Introduction to Computer Vision
CSE 152
Lecture 5
Announcements

• Assignment 1 has been posted
• See links on web page for reading
Coordinate Changes: Rigid Transformations
both translation and rotation

\[ \begin{align*} \mathbf{B} \mathbf{P} &= \mathbf{B} \mathbf{R} \mathbf{A} \mathbf{P} + \mathbf{B} \mathbf{O}_A \end{align*} \]
Rotation

• About \((k_x, k_y, k_z)\), a unit vector on an arbitrary axis (Rodrigues Formula)

\[
\begin{pmatrix}
  x' \\
  y' \\
  z' \\
  1
\end{pmatrix} =
\begin{pmatrix}
  k_x k_x (1-c) + c & k_x k_y (1-c) - k_z s & k_x k_z (1-c) + k_y s & 0 \\
  k_y k_x (1-c) + k_z s & k_y k_y (1-c) + c & k_y k_z (1-c) - k_x s & 0 \\
  k_z k_x (1-c) - k_y s & k_z k_y (1-c) - k_x s & k_z k_z (1-c) + c & 0 \\
  0 & 0 & 0 & 1
\end{pmatrix}
\begin{pmatrix}
  x \\
  y \\
  z \\
  1
\end{pmatrix}
\]

where \( c = \cos \theta \) & \( s = \sin \theta \)
Camera parameters

• Issue
  – camera may not be at the origin, looking down the z-axis
    • extrinsic parameters (Rigid Transformation)
  – one unit in camera coordinates may not be the same as one unit in world coordinates
    • intrinsic parameters - focal length, principal point, aspect ratio, angle between axes, etc.

\[
\begin{bmatrix}
U \\
V \\
W
\end{bmatrix} = \begin{bmatrix}
\text{Transformation representing intrinsic parameters}
\end{bmatrix}\begin{bmatrix}
\text{Transformation representing extrinsic parameters}
\end{bmatrix}
\begin{bmatrix}
X \\
Y \\
Z \\
T
\end{bmatrix}
\]

3 x 3  4 x 4
Camera Calibration

Given $n$ points $P_1, \ldots, P_n$ with known positions and their images $p_1, \ldots, p_n$, estimate intrinsic and extrinsic camera parameters.

- See Text book for how to do it.
Limits for pinhole cameras

2.18 DIFFRACTION LIMITS THE QUALITY OF PINHOLE OPTICS. These three images of a bulb filament were made using pinholes with decreasing size. (A) When the pinhole is relatively large, the image rays are not properly converged, and the image is blurred. (B) Reducing the size of the pinhole improves the focus. (C) Reducing the size of the pinhole further worsens the focus, due to diffraction. From Ruechardt, 1958.
Thin Lens: Image of Point

\[ \frac{1}{z'} - \frac{1}{z} = \frac{1}{f} \]
A price: Whereas the image of $P$ is in focus, the image of $Q$ isn’t.
Deviations from the lens model

Deviations from this ideal are *aberrations*

*Two types*

1. geometrical
   - spherical aberration
   - astigmatism
   - distortion- pin-cushion vs. barrel
   - coma

2. chromatic

Aberrations are reduced by combining lenses

![Compound lenses](image-url)
Radiometry, Lighting, Intensity
Lighting

• Applied lighting can be represented as a function on the 4-D ray space (radiances)

• Special light sources
  – Point sources
  – Distant point sources
  – Strip sources
  – Area sources

• Common to think of lighting at infinity (a function on the sphere, a 2-D space)
Radiance

- Power traveling at some point in a specified direction, per unit area perpendicular to the direction of travel, per unit solid angle.
- Units: watts per square meter per steradian: \( \text{w/(m}^2\text{sr}^1) \)

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

Irradiance

- How much light is arriving at a surface?
- Irradiance -- power per unit area: W/cm\(^2\)
- Total power arriving at the surface is given by adding irradiance over all incoming angles.

