Capturing, Modeling, Rendering 3D Structures

Omnidirectional Cameras

A little bit of history...

- Omnidirectional cameras are also called panoramic cameras
  - "Panorama" comes from the Greek phrase "all sight"
- Originally used for artistic purposes
- Robert Barker obtained a patent for the idea of a panorama in 1794
  - "A Painting without Equal"
- In 1800s, panorama became a common European word

A little bit of Biology...

- Some animals are capable of panoramic vision
  - e.g., certain insects, crustaceans (e.g., lobster)
- Diurnal Insect Vision
- Nocturnal Insect Vision
- Crustacean Vision

Taxonomy of Omnidirectional Camera Designs

- Single center-of-projection
  - Like a traditional camera, light rays meet at a single "focal point"
- Multiple center-of-projection
  - Camera does not have a single focal point
  - Sampled surfaces can be missing or duplicated in full image
  - Mathematical (re)projections are more complicated

- Single Camera/Image
  - One "view" is acquired per image
- Multiple Camera/Image
  - A single "view" composed by compositing several images

Cameras

- Traditional camera
  - Pinhole Camera Model
    - Problems: aberrations, distortions
    - Tradeoff between aperture, shutter speed, focus, dynamic range
- Calibration
  - Fit an assumed camera model to an actual camera
- Omnidirectional cameras
  - Single camera, multiple cameras, etc
- Localization and pose estimation
  - Where is the camera relative to the object or environment

Example Omnidirectional Camera Designs

- Rotating camera design
- Fish-eye lens design
- Multiple camera planar mirror design
- Single camera curved mirror design
Rotating Camera Design

- Place a camera on a tripod and spin it around snapping pictures every so often

- Pros
  - Simple

- Cons
  - Multiple centers-of-projection
  - Multiple (overlapping images) to composite
  - Vertical “jitter”
  - Slow acquisition process

Examples

- Tienamen

Fish-Eye Lens Design

- Use a wide field-of-view lens (~180 degrees) placed in front of a traditional camera

- Pros:
  - Also relatively simple for users (making the lens can be troublesome for designers)

- Cons:
  - Very severe image distortion
  - Low resolution around perimeter of field-of-view
  - Almost a single center-of-projection

Multiple Camera Planar Mirror Design

- Catadioptric = reflective (mirror) + refractive (lens)

- http://www.fullview.com [Nalwa96]

Single Camera Curved Mirror Design

- Theoretical solutions to a single center-of-projection panoramic camera use mirrors that are subsets of swept conic sections
  - Cones
  - Spheres
  - Ellipsoids
  - Hyperboloids
  - Paraboloids
**Single Camera Curved Mirror Design**

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**Examples**

- Walking in the mirror
- Museum

**Conical Mirror**

**Spherical Mirror**

**Ellipsoidal Mirror**

**Hyperboloidal Mirror**
Paraboloidal Mirror

Catadioptric Paraboloidal Camera

Design by [Nayar97]

Motorized cart with camera, computer, battery, radio remote control [Aliaga01,02]

Catadioptric Paraboloidal Camera

Theoretical camera model

Catadioptric Paraboloidal Camera

Practical camera model [Aliaga01]

Catadioptric Paraboloidal Camera Calibration

- Assuming incident equals reflected angle:
  \[
  \frac{i - m}{i - m} \cdot \hat{n} \equiv \frac{p - m}{p - m} \cdot \hat{n}
  \]

- And given a 3D point \( p \), mirror radius \( r \), convergence distance \( H \), we group and rewrite in terms of \( m \):
  \[
  m_1^2 p_1 + 2 m_2 m_3 + 2 m_3 p_2 H + 2 m_2 p_1 m_3 + (r^2 - 4 r^2 p_3 H m_3) (r^2 p_1 + 2 r^2 H p_3) = 0
  \]

Omnidirectional Vision Home Page

- http://www.cis.upenn.edu/~kostas/omni.html