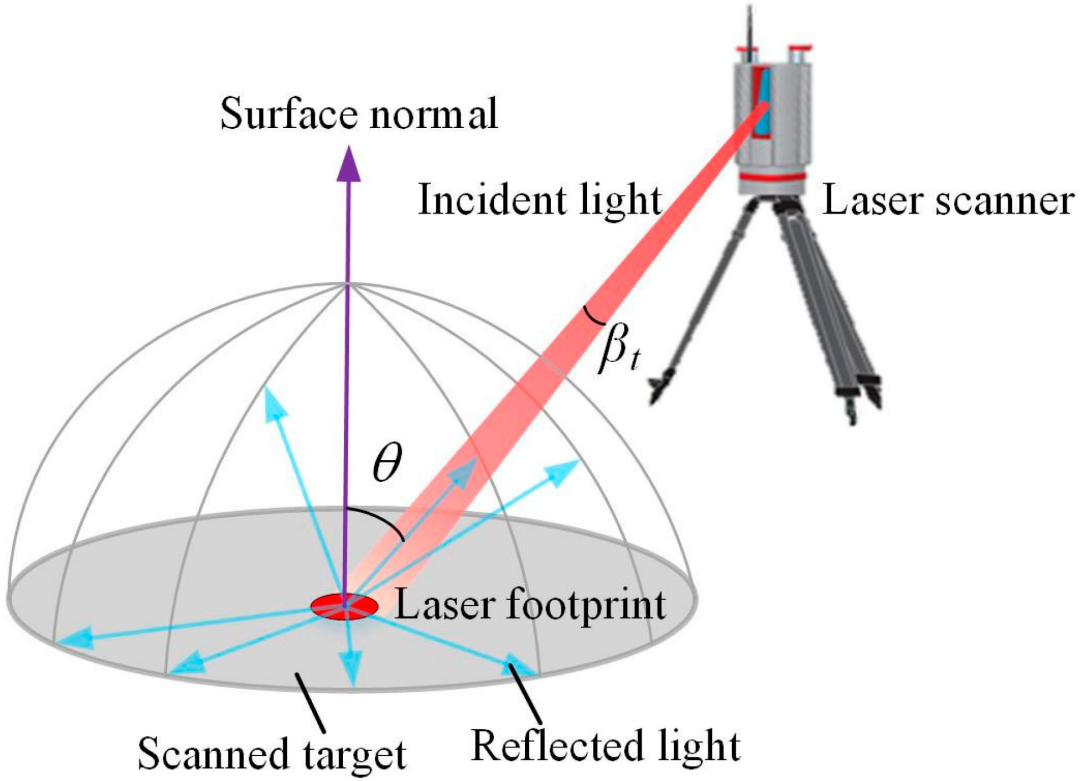
Point footprint



©Ptak 2020

Laser beam divergence

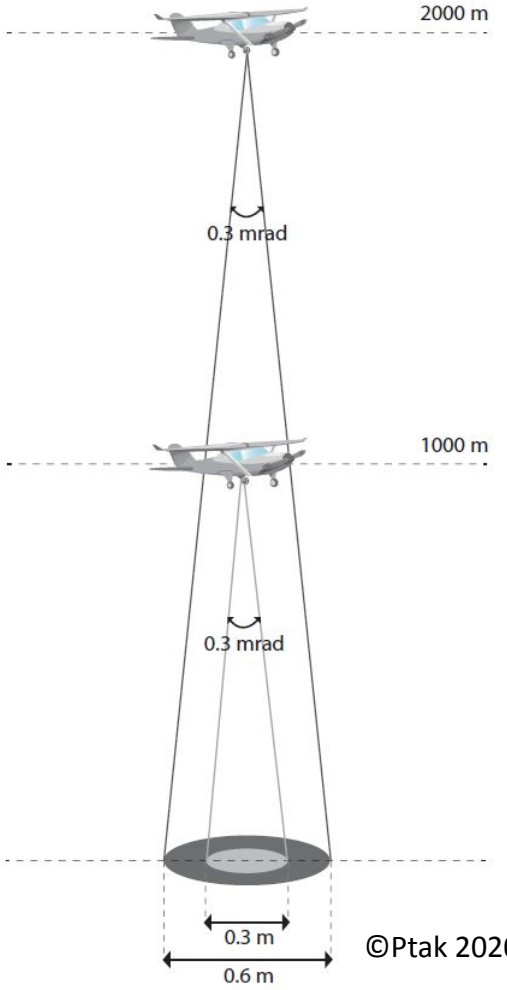
Incidence angle



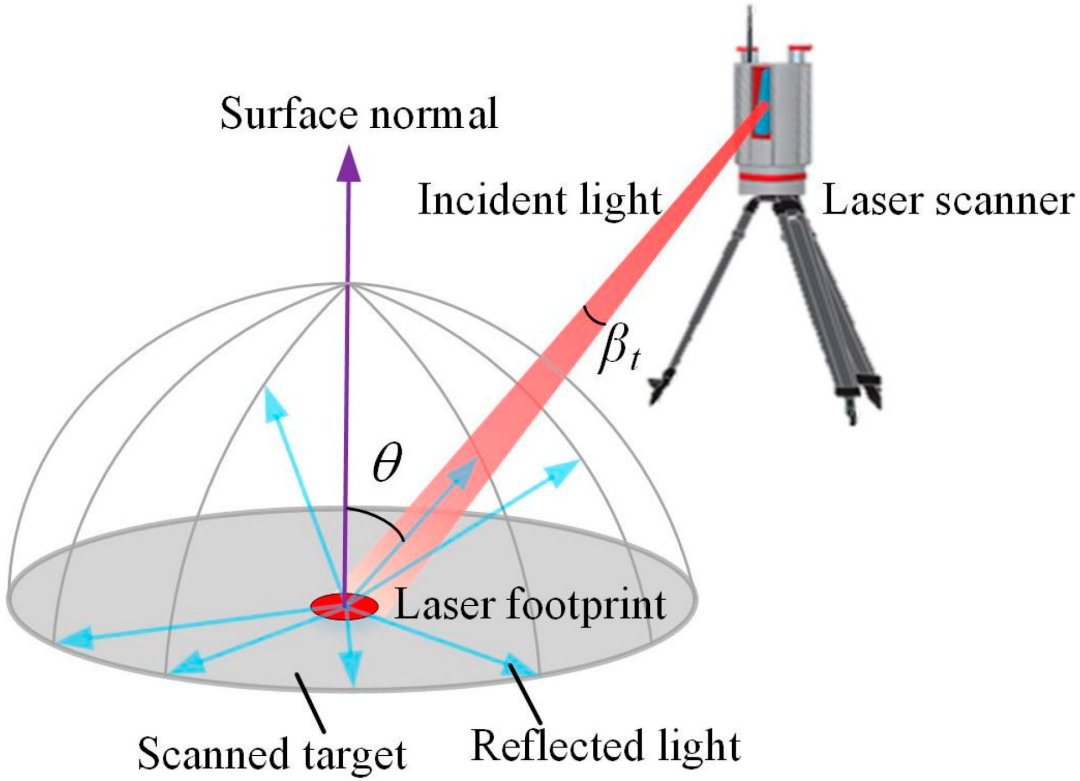
©Xu et al 2017

You can imagine here a huge cone with top at scanner and bottom on a target - so hey! Point cloud is not really a set of points but a set of elliptical areas! (Ptak 2020, https://www.linkedin.com/pulse/why-does-footprint-size-matter-what-earth-pitch-agnieszka-ptak)

