Omnidirectional Camera Models

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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

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

OR

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

Some Omnidirectional Cameras

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

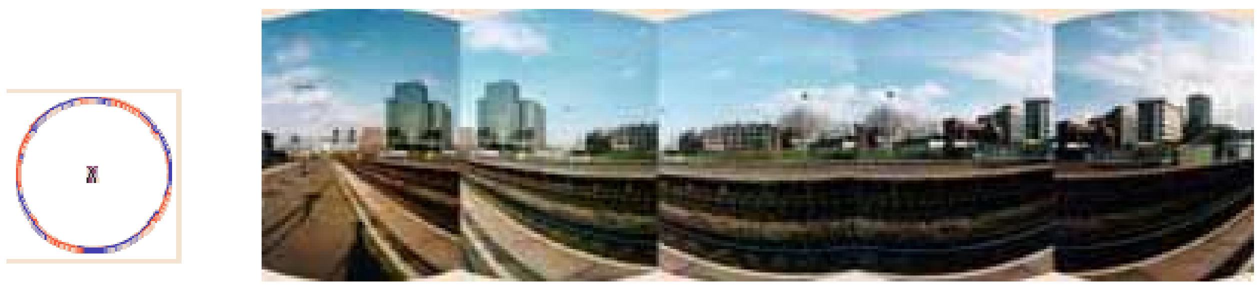
Rotating Camera Design

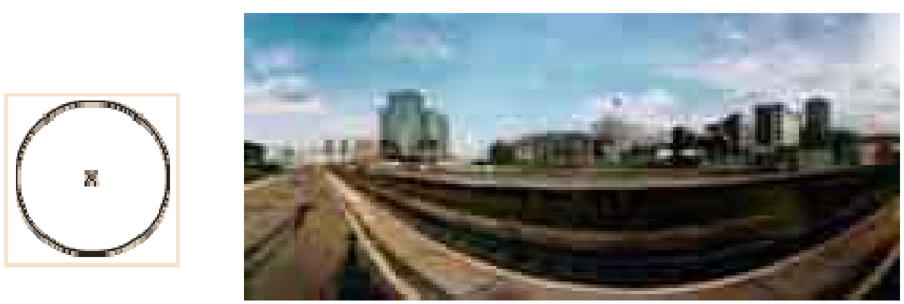
- Place a camera on a tripod and spin it around snapping pictures every so often

- Pros
  - Simple

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

Rotating Camera Design





Rotating Camera Design

- Tienamen

Panoramic Video Textures

[Agarwala-SIG05]

Panoramic Video Textures

- [pvViewer]

[Agarwala-SIG05]

Panoramic Video Textures

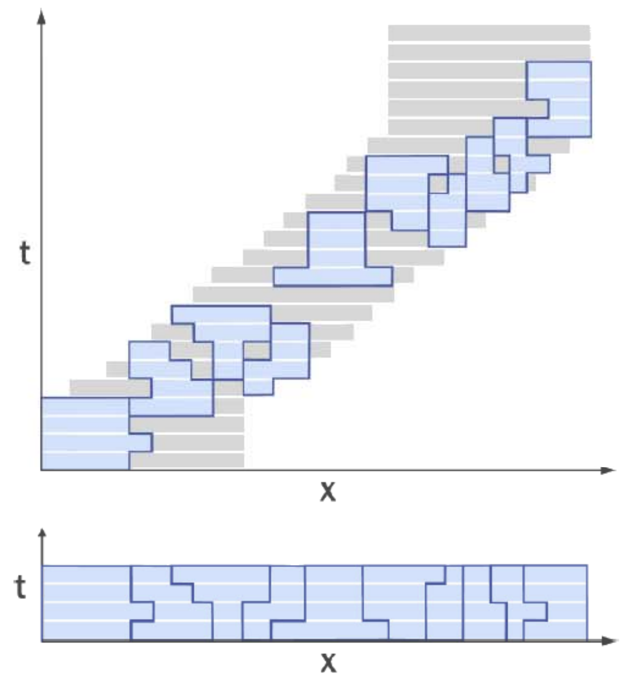


Figure 2 The top diagram shows an x,t slice of an input video volume $V(x,y,t)$. Each input video frame is shown as a grey rectangle. The frames are registered, and in this case, the camera is panning to the right. The bottom diagram shows an output video volume. The duration of the output is shorter, but each output frame is much wider than each input frame. Finally, the two diagrams show how a PVT can be constructed. The output video is mapped to locations in the input in coherent fragments; the mapping takes place in time only (as time offsets), never in space.

