CSc 83010
Topics in Computer Graphics
3D Photography

Tuesdays 11:45-1:45 – Room 3305
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Computer Vision

Sensors:
Digital Cameras (2D)
Range Scanners (3D)

Illumination

Physical 3D World

Vision System

Scene Description

Geometry

Reflectance
3D Photography & Graphics

- **Scene Description**
  - Geometry
  - Reflectance
  - Captured from Vision System

- **Model of Illumination**
  - Model of the Physical World

- **Modeling** [Representation of 3D objects]
- **Rendering** [Construction of 2D images from 3D models]
- **Animation** [Simulating changes over time]

**Representations of 3D Scenes**

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New trends: Image-Based Rendering

- Chen and Williams (1993) - view interpolation
- McMillan and Bishop (1995) - plenoptic modeling
- Levoy and Hanrahan (1996) - light field rendering

The graphics pipeline

the traditional pipeline

modeling → animation → rendering

the new pipeline?

3D scanning → motion capture → image-based rendering
CSc 83010 Syllabus

- Capturing 3D data
  - Laser scanning/Stereo basics
- 3D modeling pipeline
  - Segmentation/Registration
  - Mesh/Volume Construction
- Rendering
  - Image-based rendering
  - Texture mapping
- Student projects (to be determined)

3D Photography - Applications

- Virtual worlds (Film Industry/Graphics)
- Urban Planning (Civil Applications)
- Historical Preservation and Archaeology
- Reverse Engineering (Manufacturing)
- E-commerce (Web-based models)
- Remote presence (Google Earth)
3D Photography System

Cyrax Range Scanner
- Spot laser scanner
- Time of flight
- Max Range: 100m
- Scanning time: 20 minutes for 1000 x 1000 points
- Accuracy: 6mm
Beauvais Cathedral, France.
Range Scanning Outdoor Structures
Technical Challenges

- Global and coherent geometry
- Remove redundancy
- Handle holes
- Handle all types of geometries
- Registration of point sets
- Reducing data complexity
- Range and intensity image fusion

System Overview

```
Brightness Images
  ↓
Planar Segmentation
  ↓
Range-Intensity Registration
  ↓
Range-Range Registration
  ↓
Range-Range Registration
  ↓
Range-Range Intersection
  ↓
FINAL PHOTOREALISTIC MODEL
```

```
Range Images
  ↓
Planar Segmentation
  ↓
Range-Intensity Registration
  ↓
Range-Range Registration
  ↓
Range-Range Intersection
  ↓
FINAL SOLID MODEL
```
System Overview

Brightness Images

- 2D line extraction

Range Images

- Planar Segmentation

Range-Intensity Registration

Range-Range Registration

Volume Estimation

FINAL PHOTOREALISTIC MODEL

FINAL SOLID MODEL

Planar Segmentation (1)
Segmentation algorithm

- Fit local plane to neighborhood of range points.
- Classify range points: planar, non-planar, unknown.
- Sequentially label range image
  - Connected clusters of co-planar points.
- Fit one plane to all points of cluster.
- Identify boundaries of planes.

Local Planarity Comparison

P1 and P2 are **coplanar** if:

- \( a = \cos^{-1}(N_1 \cdot N_2) \) < angle threshold
- \( d = \max(|R_{12} N_1|, |R_{12} N_2|) \) < distance threshold
Italian House (view 1)

Planar Segmentation (view 2)
Planar Segmentation (view 3)
Flat Iron Building

Image

Scan 1  Segmented Scan 1

Scan 2
System Overview

Brightness Images

2D line extraction

Range-Intensity Registration

FINAL PHOTOREALISTIC MODEL

Range Images

Planar Segmentation

3D line extraction

Range-Range Registration

Volume Intersection

FINAL SOLID MODEL

3D Line Detection

- Intersect neighboring planes.
- Discard lines produced by far away planes.
- Keep parts of lines verified by the range-set.
3D Line Detection, Plane Intersections

\[ d_1: \text{Distance from face 1} \]
\[ d_2: \text{Distance from face 2} \]