Point footprint



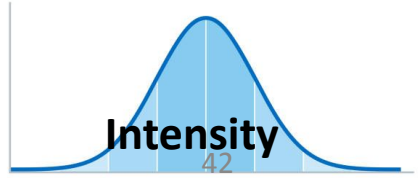
©Ptak 2020



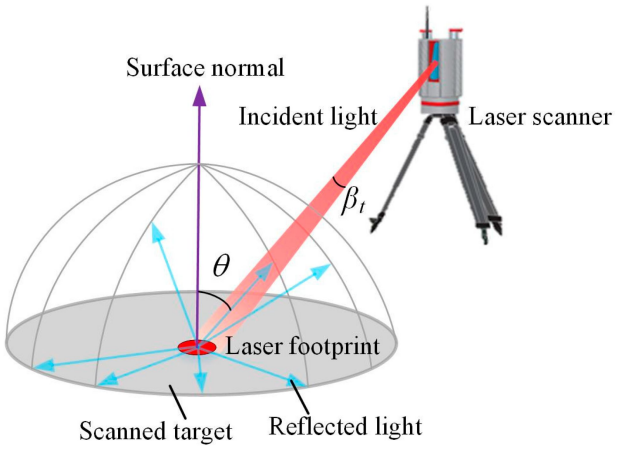
©Xu et al 2017

©Ptak 2020

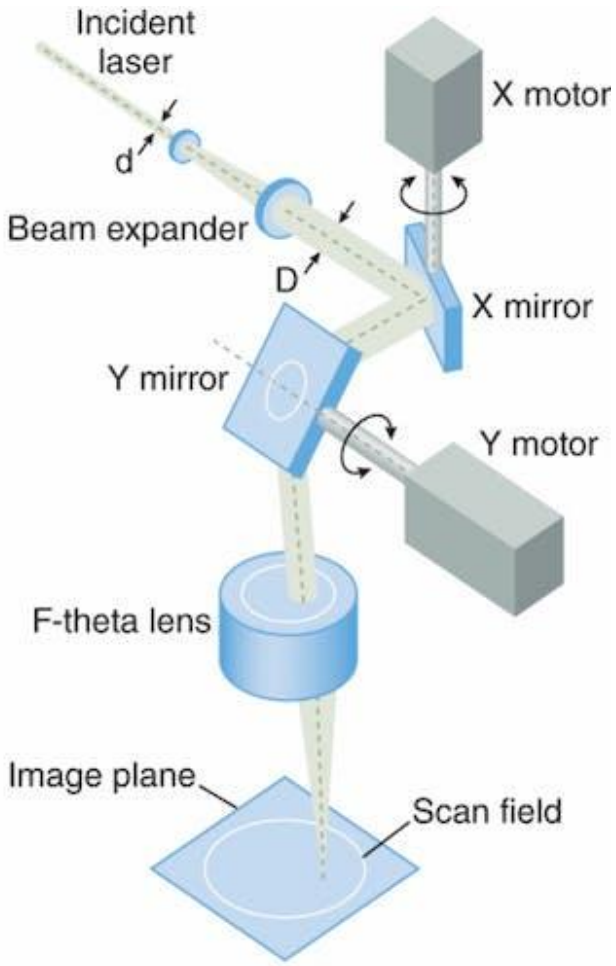
dia



Angle Measurement and Field of view



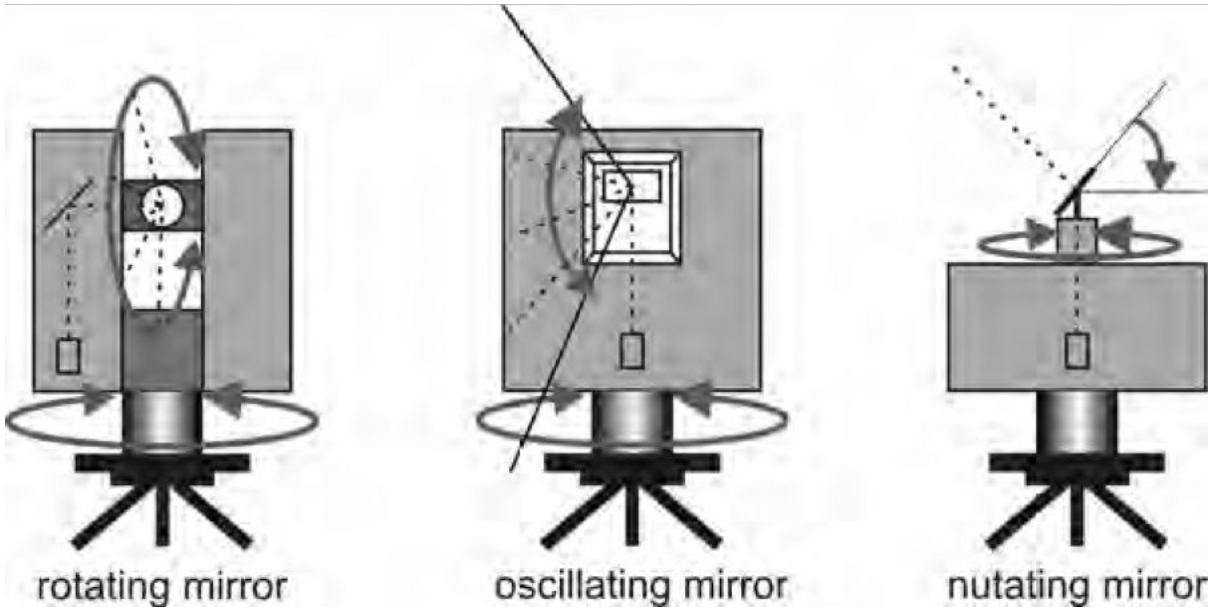
©Xu et al 2017

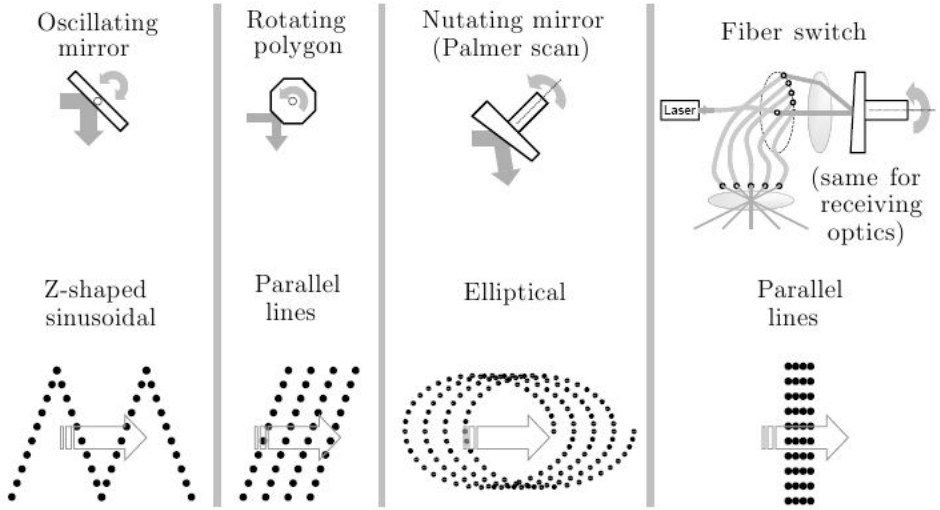


Deflection System

©https://www.laserfocusworld.com/optics/article/16554962/optical-materials-silicon-carbide-mirrors-benefit-highspeed-laser-scanning