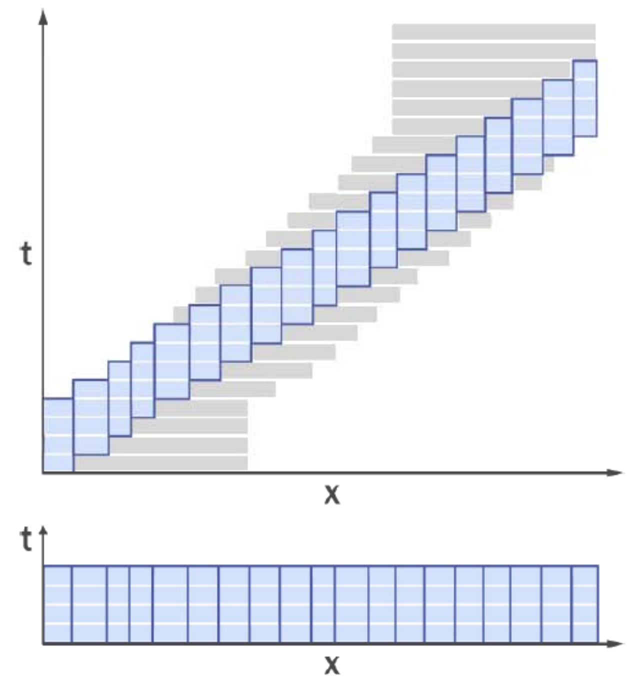


Figure 3 A simple approach to creating a PVT would be to map a continuous diagonal slice of the input video volume to the output panorama, regardless of appearance. This approach creates a valid result, but unnecessarily shears spatial structures across time (see Figure 4).

[Agarwala-SIG05]

Fish-Eye Lens Design

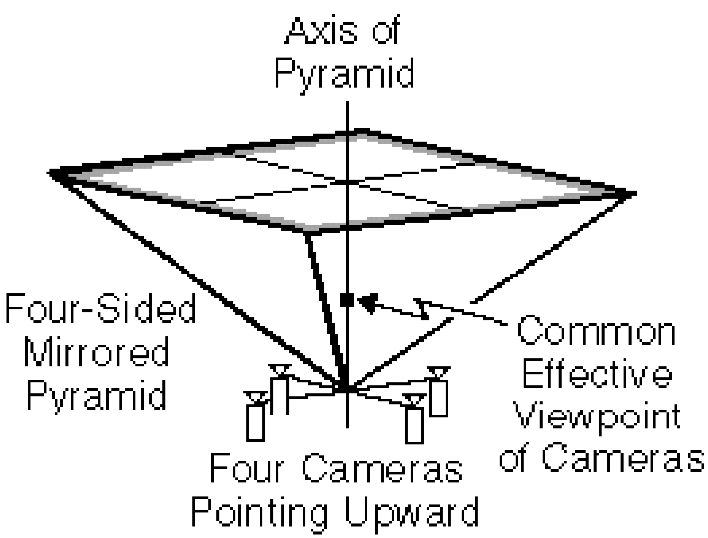
- Use a wide field-of-view lens (~180 degrees) placed in front of a traditional camera

