Structured Light + Range Imaging

Lecture #17

(Thanks to Content from Levoy, Rusinkiewicz, Bouguet, Perona, Hendrik Lensch)
3D Scanning
Stereo Triangulation

Correspondence is hard!
Structured Light Triangulation

Correspondence becomes easier!
Structured Light

- Any spatio-temporal pattern of light projected on a surface (or volume).
- Cleverly illuminate the scene to extract scene properties (e.g., 3D).
- Avoids problems of 3D estimation in scenes with complex texture/BRDFs.
- Very popular in vision and successful in industrial applications (parts assembly, inspection, etc).
Light Stripe Scanning – Single Stripe

• Optical triangulation
  – Project a single stripe of laser light
  – Scan it across the surface of the object
  – This is a very precise version of structured light scanning
  – Good for high resolution 3D, but needs many images and takes time
Triangulation

- Project laser stripe onto object

Light Plane

\[ Ax + By + Cz + D = 0 \]
• Depth from ray-plane triangulation:
  – Intersect camera ray with light plane

\[
\begin{align*}
x &= \frac{x'}{f} \\
y &= \frac{y'}{f} \\
z &= \frac{-Df}{Ax' + By' + Cf}
\end{align*}
\]
Example: Laser scanner

+ very accurate < 0.01 mm
- more than 10sec per scan
Example: Laser scanner

Digital Michelangelo Project
http://graphics.stanford.edu/projects/mich/
3D Model Acquisition Pipeline

3D Scanner
3D Model Acquisition Pipeline

3D Scanner

View Planning
3D Model Acquisition Pipeline

- 3D Scanner
- View Planning
- Alignment
3D Model Acquisition Pipeline

View Planning → 3D Scanner → Alignment → Merging
3D Model Acquisition Pipeline

- View Planning
- Done?
- 3D Scanner
- Alignment
- Merging
3D Model Acquisition Pipeline

3D Scanner

View Planning

Done?

Alignment

Merging

Display
Great Buddha of Nara

http://www.cvl.iis.u-tokyo.ac.jp/gallery_e/nara-hp/nara.html
Scanning and Modeling the Cathedral of Saint Pierre, Beauvais, France

http://www1.cs.columbia.edu/~allen/BEAUVAIS/
Portable 3D laser scanner (this one by Minolta)
Faster Acquisition?

• Project multiple stripes simultaneously
• Correspondence problem: which stripe is which?

• Common types of patterns:
  • Binary coded light striping
  • Gray/color coded light striping
Binary Coding

Faster:

\[ 2^n - 1 \] stripes in \( n \) images.

Example:

3 binary-encoded patterns which allows the measuring surface to be divided in 8 sub-regions

Projected over time
Binary Coding

- Assign each stripe a unique illumination code over time [Posdamer 82]
Binary Coding

Example: 7 binary patterns proposed by Posdamer & Altschuler

Pattern 1
Pattern 2
Pattern 3

Projected over time

Codeword of this pixel: 1010010 identifies the corresponding pattern stripe
More complex patterns

Works despite complex appearances

Works in real-time and on dynamic scenes

- Need very few images (one or two).
- But needs a more complex correspondence algorithm

Zhang et al
Real-Time 3D Model Acquisition

http://graphics.stanford.edu/papers/rt_model/
Continuum of Triangulation Methods

Single-stripe
Slow, robust

Multi-stripe
Multi-frame

Single-frame
Fast, fragile
Microsoft Kinect

IR LED Emitter

IR Camera

RGB Camera
Microsoft Kinect

Speckled IR Pattern

Depth map
3D Acquisition from Shadows
The idea

Desk

Lamp

Stick or pencil

Camera

Desk

Time t
The geometry

$P = (O, p) \cap \Pi$
The geometry

$$\Lambda = (O, \lambda) \cap \Pi_d$$

$$\Pi = (S, \Lambda)$$
The geometry

\[ \Lambda_1 = (O, \lambda_1) \cap \Pi_d \]
\[ \Lambda_2 = (O, \lambda_2) \cap \Pi_v \]
\[ \Pi = (\Lambda_1, \Lambda_2) \]
Angel experiment

Accuracy: 0.1mm over 10cm  \(~0.1\%\) error
Scanning with the sun

Accuracy: 1cm over 2m

~ 0.5% error
Fluorescent Immersion Range Scanning

http://www.mpi-inf.mpg.de/resources/FIRS/
Fluorescent Immersion Range Scanning

http://www.mpi-inf.mpg.de/resources/FIRS/
Structured Light Reconstruction

• Avoid problems due to correspondence
• Avoid problems due to surface appearance
• Much more accurate
• Very popular in industrial settings

• Reading:
  – Marc Levoy’s webpages (Stanford)
  – Katsu Ikeuchi’s webpages (U Tokyo)
  – Peter Allen’s webpages (Columbia)