Nuages de points et modélisation 3D

3D Point Cloud and Modeling

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Course Web site : https://www.caor.minesparis.psl.eu/presentation/cours-npm3d/

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Course program

Modalities

Courses and practical courses

Evaluation: reports on practical courses, project

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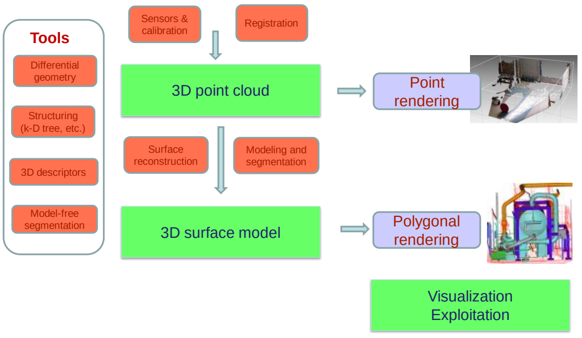
3D point cloud and modeling

Course overview



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4/ Demonstrations of 3D digitizing

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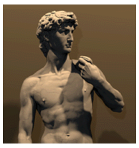
1.1 Uses of 3D perception…

Cultural heritage

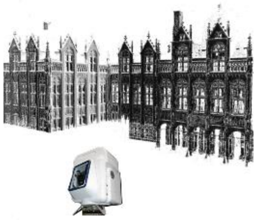
Statues, art objects



David
(Digital MichelAngelo)

Vivid 700 (Minolta)

Notable Buildings



Liège – Princes' Palace
GS 100 (MENSI)

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Civil Engineering, Mining

Laser scanner
(Faro Focus 3D)

Up to x100 kpts/s!
Low scanner cost ~30 k€

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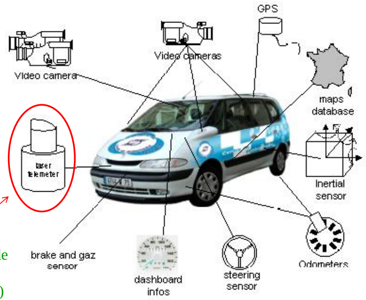
Driving Assistance
Autonomous Vehicles



Instrumented Vehicle
with laser scanner
(MINES ParisTech)

Interactive interfaces

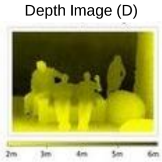
MS Kinect

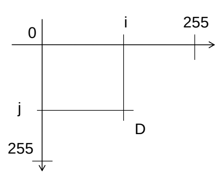
30 RGB-D frames per second!
Low Kinect cost ~€100

1.2 Concepts

- Depth Image (Definition):
  - A frame *(ensemble tramé)* of distances to surfaces in a scene or object
  - Values: distance D (Depth / Depth Image)
  - Also: Intensity

Depth Image (D)



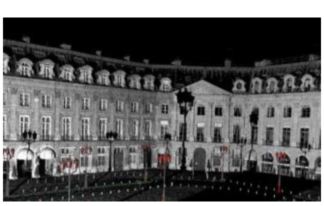


Point cloud

- Definition:
  - An unstructured set of 3D points on surfaces in a scene or object
  - Values: Spatial coordinates (X, Y, Z)
    - Associated measurements: intensity, color, etc.

Point cloud

Colorized point cloud

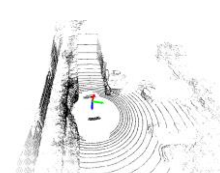


3D Points with Intensity
(grayscale, false color)

Colorized 3D points

From depth image to point cloud

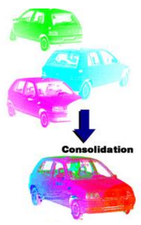
- "Simple" point cloud
  - Expressing the spatial coordinates (X, Y, Z) of points in a depth image

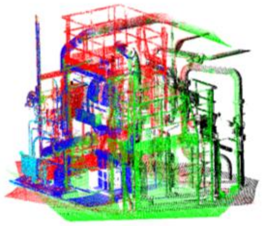


Velodyne 64 and Point Cloud

Compound point cloud

- Multiple simple point clouds
  - Acquired from different observation locations (« *stations* »)
  - Common reference frame: registration (« *consolidation* »)





Registered point clouds (colors: original clouds)

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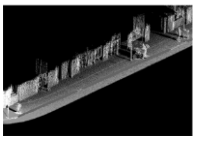
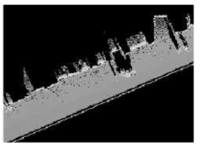
Other representations…

- Elevation Image
  - Transformation from a point cloud to an image, according to a projection direction and the calculation of a value on the discretized 2D space – e.g.: hmax, hmin, hmean, Δh...