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

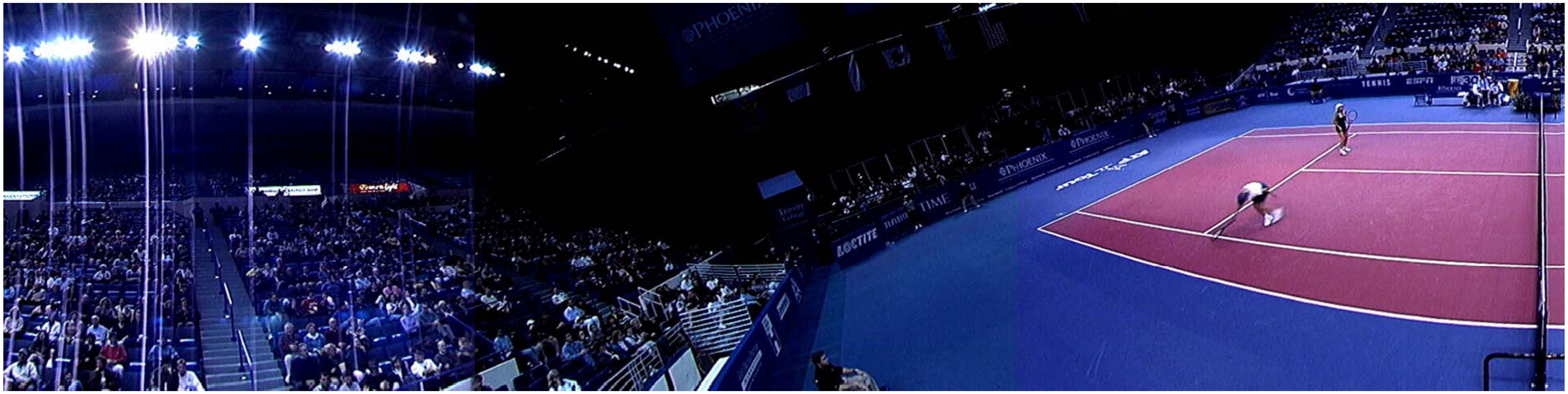
- Cons:
  - *Very* severe image distortion
  - Low resolution around perimeter of field-of-view
  - Almost a single center-of-projection

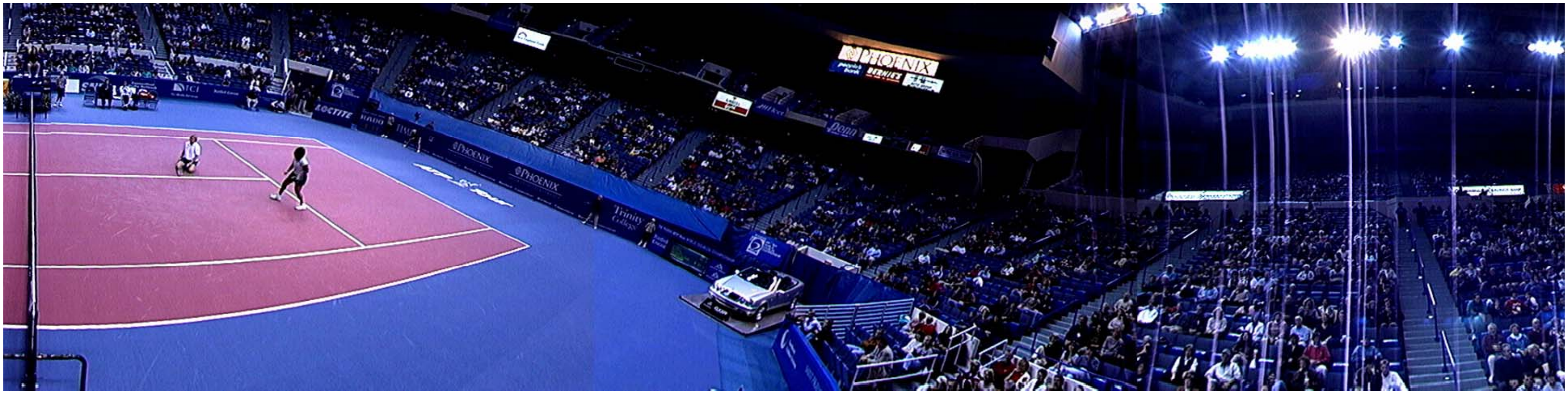
Multiple Planar Mirror Design

- Catadioptric = reflective (mirror) + refractive (lens)
- http://www.fullview.com [Nalwa96]



