3D Photography

Marc Pollefeys, Kevin Köser

Spring 2012

http://www.cvg.ethz.ch/teaching/2012spring/3dphoto
3D Photography

- Obtaining 3D shape (and appearance) of real-world objects
Motivation

- Applications in many different areas
- A few examples ...
Virtual Tourism

See http://photosynth.net
Surgery - simulation

- simulate results of surgery
- allows preoperative planning
Surgery - teaching

Capture models of surgery for interactive learning
Clothing

- Scan a person, custom-fit clothing
Forensics

- Crime scene recording and analysis
Forensics
3D urban modeling

UNC/UKY UrbanScape project
Street-Side Video

Real-Time Stereo
Reconstructions from Street-Side Video

Real-time processing of video (30fps on PC, leveraging GPU)
Building Rome on a cloudless day

(Frahm et al. ECCV 2010)

- GIST & clustering (1h35)
- SIFT & Geometric verification (11h36)
- SfM & Bundle (8h35)

Dense Reconstruction (1h58)

Some numbers
- 1PC
- 2.88M images
- 100k clusters
- 22k SfM with 307k images
- 63k 3D models
- Largest model 5700 images
- Total time 23h53
Building Rome on a cloudless day

(Frahm et al. ECCV 2010)
Industrial inspection

- Verify specifications
- Compare measured model with CAD
Scanning industrial sites

as-build 3D model of off-shore oil platform
Robot navigation

ESA project
Subtask: Calibration + Terrain modelling + Visualization

small tethered rover

pan/tilt stereo head
Driver Assistance

6D Vision (Daimler)
Architecture

Survey
Stability analysis
Plan renovations
Architecture

Survey
Stability analysis
Plan renovations
Cultural heritage

Virtual Monticello

Allow virtual visits
Cultural heritage

Stanford’s Digital Michelangelo

Digital archive
Art historic studies
Archaeology
Archaeology

Record different excavation layers

Generate 4D excavation record

Layer 1
Layer 2

Generate & verify construction hypothesis
Computer games

http://www.xbox.com/de-DE/kinect
Course objectives

- To understand the concepts that allow to recover 3D shape from images
- Explore the state of the art in 3D photography
- Implement a 3D photography system/algorithm
Material

Slides and more

http://www.cvg.ethz.ch/teaching/2012spring/3dphoto

Also check out on-line “shape-from-video” tutorial:
http://www.cs.unc.edu/~marc/tutorial/

Other interesting stuff:

- Book by Hartley & Zisserman, “Multiple View Geometry”
Content

- camera model and calibration
- single-view metrology
- triangulation
- epipolar geometry, stereo and rectification
- structured-light, active techniques
- feature tracking and matching
- structure-from-motion
- shape-from-silhouettes
- space-carving
- ...
Fast Forward!

- Quick overview of what is coming...
Camera models and geometry

Pinhole camera

\[
\lambda \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} f_x & p_x \\ f_y & p_y \\ 0 & 0 \end{bmatrix} \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} R \quad t \\ 0 \quad 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \quad \text{or} \quad \lambda \mathbf{x} = \mathbf{P} \mathbf{X}
\]

Geometric transformations in 2D and 3D
Camera Calibration

- Know 2D/3D correspondences, compute projection matrix
- also radial distortion (non-linear)
Single View Metrology

Antonio Criminisi, 2001
Single View Reconstruction

Wu et al. ‘10/’11: Repetition Detection + Reconstruction

Hoiem et al.
SIGGRAPH’05:
“Automatic Photo Popup”
Feature tracking and matching

Harris corners, KLT features, SIFT features
key concepts: invariance of extraction, descriptors
to viewpoint, exposure and illumination changes
3D from images

Triangulation
- calibration
- correspondences
Epipolar Geometry

Fundamental matrix

\[ x^\top F x = 0 \]
\[ F \leftrightarrow P, P' \]

Essential matrix

\[ x^\top [t]_x R x = 0 \]
\[ E \leftrightarrow P, P' \]