Point cloud of a street

→



Computed Elevation Image

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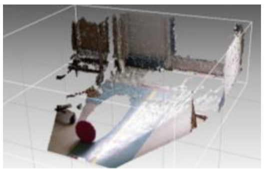
RGB-D image

- Definition
  - A frame of distances and colors of a scene or an object
  - Combining a Depth D and RGB image

Colorized depth image measured by Kinect – (shown as a point cloud)



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Examples of point clouds

- Different kinds
  - Real, synthetic, with or without color
  - Static or mobile surveys (*"relevés"*)
- Viewers:
  - **CloudCompare (OpenSource) - demo**
  - MeshLab (OpenSource)
  - RealWorks (commercial, free version of simple visualization)

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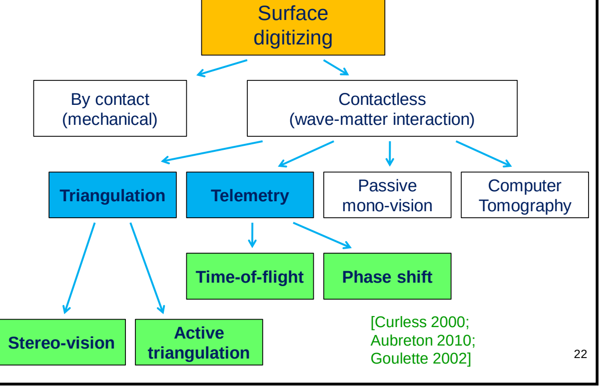
Principles and classification



[Curless 2000; Aubreton 2010; Goulette 2002]

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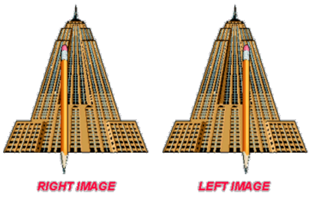
Stereovision (passive triangulation)

- Viewing the same scene from two places slightly offset from each other
- Principle of depth perception for humans



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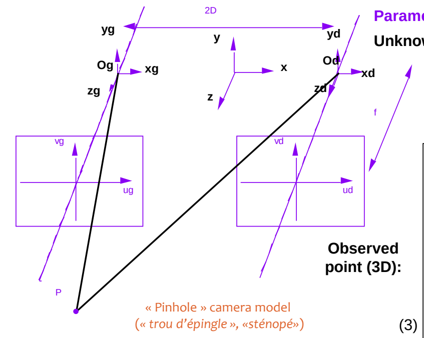
Stereovision in 3D space

Measurements: u_g, v_g, u_d, v_d
Parameters: f, D
Unknowns: x, y, z



« Pinhole » camera model
(« trou d'épingle », «sténopé»)

By definition, **disparity**:

$$\delta = u_g - u_d$$

Observed point (3D):

$$\begin{cases} x = D\dfrac{u_g + u_d}{\delta} \\ y = \dfrac{2Dv_g}{\delta} \\ z = \dfrac{2Df}{\delta} \end{cases} \quad (3)$$

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Advantages and Limitations of Stereovision

- Pros/Benefits:
  - 3D coordinates obtained without specific lighting (passive vision technique)
- Cons/Limitations:
  - Difficulty of stitch matching (*"appariement de points"*)
  - Automated Matching Methods
  - Characteristic points: SIFT, SURF
  - Dense Matching

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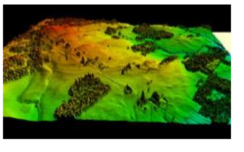
Photogrammetry

- 3D metrology based on stereo-vision
  - Historically: Manual Matching of Points in Images
  - Characteristic elements of the images: contrast breaks, protruding edges, etc.

Leica SD 2000 - 1990s
Analytical photogrammetric restitution Camera



Digital Surface Model (DSM)

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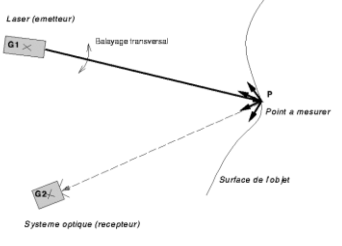
Laser triangulation laser (active)



- A laser beam is sent to the object to be measured
- The scattered light is observed by a camera
  - The depth of the point is determined

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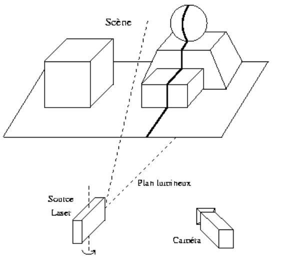
Line laser triangulation, Profilometry

•An image captured results in a line of points

•A single sweep is enough to ensure coverage of the surface
→ speed



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Example of a profilometer

Whole Body Scanner (Cyberware)

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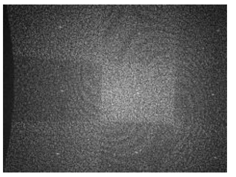
Projecting Random Patterns - Kinect model -

Kinect – without cover



Projected pattern

For each pixel (i,j) of the image (IR sensor), the disparity δi,j of the observed point of the scene with respect to the original image is calculated.