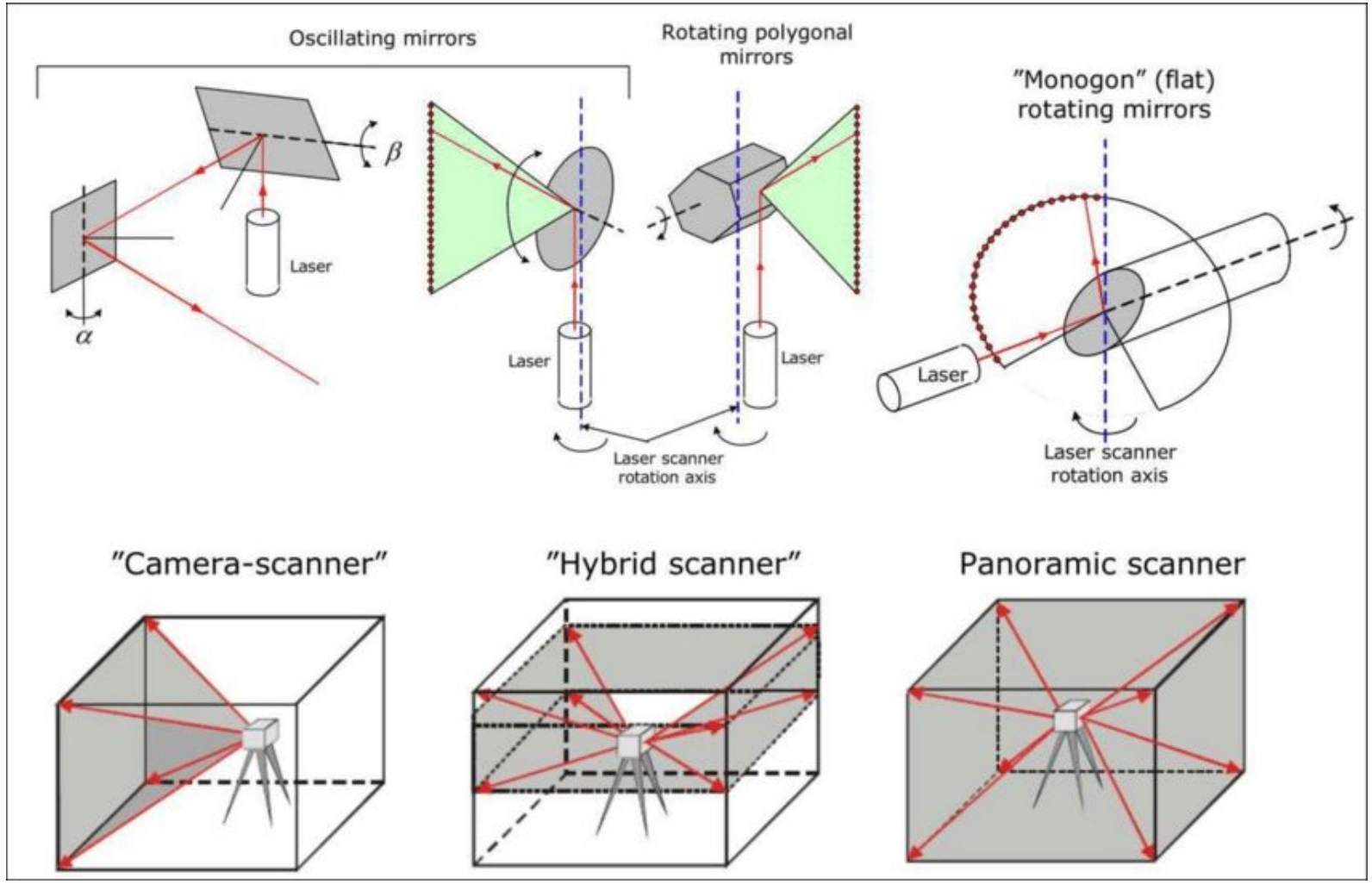
Angle Measurement and Field of view





The field-of-view defines the scanning area of a LS from a single setup position.

Angle Measurement and Field of view



©Reshetyuk 2009

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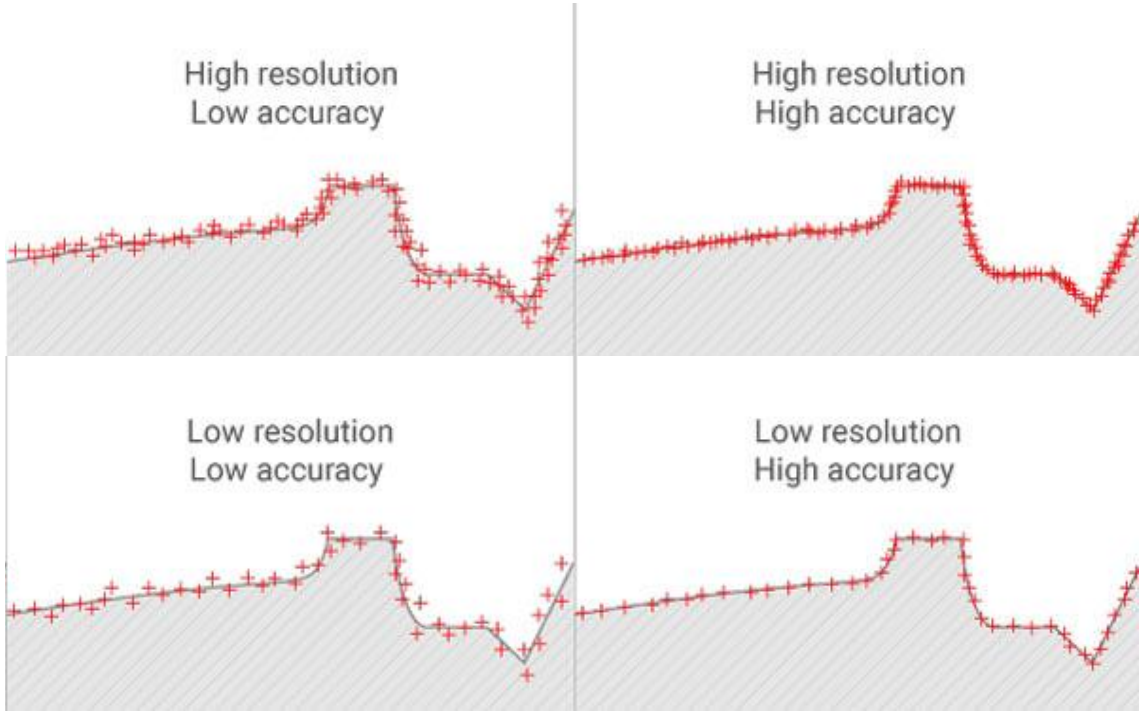
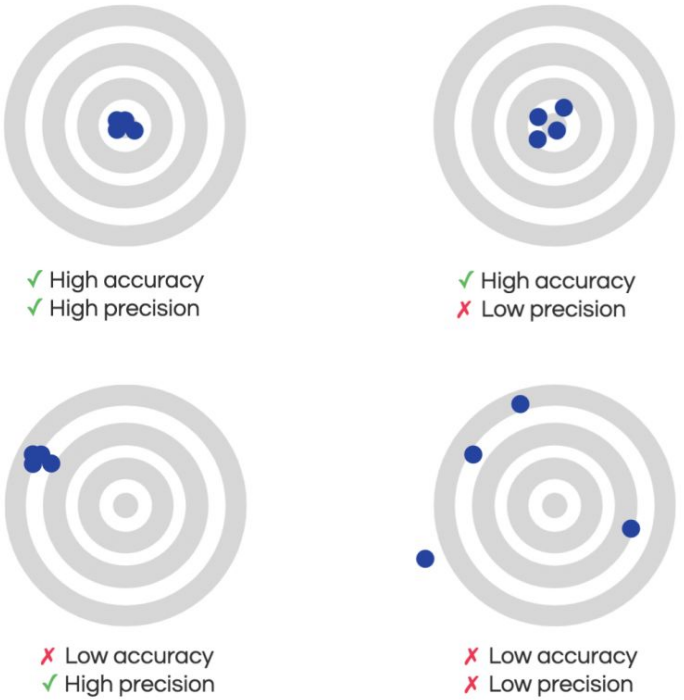
Accuracy and Resolution



©kreon3D

How close a measurement is to the true value

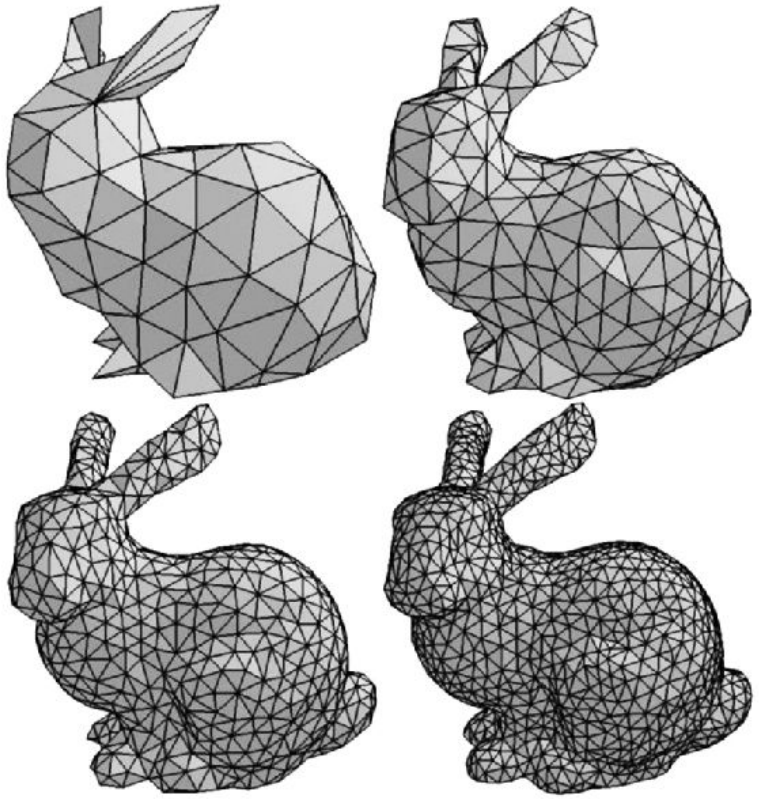
How close different measurements are to each other

