3D SCANNER: is any device that
- collects 3D coordinates of a given region of an object surface
- automatically and in a systematic pattern
- at a high rate
- achieving the results (i.e. 3D coordinates) in (near) real time.

There is no generally accepted definition concerning instruments which are considered to be 3D scanners. Some classification will be proposed.
**3D scanner basic output**: range map, point cloud, point model, scans, ... (a lot of points, with known 3D coordinates in the same reference system)

In addition to the 3D coordinates the scanner may or may not deliver reflectivity values (or RGB values)
Pros&Cons

**Topographic surveys**
+ High accuracy
+ Homogeneous overall accuracy
+ Sound scientific indicators for quality assurance of the final product
+ Good for plans and cross sections
+/- Mainly good only for objects of low complexity, otherwise not cost/time effective
- Requires more time for field work
- Point-wise mapping, no texture mapping

**Laser Scanning**
+ Good for complex continuous surfaces
+ Good for surface analysis and visualization
- Edges cannot be extracted
- Line drawings cannot be derived
- Huge amount of data to handle
CLASSIFICATION

Stationary/Mobile
- Terrestrial laser scanners (TLS)
- Aerial laser scanners

Principles of operation
- Range scanners
- Triangulation scanners

Range measurement principles
- Time-of-flight
- Phase shift
DSM & DTM

DSM

DTM
Ground Based Laser Scanner:

As a Total Station, they measure distances corresponding to a predefined angular step
3D object

scanning
- aerial lidar
- TLS

geo-referencing
- GPS + IMU data
- GPS/TS data

aligned data
- 3D point model

D. Visintini, B. Fico, F. Crosilla, F. Guerra
3D virtual model of the Gorizia downtown (Italy) by matching aerial and terrestrial surveying techniques
**Triangulation scanner**

It measures **angles** corresponding to a fixed base.

### 1 - Projector + one camera

- At one and of the base there is a *transmitting device*, sending a laser beam at a defined, incrementally changed angle (thanks to a *rotating mirror*)
- At the other end of the base there is a camera which detects the laser spot (or line) on the object.

**3D coordinates** can be derived from the resulting triangle

The **accuracy** of the distance between instrument and object decreases with the square of this distance.
**scanner a triangolazione**  - base di lunghezza fissa –
miurano **angoli** corrispondenti ad una distanza predefinita (base)

**2 - Projector + two cameras**

- **Two digital cameras** are fixed at the ends of a fixed base
- A **projector** send a **laser beam**, or **strep**, or **pattern** (moving independently from the cameras)

**3D coordinates** are computed on the same base of the previous system.

Same observation about **accuracy**.
TRIANGULATION SCANNERS

Video In

RS - 232

PC (control unit)
TRIANGULATION SCANNERS

NextEngine @GeCo Lab
TRIANGULATION SCANNERS
range scanners

they measure distances corresponding to predefined angular steps

- **Time of flight**
  A laser pulse is sent to the object and the distance between transmitter and reflecting surface is computed from the travel time between signal transmission and reception. The accuracy can be assumed as independent from the distance.

- **Phase shift**
  Better accuracy, but it requires higher energy for the coming back signal, lowering the range.
Scanning rate
- 100pts/s to 1,000,000pts/s, depending on principle of operation
- set up and moving time needs to be considered

Field of view
- one axe or two axes rotation scanner
- the acquired window/panorama can be expressed by an orizontal and a vertical angle
- it is necessary to balance quality (pseudo-orthogonality scan positions) and cost (less scans)
Angolar accuracy

- It is related to constructive techniques (i.e. mechanical devices devoted to deflect the spot)

- The measured point is moved orthogonally to the range direction

Angular accuracy: ±125µrad (v. Leica HDS6000/7000) -> The corresponding error at a distance of 50 m is:

\[ 0.000125 \times 50 \approx 0.006 \text{m} \]
Distance accuracy

- The measured point is moved along the range direction
Nowaday the 3D accuracy (both the effects of angular and distance accuracy) for phase shift and time of flight laser scanners can be almost the same.

Others specifications can change significantly: PS reach (in general) an higher scan rate than the TOF.
Scan resolution

- Points recorded by the same scan position are equally spaced considering a spherical surface centered on the scanner.

- "Scan resolution" means the space between two adjacent points, but also the quality of a set of data, i.e. the capability to describe small details on the surface.

- It states the "density" of points data.
With the same resolution setting, the measured points will be dense or sparse depending on the distance and position of the object.
Spot size

- the measuring beam is normally focused at a predefined distance -> it impacts on the object surface with a reflective area – or spot size
- it is related to the capability to describe small details on the surface
- a scan resolution lower than the spot size involves an over-sampling
“Mixed pixels”

- when the reflective area is distributed on different surfaces, the measured point does not belong to any of them

The same detail scanned by instruments with different spot size: when the spot hits on a breakline a “mixed pixel” is recorded
Real ranges
- depends on material, roughness, colors, wetness, angle of incidence ...

Reflectivity value
- Useful to better understanding the point model
- Allow to automatically recognize specific targets

Some biases have been observed, due to material and chromatic characteristics of the surface: unfavorable conditions are scan positions almost orthogonal to highly reflective surfaces, and scans facing the sun

(a digital camera can be combined to the scan head)
Automatic target recognition (software)

- Useful for data alignment
- 3D or plane target
HOW MANY POINTS ARE THERE IN A SCAN?

Resolution:

\[ 360^\circ / 5000 = 0.072 \]

1 pt/ 1.4cm @20m

\[ 5000 \times 2150 > 10 \text{ million pts} \]
Un **modello** è un referente significativo dell’oggetto (sostituto della realtà semplificato/sintetico): per descriverlo **elimina gli elementi ridondanti e enfatizza quelli ritenuti più importanti**

Un **modello di punti** è proprio l’opposto, essendo costituito da elementi ridondanti ed indifferenziati.

Gli elaborati che derivano dalle operazioni di misura: “non ricreano l’oggetto nella sua integrità ma ne danno una **caricatura maligna**”  

[M. Cunietti]
Photogrammetry and topography:
breaklines representation

3D scanning systems: high resolution surface sampling
3D MODELS
Planning the survey

The scans positions depend on the shape and size of the object
For a closed room in some cases one scan is enough; more often, in order to completely scan all the surfaces, more scans are needed.
DATA ACQUISITION
Sketches

- Outline of the area, rooms sketches, ...
- Scanner positions, target positions, model and name
• Data acquired by different scans need to be aligned in the same reference system

• In architectural or landscape application it is useful to geo-reference data

• Data can be aligned through homologous points or overlapped areas
DATA ALIGNMENT
• Partially automatic process with filters based on range, manually (and time consuming) otherwise (scaffolding, vegetation, people, cars, ...)

DATA CLEANING
• **Model partitioning** (for very big size projects):

• **Outliers** filtering

• **Noise reduction**: improves data quality by removing “speckle effect”

• **Sampling data** (random, grid, curvature sampling)
• **Triangulation** is the process to build a triangular mesh starting from points

• A **mesh** is a collection of vertices, edges and triangular faces that defines the shape of an object. Triangular faces must be continuous, not overlapped, sharing the adjacent edge.
• **Normal** correction
• **Holes** filling
• **Mesh reduction**
• (Smoothing)