Max\( (d_1, d_2) \) must be less than threshold \( T_{\text{poly}} \)

3D lines
3D lines (Italian House)

System Overview

Brightness Images

- 2D line extraction
- Range-Intensity Registration
- FINAL PHOTOREALISTIC MODEL

Range Images

- Planar Segmentation
- 3D line extraction
- Range-Range Registration
- Range-Intensity Registration
- Range-Range Intersection
- FINAL SOLID MODEL

Volume Sweeps
Italian House: 3 registered views

Common Coordinate System
System Overview

Brightness Images

- 2D line extraction
- Range-Intensity Registration

Range Images

- Planar Segmentation
- 3D line extraction
- Range-Range Registration
- Solid Sweeps
- Volume Intersection

FINAL PHOTOREALISTIC MODEL

FINAL SOLID MODEL
White Facets: Imaged Object Surfaces
Red Facets: Unimaged, Occluded Object Surfaces
Surface Classifiers:

1) Angle between facet surface normal and scan direction.
2) geometry of triangular facet.
Example: Hip Replacement

Example: Video Game Controller
Example: Propeller Blade

Italian House: 2 sweeps
Italian House (cont).

Third Sweep  Final Solid

Range-Intensity Registration

3-D depth map of the scene

Viewing Direction

Range Sensor's Coordinate System

Coordinate Transformation $R, T$
Automated Range-Image Registration

1. Find internal camera calibration: use vanishing points.

2. Find camera rotation: Use vanishing points and orthogonality constraints.

3. Find camera translation: Match rectangular features.

4. Refinement of Rotation, Translation: back-projection of 3D lines on 2D image.

Vanishing Points
Matching higher order features

Results: Extracted Rectangles (1)
2D rectangles  3D rectangles
Results (cont)
Second View

2D rectangles

3D rectangles

Matched Rectangles (1)

Set of 6 matched rectangles found by RANSAC.

2D rectangles: GREEN.
3D rectangles projected on image (after registration): RED.
Matching: Refinement

Matched Rectangles (2)

2D rectangles: GREEN.
3D rectangles projected on image (after registration): RED.

Set of 8 matched Rectangles found by RANSAC.

All rectangles.
Flat Iron Building
3 novel views

Guggenheim Museum, NYC
A Site Modeling Robot

• Build accurate models of large structures
• Given a 2-D map, build 3-D models
• Integrates 2-D imagery with range data
• Use planning to navigate to new views
• Register sensor data with the environment
Mobile Robot for Site Modeling

AVENUE

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Autonomous Vehicle
Exploring & Navigating Urban Environments

The Digital Michelangelo Project

Marc Levoy

Computer Science Department
Stanford University
Marc Levoy (Stanford)

Calibrated motions:
- pitch (yellow)
- pan (blue)
- horizontal translation (orange)

Uncalibrated motions:
- vertical translation
- remounting the scan head
- moving the entire gantry

Scanner design:
- 4 motorized axes
- truss extensions for tall statues
- laser, range camera, white light, and color camera
Scanning the David

- Height of gantry: 7.5 meters
- Weight of gantry: 800 kilograms

Statistics about the scan

- 480 individually aimed scans
- 2 billion polygons
- 7,000 color images
- 32 gigabytes
- 30 nights of scanning
- 22 people
Head of Michelangelo’s David

photograph 1.0 mm computer model

David’s left eye

0.25 mm model
holes from Michelangelo’s drill
artifacts from space carving
noise from laser scatter

photograph
Dynamic Scenes

Image sequence (CMU, Virtualized Reality Project)

Dynamic 3D model.
Dynamic Scenes

Dynamic texture-mapped model.

Lumigraph Example

acquisition stage  volumetric model  novel view

Recent work: Unstructured Lumigraph (SIGGRAPH 2001)
Acquiring the light field (IBR)

- natural eye level
- artificial illumination

7 light slabs, each 70cm x 70cm