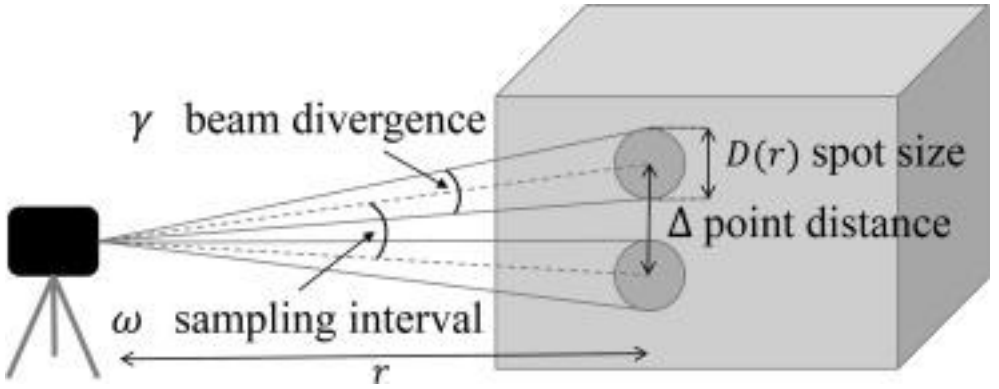


aniwaa

Resolution = PPS (points per scan)

Accuracy and Resolution





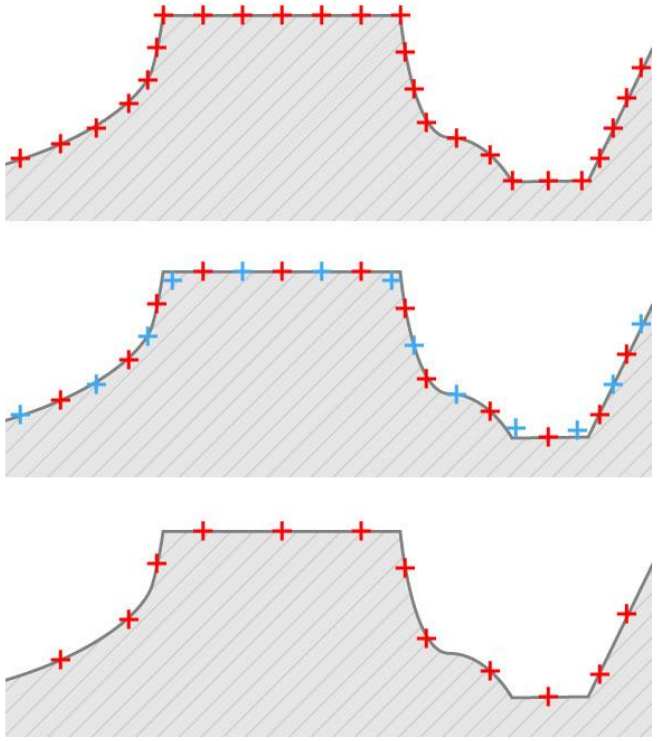
The more points your mesh includes, the smoother, more detailed it will look.

Accuracy and Resolution

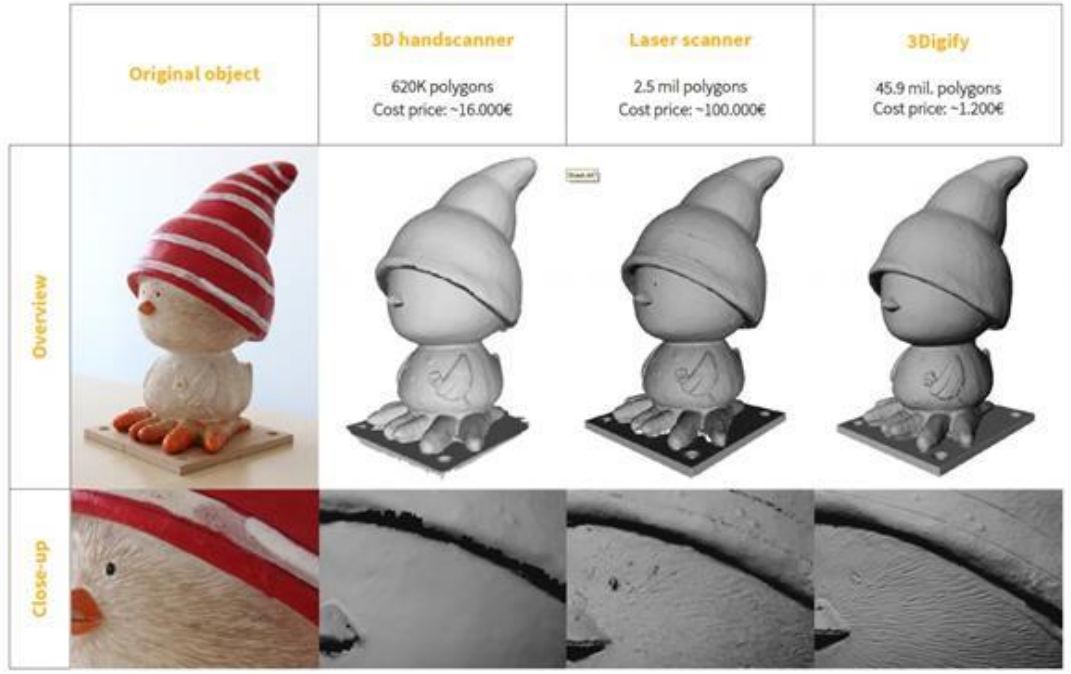
High resolution

Low resolution enhanced with interpolated points (Sharp details rounded)

Low resolution without interpolated points



©kreon3D



©*3ders.org*

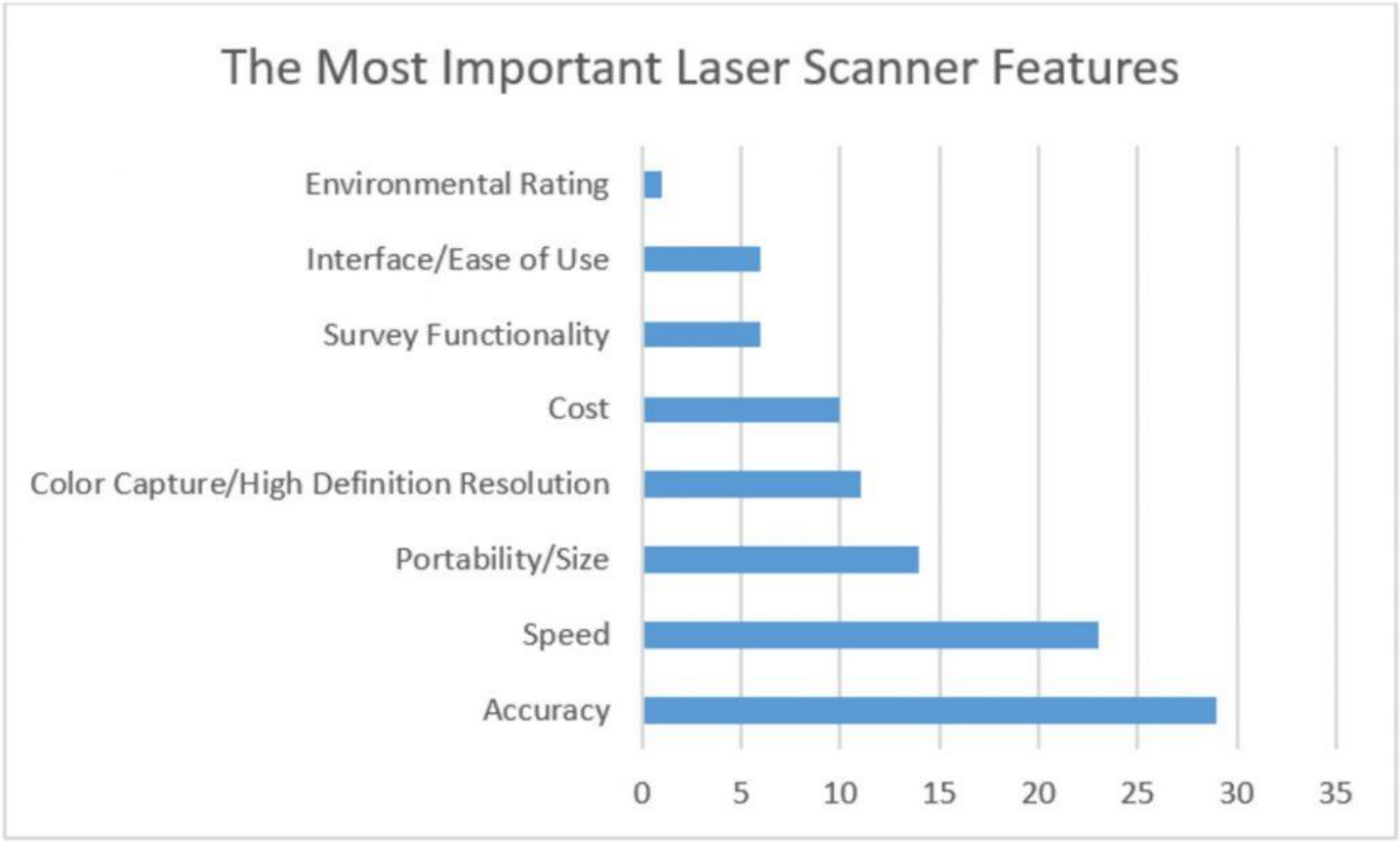
Single point accuracy / multiple points accuracy