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Telemetry

Surface digitizing

- By contact (mechanical)
- Contactless (wave-matter interaction)
  - Triangulation
    - Stereo-vision
    - Active triangulation
  - Telemetry
    - Time-of-flight
    - Phase shift
  - Passive mono-vision
  - Computer Tomography

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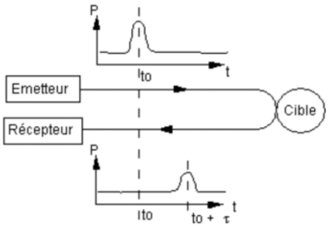
Time-of-flight telemetry



Pulse types:
- light (laser)
- ultrasonic (SONAR)
- radio waves (RADAR)

$$d = \frac{1}{2} v \tau$$

With: v: wave velocity

Reminder: light speed in the void: c = 3x108 m/s

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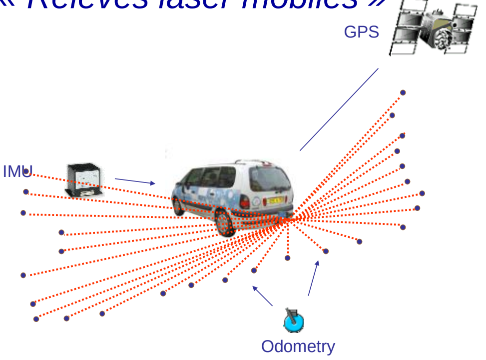
Mobile laser surveys
« Relevés laser mobiles »



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Computation of the point cloud Urban scene

The point cloud is geo-referenced

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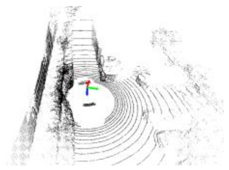
Multiple simultaneous single-scan scanners



Velodyne 64 and point cloud:
→ 64 laser scanners
→ Advantage: Speed (1 M pts/s)

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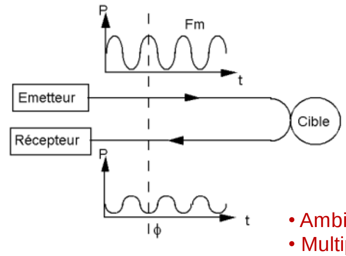
Amplitude modulation (phase shift) « décalage de phase »



$$\tau = \frac{1}{F_m}\left(N + \frac{\phi}{2\pi}\right)$$

$$d = \frac{1}{2} v \tau$$

$$= \frac{v}{2F_m}\left(N + \frac{\phi}{2\pi}\right)$$

- Ambiguity Distance
- Multiple Frequencies
- Accuracy better than per pulse

[Grussenmeyer 2011]

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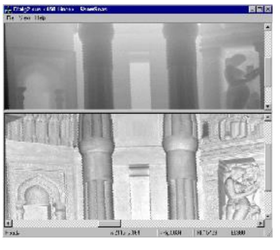
Some Phase Difference Sensors

LARA (Zoller+Fröhlich)

Faro Focus 3D



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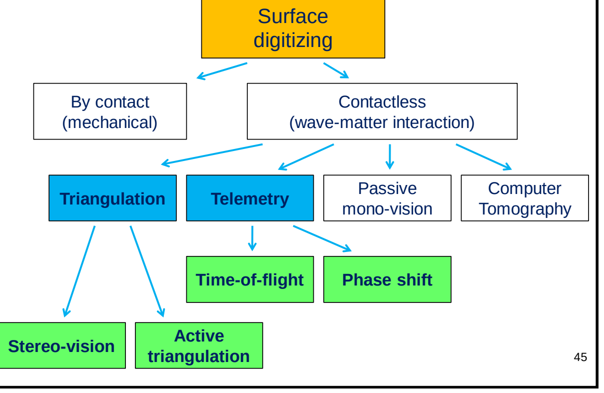
Overview



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3/ Precision and calibration

- 3D points are geometric measurements
  - Obtained by physical (contact, light, etc.) and mechanical principles
- Systematic measurement errors can be improved
  - Using calibration ("étalonnage")