Multiple Planar Mirror Design





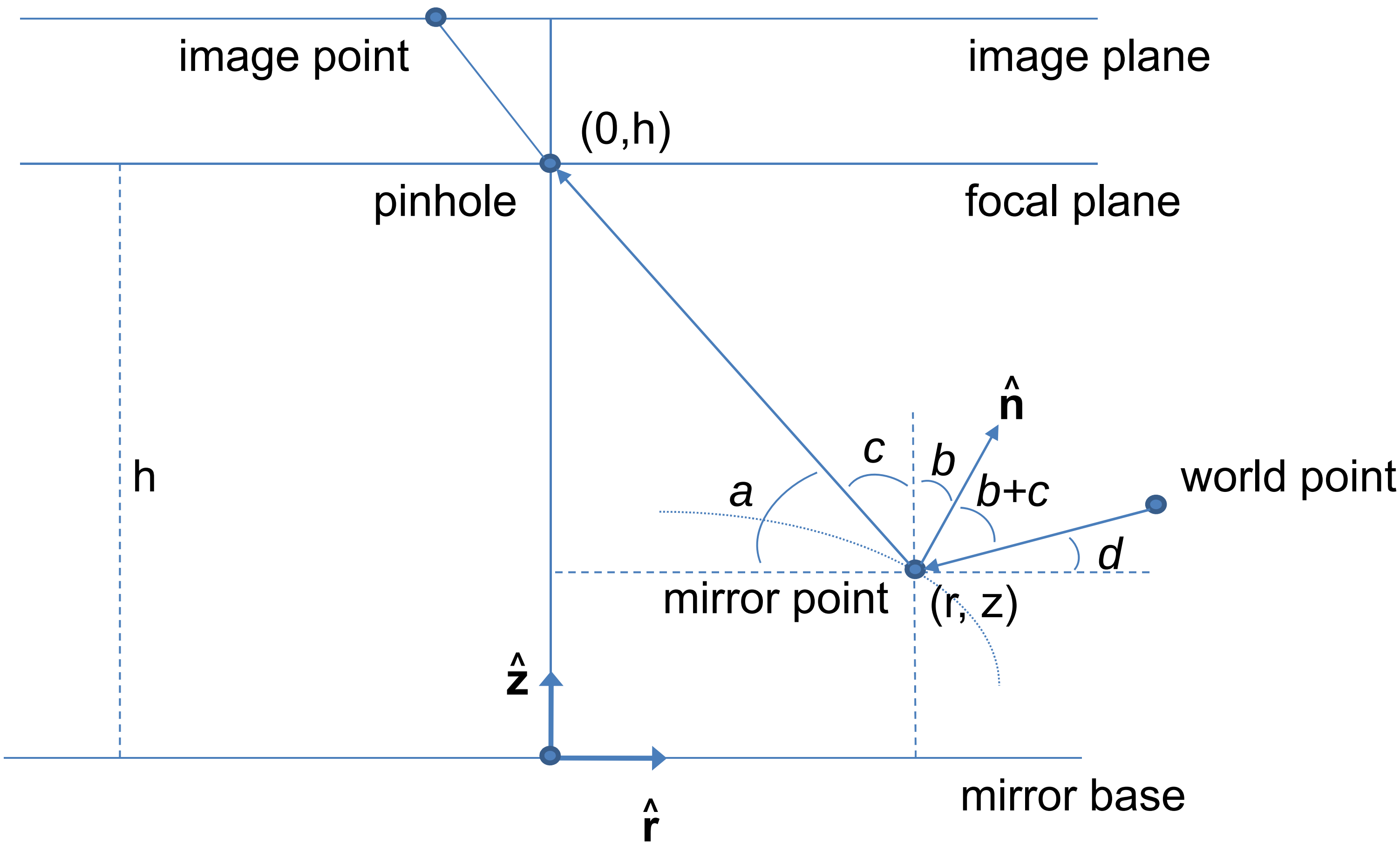
[Fullview]

Multiple Planar Mirror Design

[Fullview]

Multiple Planar Mirror Design

Fixed Viewpoint Constraint



Property 1: $c = 90^o - a$

Property 2: $a + d + 2b + 2c = 180^o$

Fixed Viewpoint Constraint

Property 1: $c = 90^{o} - a$

Property 2: $a + d + 2b + 2c = 180^{o}$

$$\Downarrow$$

$$2b = a - d$$

$$\Downarrow$$

$$\frac{2\tan(b)}{1-\tan^2(b)} = \frac{\tan(a)-\tan(d)}{1+\tan(a)\tan(d)}$$

$$\Downarrow$$

$$\boxed{r(h-2z)(dz/dr)^2 - 2(r^2+hz-z^2)(dz/dr) + r(2z-h) = 0}$$

Quadratic first-order ODE (constraint equation)