Accuracy and Resolution

Resolution	Scanning Time (min)	Number of points in the generated point cloud (Millions)	Eye Safety Distance (m)
1/10	1.11	7	0.3
1/8	1.74	11	0.7
1/5	4.44	28	1.0
¼	6.94	44	1.3
½	27.78	175	2.5
1	111.11	700	4.9

©Mahmoud et al 2011

Accuracy and Resolution



©https://www.engineering.com/story/why-choose-3d-laser-scanning-over-touch-probes-in-manufacturing-quality-control

Errors

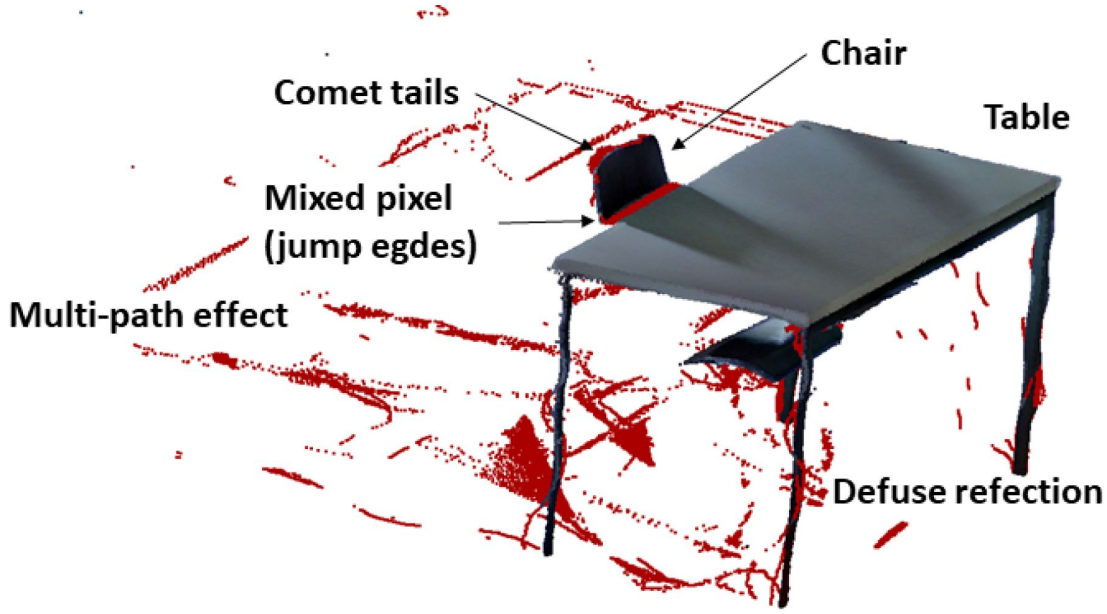
internal → **Instrumental**: calibration, beam divergence, angle measurement, ..

external → **Object-related**: size, surface properties, curvature, …

external → **Environmental**: refraction, meteo-conditions, background, …

external → **Methodological**: distance to object, object orientation, point density, …

