3D Models from Range Sensors

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Who

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 - Expertise: 3D scanning, Mesh Processing, Computer Graphics
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Office hours

- Where
 - Room I-54, Gate 7 or 8, ISTI-CNR, via G. Moruzzi
 n. 1
- When
 - Tuesday from 15:00 to 17:00, or by appointment
 - Please, send an e-mail to confirm an appointment

3D Models from Range Sensors

 How to create a complete 3D model of your object of interest using 3D active optical scanning devices



3D Models from Range Sensors

- Why active optical scanning devices?
 - High accuracy
 - Several technologies that scale with the object size
 - Cheaper than a CT scanner, more accurate output than passive technologies

Outline

- 1. 3D scanning pipeline (1h)
- 2. 3D optical active scanning devices (2h)
- 3. Surface cleaning and smoothing (1h)
- 4. Surface registration (2h)
- 5. Surface recostruction (2h)
- 6. Mesh repairing and simplification (2h)
- 7. Color integration and appearance modeling (2h)

Laboratory with **MeshLab** (8h)

3D scanning pipeline



3D scanning pipeline: Planning

- Select the scanning technology
 - Accuracy of the final model
 - Size of the object
 - Optical properties of the objects
- Planning the acquisition
 - E.g. Do you need scaffolding?



3D scanning pipeline: Acquisition

- Setting of the support structures from the acquisition
 - E.g. scaffolding, support for markers, lighting condition
- Acquisition of multiple range scans from different point of views
 - Complete coverage of the object
 - High redundancy of data



Each pixel in the image encodes the distance of the surface from the camera

- Metadata:
 - Camera extrinsics: position and rotation
 - Camera intrinsics: field of view, size of pixels in mm
- From Metadata:
 - we can obtain 3D points!



Camera Model: Pinhole Camera

The perspective projection is defined as

$$\mathbf{m} = P \cdot \mathbf{M} \qquad \qquad \mathbf{m}' = \mathbf{m}/\mathbf{m}_z$$
$$P = K[I|\mathbf{0}]G = K[R|\mathbf{t}]$$

$$K = \begin{bmatrix} -fk_u & 0 & u_0 \\ 0 & -fk_v & v_0 \\ 0 & 0 & 1 \end{bmatrix} \mathbf{t} = \begin{bmatrix} t_1 \\ t_2 \\ t_3 \end{bmatrix} \quad R = \begin{bmatrix} \mathbf{r}_1^\top \\ \mathbf{r}_2^\top \\ \mathbf{r}_3^\top \end{bmatrix}$$

Intrinsic Matrix

Extrinsic Matrix

Camera Model: Pinhole Camera – Inverse projection

 Using the depth d of the point and its image coordinates m', the inverse perspective projection is defined as

$$\mathbf{m} = [\mathbf{m}'_{\mathbf{x}} \ \mathbf{m}'_{\mathbf{y}} \ 1] \qquad \mathbf{M} = P^{-1}\mathbf{m}$$
$$\mathbf{P} = R^{-1}[I| - \mathbf{t}]DK^{-1}$$

$$D = \begin{bmatrix} -d & 0 & 0 \\ 0 & -d & 0 \\ 0 & 0 & -d \end{bmatrix} \quad K^{-1} = \begin{bmatrix} \frac{1}{-fk_u} & 0 & 0 \\ 0 & \frac{1}{-fk_v} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & -u_0 \\ 0 & 1 & -v_0 \\ 0 & 0 & 1 \end{bmatrix}$$

3D Scanning Outputs: Range Maps as Point Cloud



3D Scanning Outputs: Range Maps as Triangle Mesh

 Topology from adjacent pixels in the range maps



 Discard bad triangles (viewed from very grazing direction)



- A range map is already a 3D model... but it will be surely incomplete
- A single acquisition *IS NOT enough* to reconstruct an entire object
- Multiple shots are needed to obtain a complete sampling of the surface with the requested accuracy
 - How many?
 - Which ones to choose?



3D scanning pipeline: Editing

- Remove noise
- Remove scanning artefact
 - Outliers
 - Wrong geometry





3D scanning pipeline: Registration

- Alignment of the range maps in the same reference system
 - 1. Rough alignment (manual or automatic)
 - 2. Pair-wise refinement by ICP (Iterative Closest Point)
 - 3. Global registration



3D scanning pipeline: Merging

 To compute a continuous surface by integration of the redundant data in the overlap regions of the input range maps



3D scanning pipeline: Simplification and Repairing

- Correct small artifact of the 3D models (e.g. nomanifolds vertices and edges, holes)
- Create smaller versions of the 3D models by removing the triangles in a controlled way



4M TRIANGLES

1M TRIANGLES

250K TRIANGLES

3D scanning pipeline: Color and Appearance

- How to add color and appearance information on the surface
- Ad-hoc photographic campaign
 - Registration of the images, projection and integration of the color data



References

- Curless, Brian. "From range scans to 3D models." ACM SIGGRAPH Computer Graphics 33.4 (1999): 38-41.
- Bernardini, Fausto, and Holly Rushmeier. "The 3D model acquisition pipeline." *Computer graphics forum*. Vol. 21. No. 2. Blackwell Publishers Ltd, 2002.
- Levoy, Marc, et al. "The digital Michelangelo project: 3D scanning of large statues." Proceedings of the 27th annual conference on Computer graphics and interactive techniques. ACM Press/Addison-Wesley Publishing Co., 2000.
- Bernardini, Fausto, et al. "Building a digital model of Michelangelo's Florentine Pieta." *IEEE Computer Graphics and Applications* 22.1 (2002): 59-67.