Fixed Viewpoint Constraint

Property 1: $c=90^o-a$

Property 2: $a+d+2b+2c=180^o$

$2b=a-d$

$$\frac{2\tan(b)}{1-\tan^2(b)} = \frac{\tan(a)-\tan(d)}{1+\tan(a)\tan(d)}$$

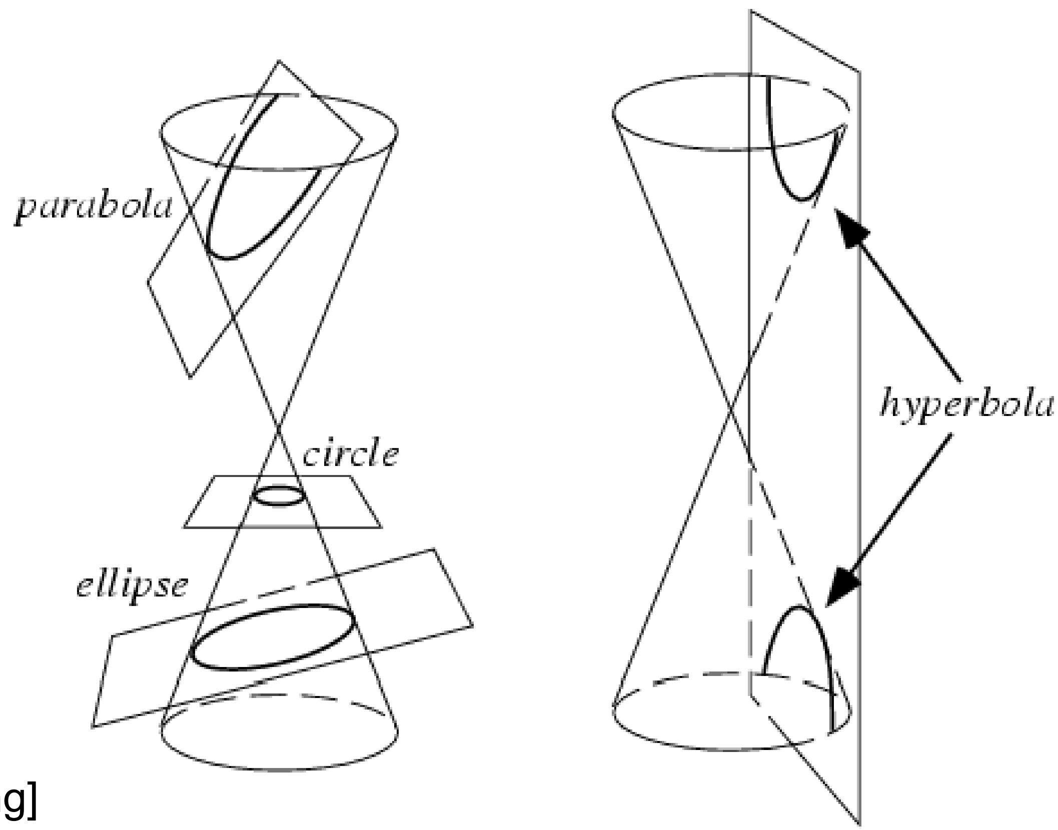
$(z-h/2)^2-r^2(k/2-1)=h^2(k-2)/4k$ for $k \geq 2$

$(z-h/2)^2+r^2(1+h^2/2k)=(2k+h^2)/4$ for $k \geq 0$

Generalized solution to constraint equation

Single 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



["Panoramic Vision", Benosman/Kang]

Examples

- Walking in the mirror
- Museum

Conical Mirror

Spherical Mirror

Ellipsoidal Mirror

Hyperboloidal Mirror

Hyperboloidal Mirror

- ACCOWLE Co., LTD, A Spin-off at Kyoto University
  - http://www.accowle.com/english/
- Spherical Mirror
- Hyperbolic Mirror