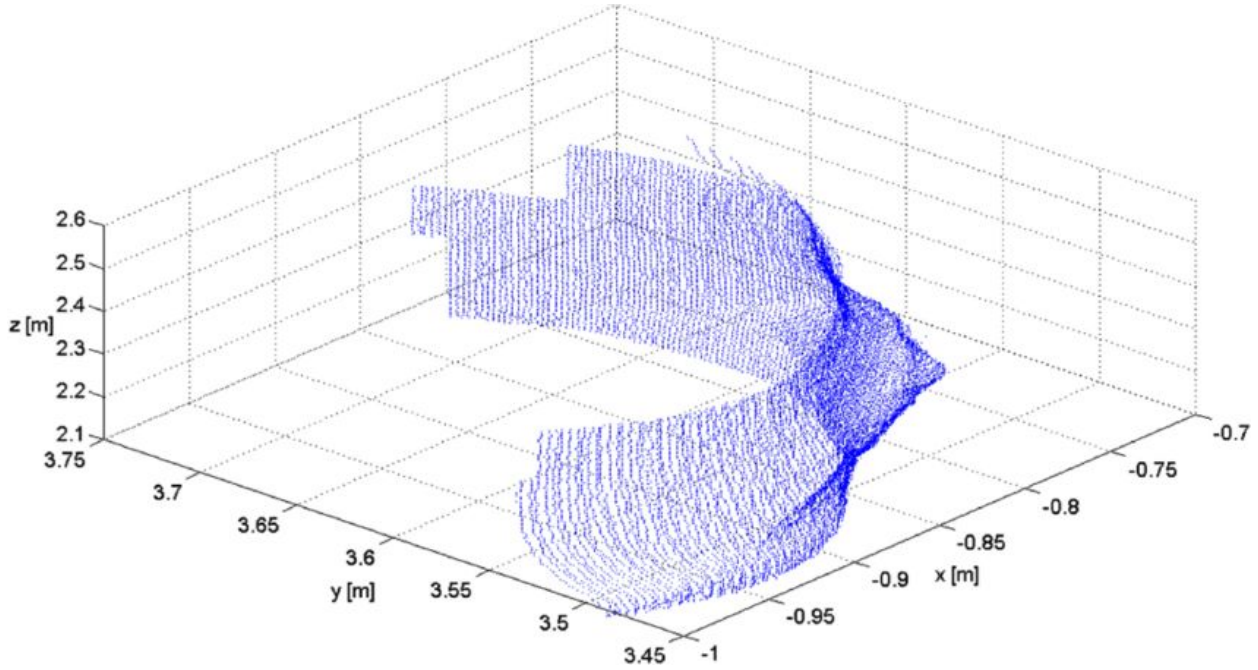
\+ **post-processing algorithms**



©Barnefske, Sternberg 2022

BREAK 15 MIN

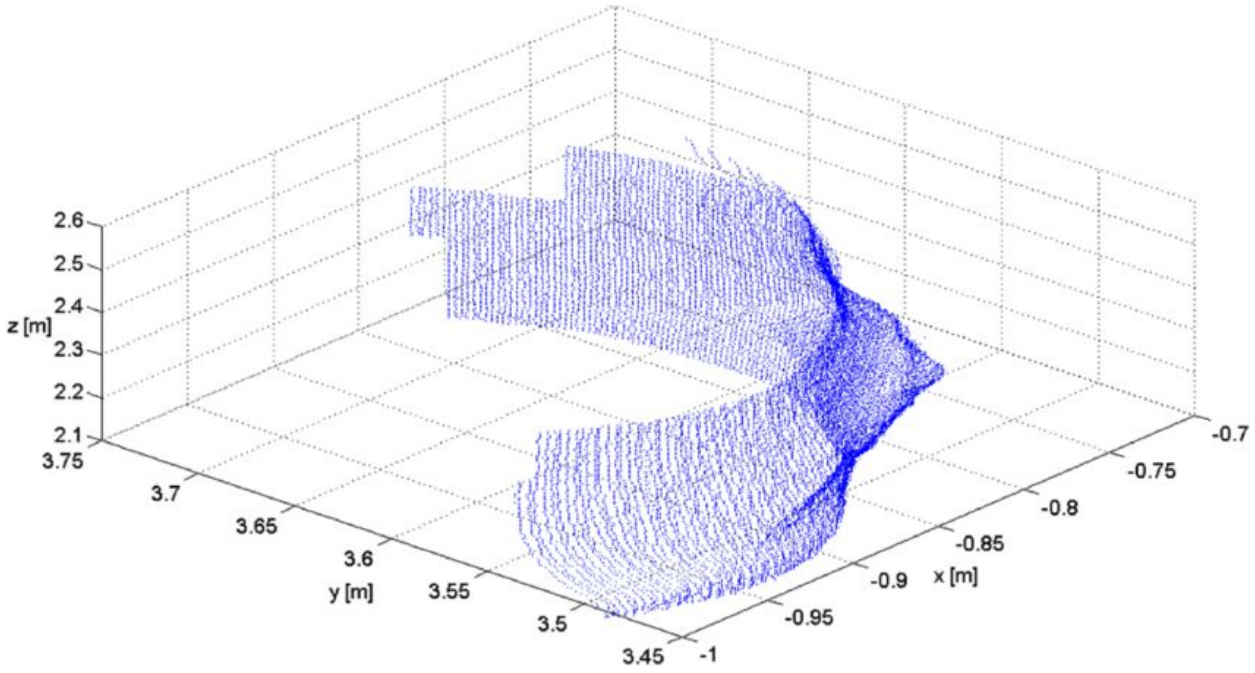
Point Cloud



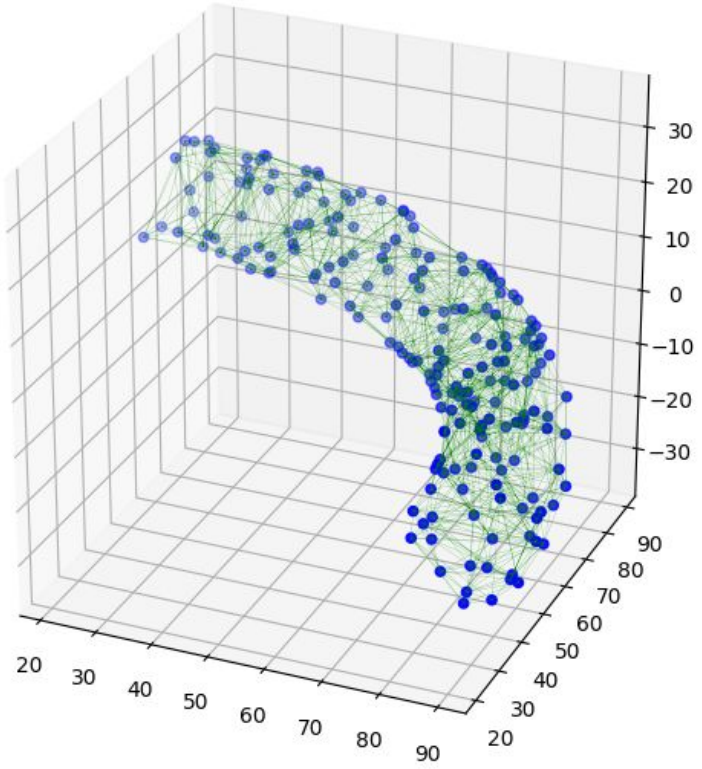
©Kretschmer 2017

A point cloud is a discrete set of data points in space. The points may represent a 3D shape or object. Each point position has its set of Cartesian coordinates. Point clouds are generally produced by 3D scanners or by photogrammetry software, which measure many points on the external surfaces of objects around them. (Wikipedia)

Point Cloud



©Kretschmer 2017



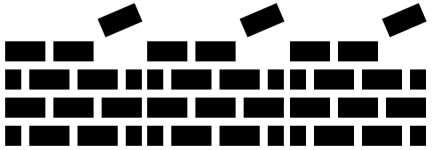
©Hanniel 2021

The single point precision and the accuracy of modelled objects describe the quality and characteristics of a 3D-point cloud.

→ object

Survey Project

Acquisition



Huge amount of data

Scanner allocation

Reference points

Algorithms

Tacheometry references

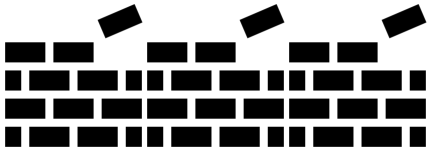
Environments

Objects

…

Point cloud: Quality dependency

Survey Project



Acquisition — Huge amount of data

Pre-processing (data cleaning, outliers detection, …)

Registration

Data cleaning

Integration

Model editing

Data filtering

Post-processing

Texturing

Outputs (2D, 3D, printing, …)

Modelling = reconstruction of virtual objects from 3D point clouds.

Time consuming

Automatic / semi-automatic

Operator interactions

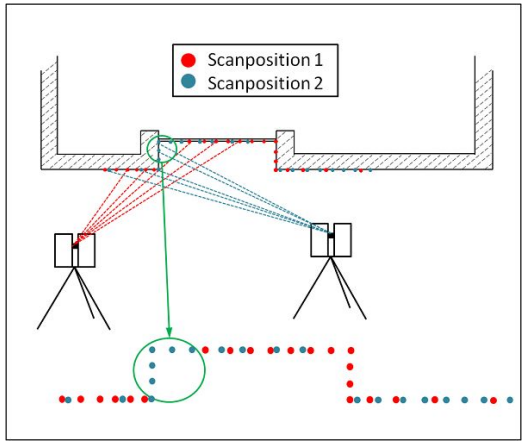
Registration

What is registration? Registration is the first step in point cloud processing and 3D model conception.

Determining the correspondences

↓

Estimation of the transformation



1 Target-based

2 Cloud-to-cloud (data driven)

3 Features based (data driven)

©https://www.laserscanning-europe.com/en/news/correctly-positioning-laser-scanner

Registration

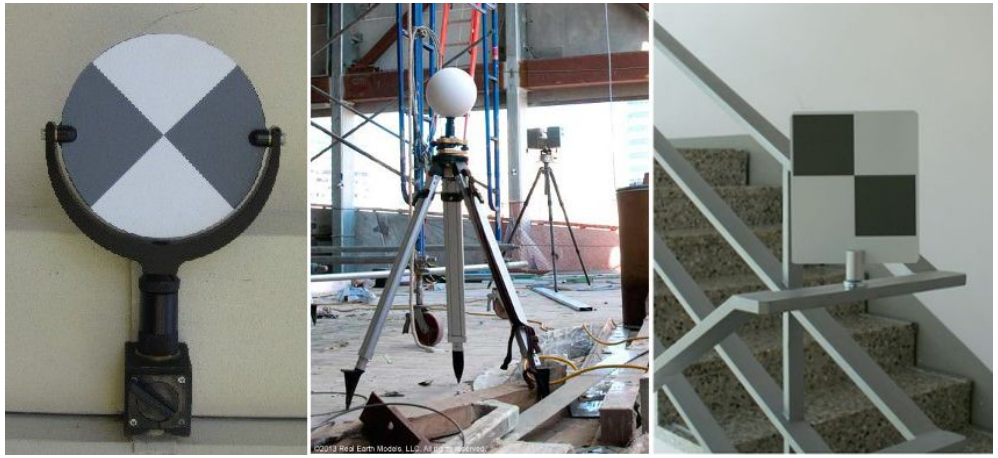
1 – Target-based

Affecting factors:

- ➔ Resolution
- ➔ Distance
- ➔ Environment
- ➔ Size Vibration

Do's and Dont's:

- ➔ -leave the targets from your very first scan up to the last
- ➔ -avoid symmetrical arrangements
- ➔ -avoid similar configurations in different rooms
- ➔ -avoid movable objects
- ➔ -educate individuals
- ➔