Also how to robustly compute from images
Stereo and rectification

Warp images to simplify epipolar geometry

Compute correspondences for all pixels
Structured-light

- Projector = camera
- Use specific patterns to obtain correspondences
Structure from motion

Initialize Motion
\((P_1, P_2)\) compatible with F

Initialize Structure
(minimize reprojection error)

Extend motion
(compute pose through matches seen in 2 or more previous views)

Extend structure
(Initialize new structure, refine existing structure)
Auto-calibration

$$\omega_i^* = P_i \Omega^* P_i^T = \lambda K_i K_i^T$$

projection constraints

$$\lambda \omega_j^* = H_{ij} \Omega_i^* H_{ij}^T$$
Shape-from-Silhouette
Space-carving

Only keep photo-consistent voxels
Shape-from-X

- Shape-from-focus
- Shape-from-texture
- Shape-from-symmetry
3D modeling and texturing

- Multiple depth images
- Surface model
- Texture integration
- Patchwork texture map
3D registration & Volumetric Modeling

Digital Michelangelo Scanner

KinectFusion

(Brown and Rusinkiewicz, Siggraph 2007)

(Newcombe et al., ISMAR 2011,
Organization of Class

- Interactive: Lectures + Discussion of recent publications
- Hands-on experience: implement a 3D photography project
- Grading: 25% Presentation/Discussion, 75% Project
Course project:
Build your own 3D scanner!

Example: Bouguet ICCV’98
Project Suggestions

- Kinect-based Scene modeling
- Android 3D Reconstruction
- Single-View Modeling from Water Reflection
- Dense Streetview Reconstruction
- Shape from Shadows
- ...
- See class homepage or propose own
Projects

- Team-up with another student
- Propose a project (3 weeks from now)
  - topic / solution idea
  - milestones / steps
- Project Update (after Easter)
- Final Demo / Report (end of May)

- No final exam:
  4 ECTS effort DURING semester!
Papers and discussion

- recent state of the art
- list of “presentable” papers: will be on course homepage
- Selected paper (1x): ca. 20 min. presentation + discussion
- Assigned paper (1x): prepare questions
# Schedule (tentative)

<table>
<thead>
<tr>
<th>Date</th>
<th>Event</th>
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<tbody>
<tr>
<td>Feb 20</td>
<td>Introduction</td>
</tr>
<tr>
<td>Feb 27</td>
<td>Lecture: Geometry, Camera Model, Calibration</td>
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<tr>
<td>Mar 5</td>
<td>Lecture: Features, Tracking/Matching</td>
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<tr>
<td>Mar 12</td>
<td><strong>Project Proposals by Students</strong></td>
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<tr>
<td>Mar 19</td>
<td>Lecture: Epipolar Geometry</td>
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<td>Mar 26</td>
<td>Short lecture “Stereo”</td>
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<td>+ 2 papers (2 teams of 2 students)</td>
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<td>Apr 2</td>
<td>Short lecture “Active Ranging, Structured Light” + 2 papers</td>
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<tr>
<td>Apr 9</td>
<td>Easter</td>
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<tr>
<td>Apr 16</td>
<td>Project Updates (Sechseläuten in afternoon)</td>
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<tr>
<td>Apr 23</td>
<td>Short lecture “Volumetric Modeling” +2 papers</td>
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<td>Apr 30</td>
<td>Short lecture “Single View” + 2 papers</td>
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<td>May 7</td>
<td>Short lecture “SfM from Photo Collections” + 2 papers</td>
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<tr>
<td>May 14</td>
<td>Short lecture “Silhouettes” + 2 papers</td>
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<td>May 21</td>
<td>Short lecture + 2 papers</td>
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<td>May 28</td>
<td>Pentecost / White Monday</td>
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<td>May 29-June 1</td>
<td>Final Demos</td>
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3D Photography Team

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Next week ...

- Geometry
- Camera Model
- Calibration
Your task ... 

- Register in mystudies!
- Think about project
- Introduce yourself / Talk to your neighbors (check for possibility to team up!)