

Radiometry

Computer Vision I
CSE252A
Lecture 5

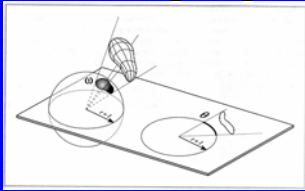
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Radiometry

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

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Measuring Angle



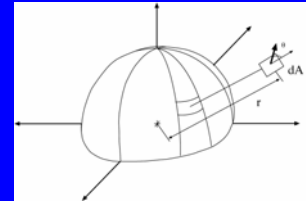
- The solid angle subtended by an object from a point P is the area of the projection of the object onto the unit sphere centered at P.
- Measured in *steradians*, sr
- Definition is analogous to projected angle in 2D
- If I'm at P, and I look out, solid angle tells me how much of my view is filled with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

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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

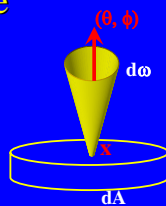
$$d\omega = \frac{dA \cos \theta}{r^2}$$



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Radiance

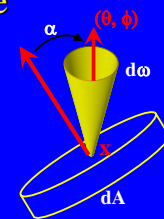
- Power is energy per unit time
- Radiance: Power traveling at some point in a specified direction, per unit area perpendicular to the direction of travel, per unit solid angle
- Symbol: $L(x, \theta, \phi)$
- Units: watts per square meter per steradian : $w/(m^2 \cdot sr)$



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Radiance

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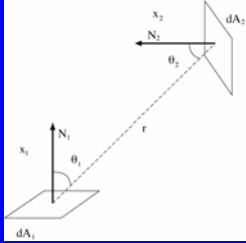
$$L = \frac{P}{(dA \cos \alpha) d\omega}$$

Power emitted from patch, but radiance in direction different from surface normal

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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

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

$$P = L dA_1 \cos \theta_1 d\omega_{1 \rightarrow 2} \\ = \frac{L}{r^2} dA_1 dA_2 \cos \theta_1 \cos \theta_2$$

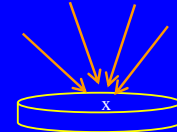
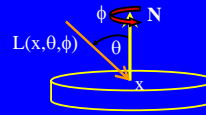
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Irradiance

- How much light is arriving at a surface?
- Units of Irradiance: Watts/m²
- This is a function of incoming angle.
- A surface experiencing radiance $L(x, \theta, \phi)$ coming in from solid angle $d\omega$ experiences **irradiance**:
- Crucial property: Total **Irradiance** arriving at the surface is given by adding irradiance over all incoming angles. Total irradiance is

$$E(x) = \int_{\text{hemisphere}} L(x, \theta, \phi) \cos \theta d\omega \\ = \int_0^{2\pi} \int_0^{\pi/2} L(x, \theta, \phi) \cos \theta \sin \theta d\theta d\phi$$

$$dE(x) = L(x, \theta, \phi) \cos \theta d\omega$$



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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 $C(\cdot)$ may not be linear

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

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Image sensor

Two types :

1. CCD
2. CMOS

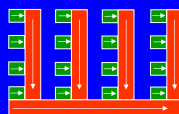
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CCD

separate photo sensor at regular positions
no scanning
charge-coupled devices (CCDs)

:
intertine transfer and frame transfer

- photosensitive
- storage



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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



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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

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Color Cameras

We consider 3 concepts:

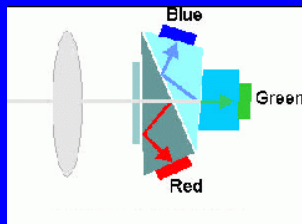
1. Prism (with 3 sensors)
2. Filter mosaic
3. Filter wheel

... and X3

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Prism color camera

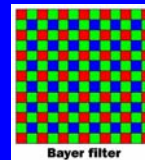
Separate light in 3 beams using dichroic prism
Requires 3 sensors & precise alignment
Good color separation



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Filter mosaic

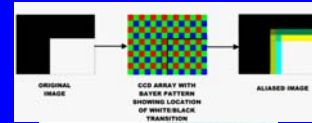
Coat filter directly on sensor



Bayer filter



Demosaicing (obtain full colour & full resolution image)



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Filter wheel

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



Only suitable for static scenes

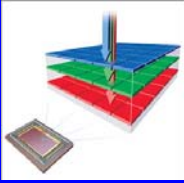
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Prism vs. mosaic vs. wheel

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

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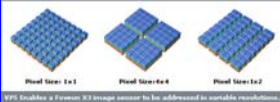
“newer” color CMOS sensor
Foveon’s X3



better image quality



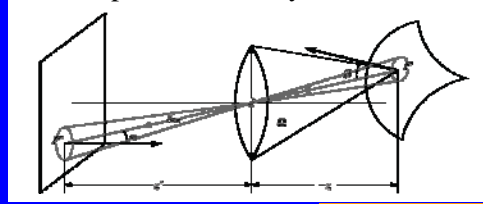
smarter pixels



Pixel Size: 1x1 Pixel Size: 4x4 Pixel Size: 1x2

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Example: Radiometry of thin lenses



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

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

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

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

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

E: Image irradiance

L: emitted radiance

d: Lens diameter

Z: depth

α : Angle of patch from optical axis