Image: High res. in the top

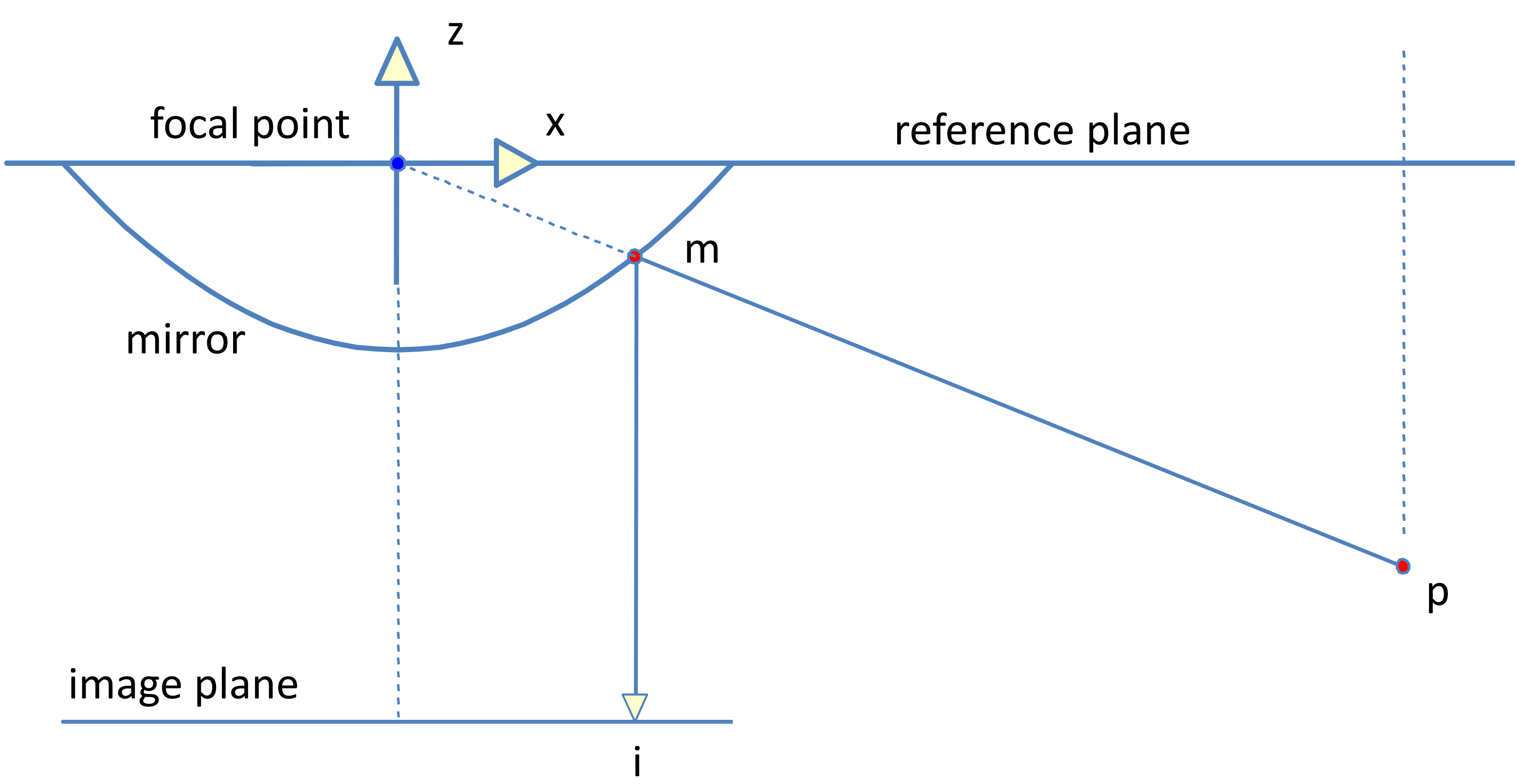
Paraboloidal Mirror

Catadioptric Paraboloidal Camera

Design by [Nayar97]

