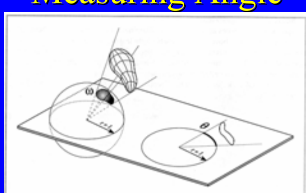
Radiometry

Computer Vision I
CSE252A
Lecture 5

Radiometry

- Read Chapter 4 of Ponce & Forsyth
- Solid Angle
- Irradiance
- Radiance
- BRDF
- Lambertian/Phong BRDF

Measuring Angle

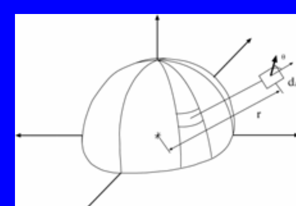


- **The solid angle subtended by an object from a point P is the area of the projection of the object onto the unit sphere centered at P.**
- Measured in *steradians*, sr
- Definition is analogous to projected angle in 2D
- If I'm at P, and I look out, solid angle tells me how much of my view is filled with an object

Solid Angle

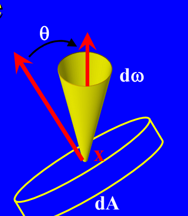
- By analogy with angle (in radians), the solid angle subtended by a region at a point is the area projected on a unit sphere centered at that point
- The solid angle subtended by a patch area dA is given by

$$d\omega = \frac{dA\cos\theta}{r^2}$$



Radiance

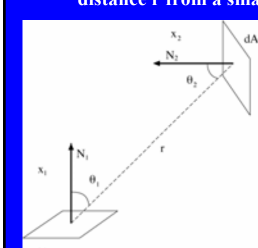
- Power is energy per unit time
- **Radiance: Power traveling at some point in a specified direction, per unit area perpendicular to the direction of travel, per unit solid angle**
- Symbol: L(**x**,θ,ϕ)
- Units: watts per square meter per steradian : $w/(m^2sr^1)$



$$L = \frac{P}{(dA\cos\theta)d\omega}$$

Radiance transfer

What is the power received by a small area dA_2 at distance r from a small emitting area dA_1?



From definition of radiance

$$L = \frac{P}{(dA\cos\theta)d\omega}$$

From definition of solid angle

$$d\omega = \frac{dA\cos\theta}{r^2}$$

$$P = L dA_1 \cos\theta_1 d\omega_{1->2}$$

$$= \frac{L}{r^2} dA_1 dA_2 \cos\theta_1 \cos\theta_2$$

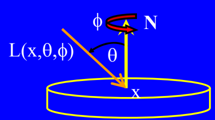
Irradiance

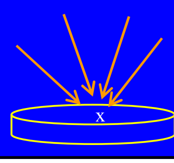
- How much light is arriving at a surface?
- Sensible unit is *Irradiance*
- This is a function of incoming angle.
- A surface experiencing radiance L(x,θ,φ) coming in from solid angle dω experiences **irradiance**:

$$E(x) = L(\underline{x}, \theta, \phi) \cos\theta \, d\omega$$

- Crucial property: Total **power** arriving at the surface is given by adding irradiance over all incoming angles Total power is

$$P(x) = \int_0^{2\pi} \int_0^{\pi/2} L(\underline{x}, \theta, \phi) \cos\theta \sin\theta \, d\theta \, d\phi$$





Intermezzo: Camera's sensor

- Measured pixel intensity is a function of irradiance integrated over
  - pixel's area
  - over a range of wavelengths
  - For some time

$$I = \int_t \int_\lambda \int_x \int_y E(x, y, \lambda, t) s(x, y) q(\lambda) dy dx d\lambda \, dt$$

- Ideally, it's linear to the radiance, but the camera response C(.) may not be linear

$$I = C\left(\int_t \int_\lambda \int_x \int_y E(x, y, \lambda, t) s(x, y) q(\lambda) dy dx d\lambda \, dt \right)$$

Image sensor

Two types :