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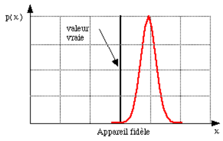
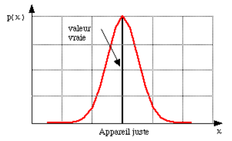
Measurement precision

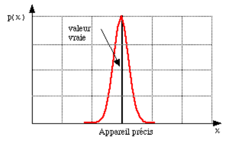




Fidelity (*"fidélité"*): Analyzed by standard deviation

Accuracy (*"justesse"*): analysed by the average

$$\sigma = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2}$$



$$\bar{x} = E(X) = \frac{1}{n}\sum_{i=1}^{n} x_i$$

$$RMS = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(x_i - x_{vrai})^2}$$

Precision: Analyzed by RMS value

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Principles of Calibration

- Sensor Model G (Optical, Geometry)
  - Allows to switch from the raw B_i sensor data to the 3D points X_i
    - Example of raw data: distance, scanning angle
  - Several q parameters:
    - intrinsic q_{int}; extrinsic q_{ext} (position and orientation) of the sensor.

$$X_i = g(B_i, q) \quad (1)$$

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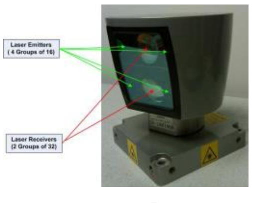
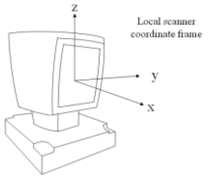
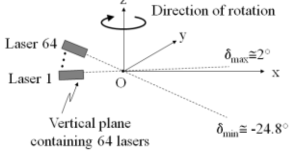
Modeling a Velodyne 64







→ Model for each of the 64 lasers (denoted i)

[Glennie and Lichti 2010]

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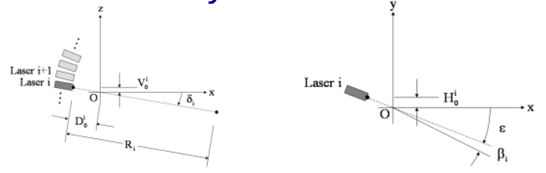
Velodyne 64 – laser i



$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \begin{bmatrix} (s^i * R_i + D_o^i) * \cos(\delta_i) * [\sin(\varepsilon) * \cos(\beta_i) - \cos(\varepsilon) * \sin(\beta_i)] - H_o^i * [\cos(\varepsilon) * \cos(\beta_i) + \sin(\varepsilon) * \sin(\beta_i)] \\ (s^i * R_i + D_o^i) * \cos(\delta_i) * [\cos(\varepsilon) * \cos(\beta_i) + \sin(\varepsilon) * \sin(\beta_i)] + H_o^i * [\sin(\varepsilon) * \cos(\beta_i) - \cos(\varepsilon) * \sin(\beta_i)] \\ (s^i * R_i + D_o^i) * \sin(\delta_i) + V_o^i \end{bmatrix}$$

where:

Parameters:

- s^i is the distance scale factor for laser i;
- D_o^i is the distance offset for laser i;
- δ_i is the vertical rotation correction for laser i;
- β_i is the horizontal rotation correction for laser i;
- H_o^i is the horizontal offset from scanner frame origin for laser i;
- V_o^i is the vertical offset from scanner frame origin for laser i;

Measurements:

- R_i is the raw distance measurement from laser i;
- ε is the encoder angle measurement.

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Calibration Method

- Procedure for precisely determining sensor parameters (q_{int}, q_{ext})
- Based on
  - Experimental measurements, raw data set B_i and calculated points X_i
  - An R reference (3D points, model) and a metric (Euclidean distance, etc.)
  - Gives an estimated error ε_i for each point

$$\varepsilon_i = d(X_i, R)$$

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Solution

- Least Squares Solving
  - Assumptions about measurement noises and the metric used: (normal distribution, etc.)
- Error function to minimize on parameter space:

$$f(q) = \sum_{i=1}^{n} \varepsilon_i^2 \quad (2)$$

$$f(q) = \sum_{i=1}^{n} d(g(B_i, q), R)^2 \quad (3)$$

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Example: calibration of a laser-camera system

- Objective:
  - Finding the rigid transformation between a single beam scanner and a camera

Marlin AVT camera and IBEO LD scanner.

Canon EOS 5D Camera and SICK LMS 221 Scanner

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Usage: colorization of point clouds

Rue Soufflot in Paris, point cloud acquired by LARA-3D [Deschaud 2010]

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4/ 3D scanning demonstrations

4.1 Real-Time 3D Acquisition – Kinect

4.2 Laser Survey & Images - Faro Focus

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References

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