\[
\int \int L(x, \theta, \phi) \cos \theta d\omega
\]

\[
= \int \int L(x, \theta, \phi) \cos \theta \sin \theta d\theta d\phi
\]
Camera’s sensor

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

\[
I = \iiint_{t, \lambda, x, y} E(x, y, \lambda, t)s(x, y)q(\lambda) dy dx d\lambda dt
\]
Light at surfaces

Many effects when light strikes a surface -- could be:

• transmitted
  – Skin, glass
• reflected
  – mirror
• scattered
  – milk
• travel along the surface and leave at some other point
• absorbed
  – sweaty skin

Assume that

• surfaces don’t fluoresce
  – e.g. scorpions, detergents
• surfaces don’t emit light (i.e. are cool)
• all the light leaving a point is due to that arriving at that point
BRDF

- Bi-directional Reflectance Distribution Function
  \[ \rho(\theta_{in}, \phi_{in} ; \theta_{out}, \phi_{out}) \]

- Function of
  - Incoming light direction:
    \[ \theta_{in}, \phi_{in} \]
  - Outgoing light direction:
    \[ \theta_{out}, \phi_{out} \]

- Ratio of incident irradiance to emitted radiance
Surface Reflectance Models in Graphics & Vision

Common Models

• Lambertian
• Phong
• Physics-based
  – Diffuse [Hanrahan, Kreuger 1993]
  – Generalized Lambertian [Oren, Nayar 1995]
  – Thoroughly Pitted Surfaces [Koenderink et al 1999]
• Phenomenological [Koenderink, Van Doorn 1996]

Arbitrary Reflectance

• Non-parametric model
• Anisotropic
• Non-uniform over surface
• BRDF Measurement [Dana et al, 1999], [Marschner]
Lambertian Surface

Without shadows

At image location \( (u,v) \), the intensity of a pixel \( x(u,v) \) is:

\[
E(u,v) = [a(u,v) \hat{n}(u,v)] \cdot [s_0\hat{s}]
\]

where

- \( a(u,v) \) is the albedo of the surface projecting to \( (u,v) \).
- \( \mathbf{n}(u,v) \) is the direction of the surface normal.
- \( s_0 \) is the light source intensity.
- \( \hat{s} \) is the direction to the light source.
Specular Reflection: Smooth Surface

Phong – rough, specular
Rough Specular Surface

Symmetric V-shaped grooves – ‘microfacets’

Average surface normal

Phong Lobe
Phong Model

Mirror

Diffuse

CS348B Lecture 10

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Pat Hanrahan, Spring 2002
Shadows cast by a point source

- A point that can’t see the source is in shadow
- For point sources, the geometry is simple
At the top, geometry of a gutter with triangular cross-section; below, predicted radiosity solutions, scaled to lie on top of each other, for different albedos of the geometry. When albedo is close to zero, shading follows a local model; when it is close to one, there are substantial reflexes.
Color Cameras

Eye:
Three types of Cones

Cameras:
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

Demosaicng (obtain full colour & full resolution image)
Filter wheel

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

Only suitable for static scenes
new color CMOS sensor
Foveon’s X3

better image quality

smarter pixels

VPS Enables a Foveon X3 image sensor to be addressed in variable resolutions.
The appearance of colors

• Color appearance is strongly affected by (at least):
  – Spectrum of lighting striking the retina
  – other nearby colors (space)
  – adaptation to previous views (time)
  – “state of mind”
4.1 NEWTON'S SUMMARY DRAWING of his experiments with light. Using a point source of light and a prism, Newton separated sunlight into its fundamental components. By reconverging the rays, he also showed that the decomposition is reversible.
Color Afterimage: South African Flag

opponent colors
Blue -> yellow
Red -> green
Light Spectrum
Talking about colors

1. Spectrum –
   • A positive function over interval 400nm-700nm
   • “Infinite” number of values needed.

2. Names
   • red, harvest gold, cyan, aquamarine, auburn, chestnut
   • A large, discrete set of color names

3. R,G,B values
   • Just 3 numbers