1. CCD

2. CMOS

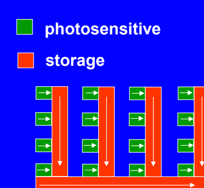
CCD

separate photo sensor at regular positions
no scanning

charge-coupled devices (CCDs)

:

interline transfer and *frame transfer*



CMOS

Each photo sensor has its own amplifier

- More noise (reduced by subtracting 'black' image)
- Lower sensitivity (lower fill rate)

Uses standard CMOS technology

- Allows to put other components on chip
- 'Smart' pixels

CCD vs. CMOS

- Mature technology
- Specific technology
- High production cost
- High power consumption
- Higher fill rate
- Blooming
- Sequential readout

- Recent technology
- Standard IC technology
- Cheap
- Low power
- Less sensitive
- Per pixel amplification
- Random pixel access
- Smart pixels
- On chip integration with other components

Color Cameras

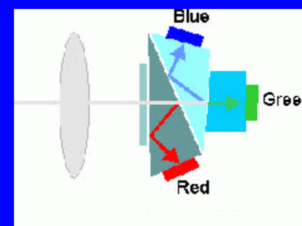
We consider 3 concepts:

1. Prism (with 3 sensors)
2. Filter mosaic
3. Filter wheel

… and X3

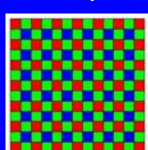
Prism color camera

Separate light in 3 beams using dichroic prism
Requires 3 sensors & precise alignment
Good color separation

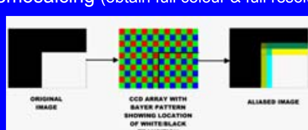


Filter mosaic

Coat filter directly on sensor


Bayer filter

Demosaicing (obtain full colour & full resolution image)



Filter wheel

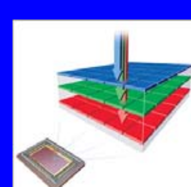
Rotate multiple filters in front of lens
Allows more than 3 colour bands

Only suitable for static scenes

Prism vs. mosaic vs. wheel

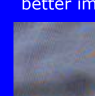
approach	Prism	Mosaic	Wheel
# sensors	3	1	1
Separation	High	Average	Good
Cost	High	Low	Average
Framerate	High	High	Low
Artefacts	Low	Aliasing	Motion
Bands	3	3	3 or more
	High-end cameras	Low-end cameras	Scientific applications

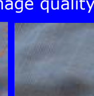
new color CMOS sensor Foveon's X3



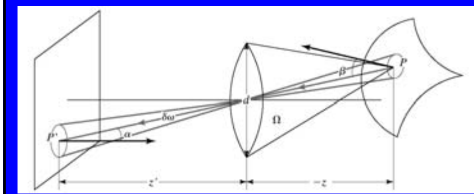
better image quality

smarter pixels





Example: Radiometry of thin lenses



$$\delta\omega = \frac{\delta A' \cos\alpha}{(z'/\cos\alpha)^2} = \frac{\delta A \cos\beta}{(z/\cos\beta)^2}$$

$$\frac{\delta A}{\delta A'} = \frac{\cos\alpha}{\cos\beta}\left(\frac{z}{z'}\right)^2$$

$$\Omega = \frac{\pi}{4}\frac{d^2\cos\alpha}{(z/\cos\alpha)^2} = \frac{\pi}{4}\left(\frac{d}{z}\right)^2 \cos\alpha^3$$

$$\delta P = L\Omega\delta A\cos\beta = \frac{\pi}{4}\left(\frac{d}{z}\right)^2 L\,\delta A\cos^3\alpha\cos\beta$$

$$E = \frac{\delta P}{\delta A'} = \frac{\pi}{4}\left(\frac{d}{z}\right)^2 L\frac{\delta A}{\delta A'}\cos^3\alpha\cos\beta$$

$$E = \left[\frac{\pi}{4}\left(\frac{d}{z}\right)^2 \cos^4\alpha\right] L$$

E: Image irradiance

L: emitted radiance

d : Lens diameter

Z: depth

α: Angle of patch from optical axis