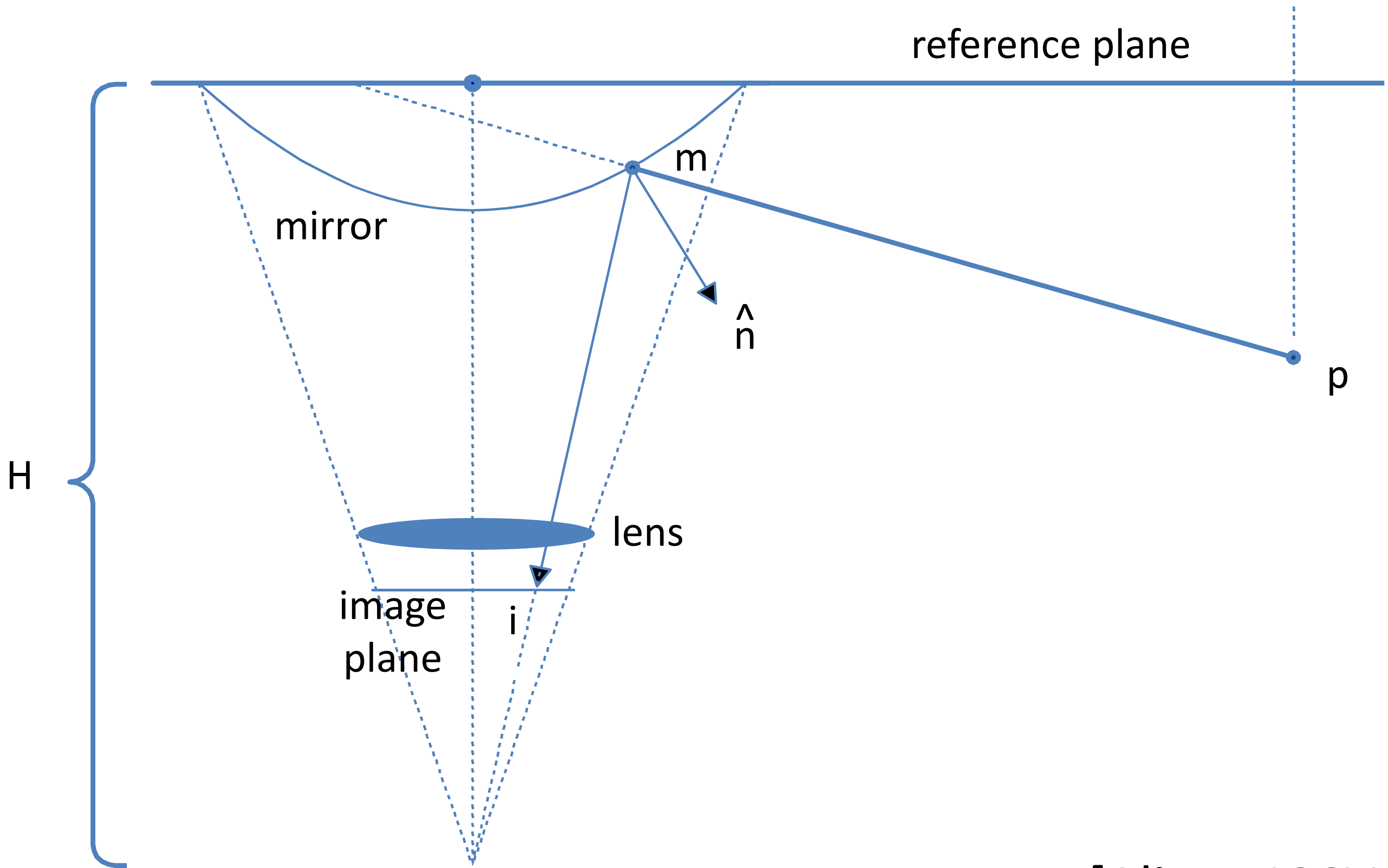
Motorized cart with camera, computer, battery, radio remote control [Aliaga01,02]

Catadioptric Paraboloidal Camera



Theoretical camera model

Catadioptric Paraboloidal Camera



[Aliaga-ICCV01]

Catadioptric Paraboloidal Camera Calibration

- Assuming incident equals reflected angle:

$$\frac{i - m}{i - m} \times \frac{\hat{n}}{\hat{n}} = \frac{p - m}{p - m} \times \frac{\hat{n}}{\hat{n}}$$

- And given a 3D point *p*, mirror radius *r*, convergence distance *H*, we group and rewrite in terms of m_r:

$$m_r^5 - p_r m_r^4 + 2r^2 m_r^3 + (2p_r rH - 2r^2 p_r)m_r^2 + (r^4 - 4r^2 p_z H)m_r - (r^4 p_r + 2r^3 H p_r) = 0$$

[Aliaga-ICCV01]

Omnidirectional Vision Home Page

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