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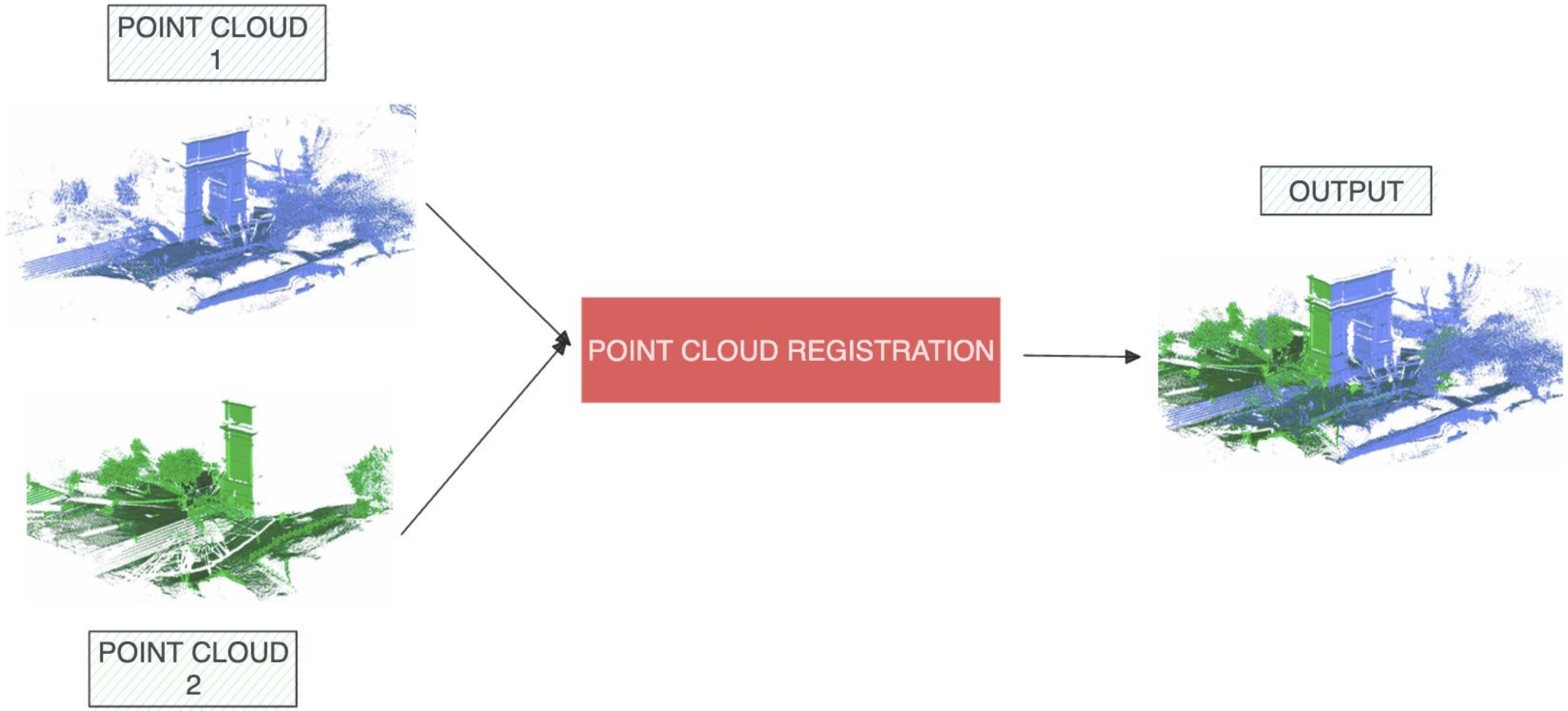
Registration



©https://www.thinkautonomous.ai/blog/point-cloud-registration/

https://www.youtube.com/watch?v=CN9kfPyOuCU

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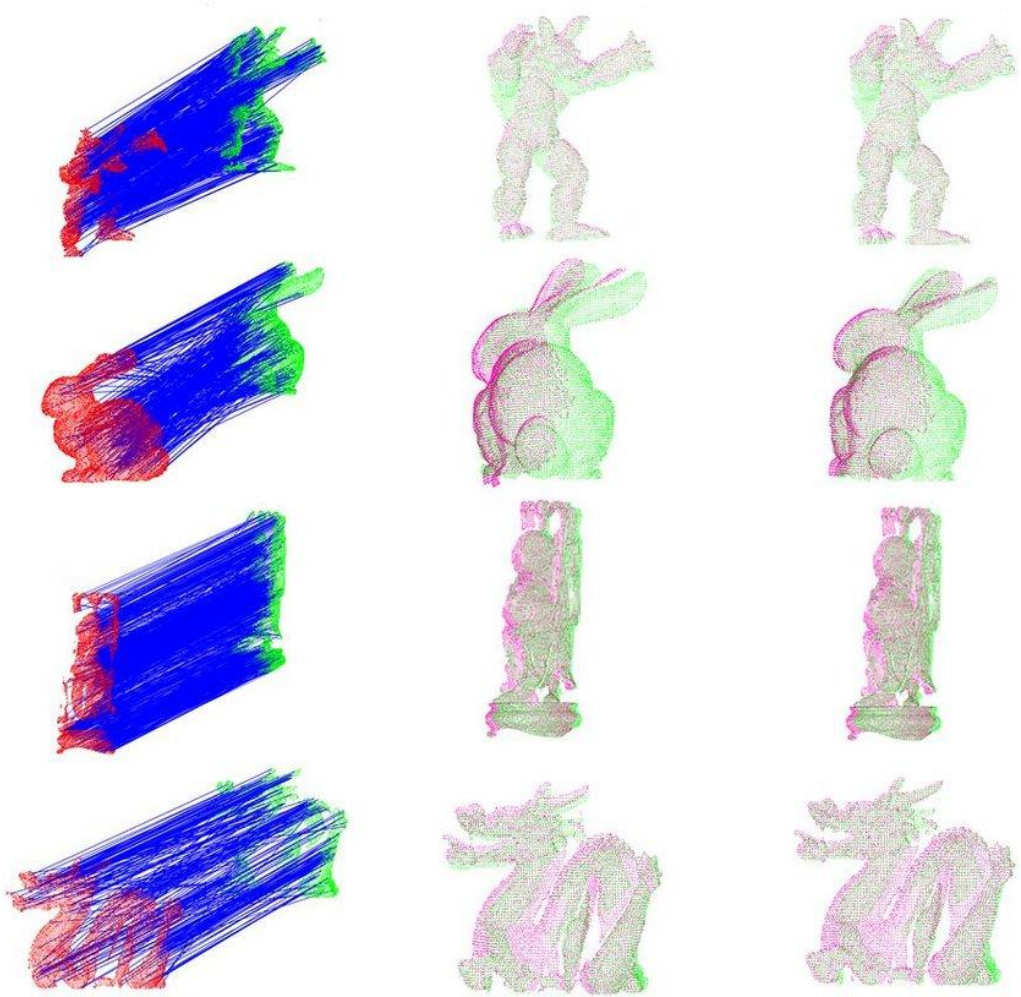
diaz@arch.ethz.ch

Registration

3 – Featured-based



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diaz@arch.ethz.ch

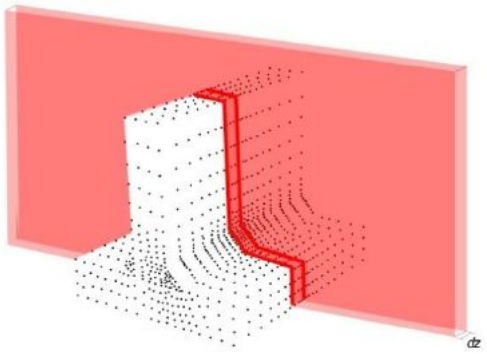
Registration

File formats

- **PTS:** PTS is an open format for 3D point cloud data. Because open formats are maintained by standards organizations, anyone can use them.
- **XYZ:** XYZ is an archetypal American Standard Code for Information Interchange (ASCII) format. It's compatible with many programs, but it has no unit standardizations, which can make data transfer more difficult.
- **PTX:** This is another common format for storing point cloud data, usually from LIDAR scanners. It can only be used on organized clouds — no unordered ones. It's also an ASCII format.
- **E57:** This file format is vendor-neutral and compact. It can store point clouds and metadata from 3D imaging systems — like laser scanners. It's also specified by ASTM International, with documentation in the ASTM E2807 standard. Additionally, it can store properties connected to 3D point cloud data, such as intensity and color.
- **LAS:** This open format is designed for data obtained from LIDAR scanning, though it can also accommodate other point cloud data records. It combines Global Positioning System (GPS) data, laser pulse range information and inertial measurement units (IMU) to create data that fits on the X, Y and Z axes.
- **PLY:** Known as the Polygon File Format, this type stores data from 3D scanners. It accommodates properties such as color, texture and transparency. It can contain data from both the point cloud and the 3D mesh.

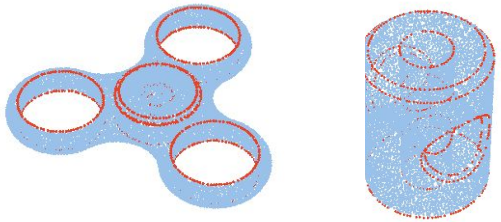
Survey project:
3D modelling and meshes

1 - Detection of cross sections (semi-automatic, 2D)



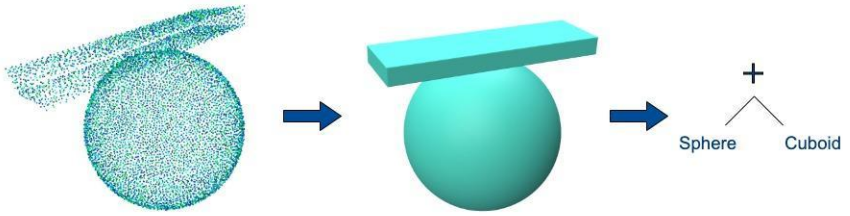
©Munaretto, Roggero 2013

2 – Boundary representation (semi-automatic, 2.5D)



©Loizou et al 2020

3 – Geometric primitives (automatic, 3D)



©Obermeier

Onsite organization:

https://shop.leica-geosystems.com/sites/default/files/2019-04/blk360_spec_sheet_2_0.pdf

- LS presentation: Leica BLK
- 10’ recap of good practices
- Scanning activity divided into 5 groups
- 10’ choose of objects (1 group scanning the Loggia)
- First group showcase

Tasks:

- Sketches of scanned objects with targets and scan positions + photos of the survey
- Download softwares for 2D and 3D modelling
- Download data from iPad (if time allows it)

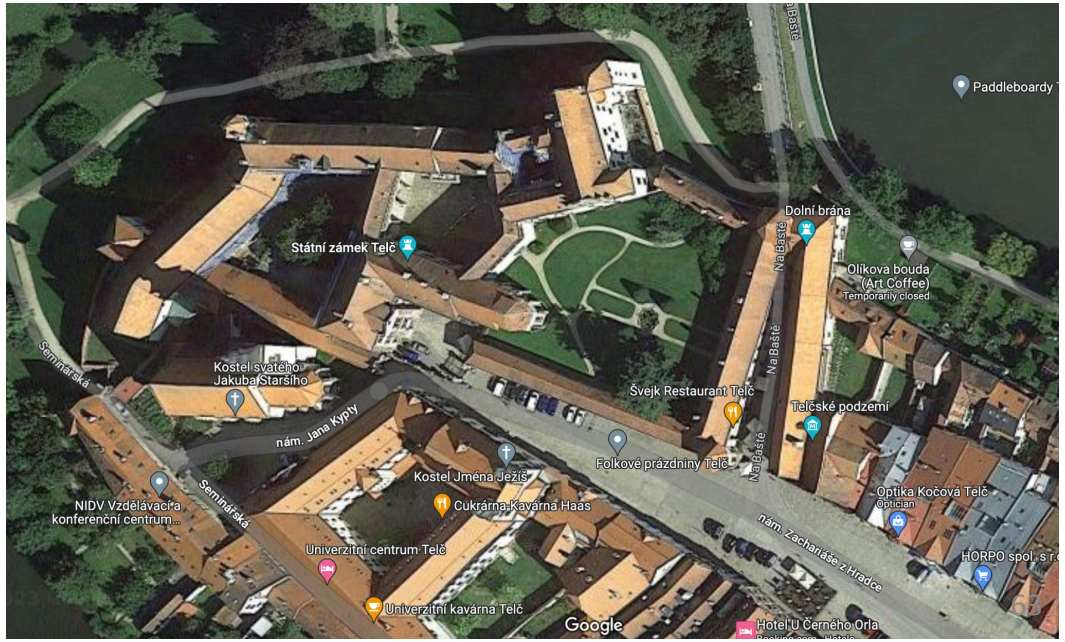
Tuesday:

- Download LS raw data + registration

Remember:

- Take pictures and screenshots while working to document your steps and for the final presentation

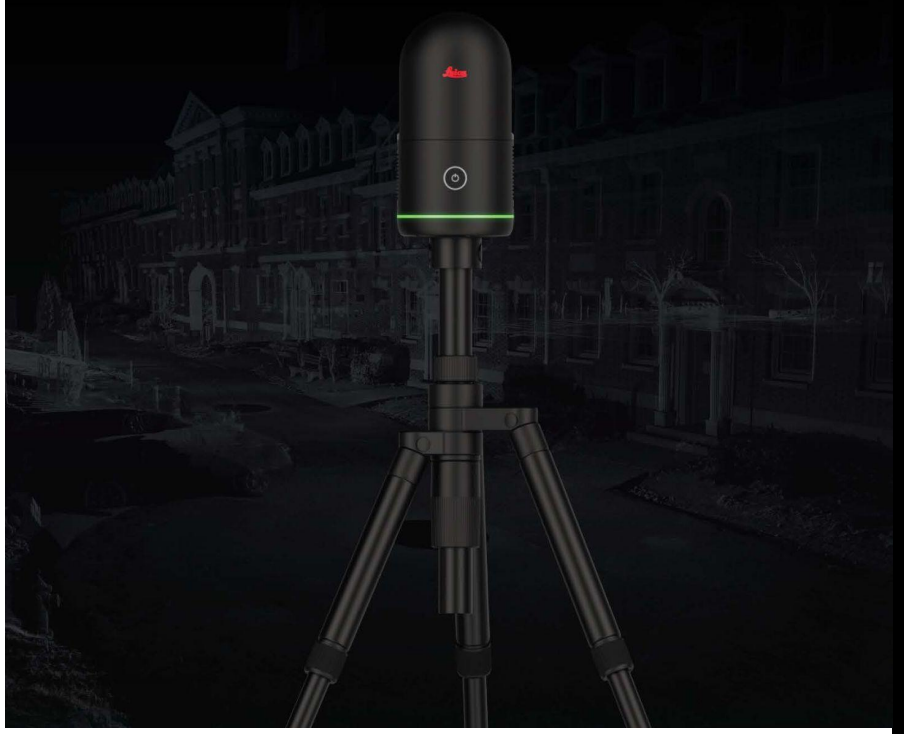
Next: Laser scanning in the Castle



Leica Geosystems BLK

LEICA BLK360

REALITY CAPTURE. NOW.



LEICA BLK360

IMAGING LASER SCANNER

GENERAL

Imaging scanner	3D scanner with integrated high-speed HDR spherical imaging system and Visual Inertial System (VIS) for real-time pre-registration

DESIGN & PHYSICAL

Housing	Black anodized aluminium
Dimensions	Height: 155 mm Diameter: 80 mm
Weight	0.75 kg (0.85 kg incl. battery)
Transport cover	GVP739 transportation cover
Mounting mechanism	Button-press quick release

OPERATION

Standalone operation	One-button operation
Mobile devices	BLK Live app for iOS and Android smartphones Leica Cyclone FIELD 360 app for iOS and Android tablet computers and smartphones
Wireless communication	Integrated wireless LAN (802.11 b/g/n)
Internal memory	Storage for up to 1500 setups
Instrument orientation	Upright and upside down

POWER

Battery type	Internal, rechargeable Li-Ion battery (Leica GEB825)
Capacity	Up to 70 setups per battery

SCANNING

Distance measurement system	High speed time of flight enhanced by Waveform Digitizing (WFD) technology
Laser class	1 (in accordance with IEC 60825-1:2014)
Wavelength	830 nm
Field-of-view	360° (horizontal) / 270° (vertical)
Range*	Minimum 0.5 m - up to 45 m
Point measurement rate	Up to 680,000 pts/sec.
Measurement modes	4 user selectable resolution settings (6/12/25/50 mm @ 10 m)

IMAGING

Camera system	13 Mpixel 4-camera system captures 104 Mpx raw data for calibrated 360° x 270° spherical image
Speed	< 8 sec. for full spherical LDR image in any light conditions < 20 sec. for full spherical 5-brackets HDR image in any light conditions
Image modes	• Auto-exposed LDR • 5-brackets HDR • Off - scanning only

PERFORMANCE

Data acquisition	< 20 sec. for complete full dome scan and spherical LDR image at 50 mm @ 10 m resolution with automatic tilt measurements
3D point accuracy*	4 mm @ 10 m
Real-time pre-registration	Automatic point cloud alignment based on real-time tracking of scanner movement between setups based on Visual Inertial System (VIS) by video-enhanced inertial measurement unit

ENVIRONMENTAL

Robustness	Designed for indoor and outdoor use
Operating temperature	0° C to + 40° C
Dust/Humidity	Solid particle/liquid ingress protection IP54 (IEC 60529)

DATA PROCESSING

Data transfer	Wireless and USB 3.0
Desktop software	Leica Cyclone REGISTER 360 and Cyclone REGISTER 360 (BLK Edition)
Cloud software	HxDR Digital Reality: cloud-based digital reality platform

* At 18% albedo
All specifications are subject to change without notice.
All accuracy specifications are one sigma unless otherwise noted.

Leica Geosystems BLK

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