Lecture 5: CS677

Sept 5, 2017

Review

- HW1 due September 12
- Cloud computing: students can get a better personal account at: https://console.cloud.google.com/freetrial?_ga=2.228461851.-722665125.1503520492&page=1
- Previous class
  - Weak-perspective projection
  - Projective geometry (very briefly)
  - Camera calibration
  - Computing brightness of image points
  - Shape from shading (basics)
- Today's objective
  - More on shape from shading
  - Color perception

Shape From Shading

- Can we get 3-D shape from intensity variations?
  - Infer depth or orientation of surface at each point
  - Changes may be due to changes in illumination, reflectivity or surface shape
  - Assuming constant illumination and reflectivity, **N** is still ambiguous
  - We can recover **N.S** but not **N** (is defined on a cone)
- We can get N at occluding contours (perpendicular to viewing direction)
- Can propagate to interior using continuity of surface (*i.e.* direction doesn't change suddenly)
- Book has sketchy details on p.60
- Techniques effective if no inter-reflections, known reflectance function and constant *albedo*.
- Useful in very limited cases

Photometric stereo

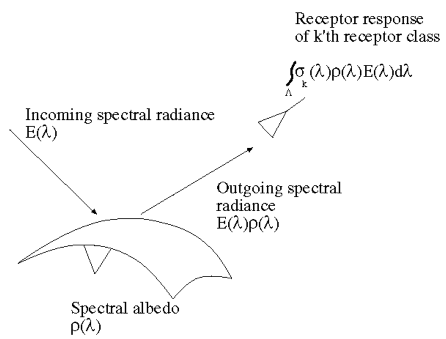
- Assume:
  - A local shading model with set of distant point sources
  - A set of point sources that are infinitely distant
  - A set of images of an object, obtained in exactly the same camera/object configuration but using different sources
  - A Lambertian object (or the specular component has been identified and removed)
- Each image gives one equation for surface normal at each point
  - 2 images can provide a solution with some ambiguity
  - More images provide a unique least mean squared solution
  - Details in the FP book, section 2.2.4
- Hard to control illumination under most conditions
  - Some applications in industrial inspection/manufacturing tasks

Depth Perception from Real Images

- Humans see depth in 2-D images readily
  - Our absolute distance perception is not accurate but relative accuracy is very high; shapes are not distorted
- Believe humans use many “cues” that include shading, texture gradients, contours…
  - Known methods depend on many simplifying assumptions which are not valid in images of common scenes
- Research topic had been dormant for some time but modern machine learning techniques are starting to show promise
  - We will study these towards end of course if time permits

Color Perception

- Measured color is given by the spectral distribution of illumination, the spectral reflectance function and spectral sensor response

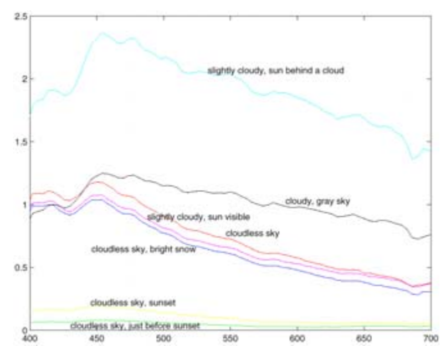


Color

- Color is defined by distribution of energy in different wavelengths in the light spectrum
- Measured image responses are from integrated product of illumination, reflection and sensor responses
- Daylight: distribution changes with time and weather
  - Fig. 3.1
- Artificial light distribution is different from sunlight
  - Fig 3.4
- Objects have different spectral albedo
  - Fig. 3.6
- Sensor responses
  - Fig. 3.3

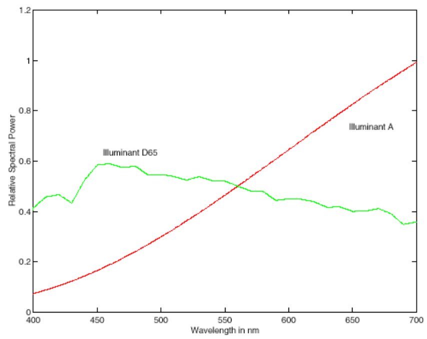
Illumination Color: natural light

- Fig. 3.1



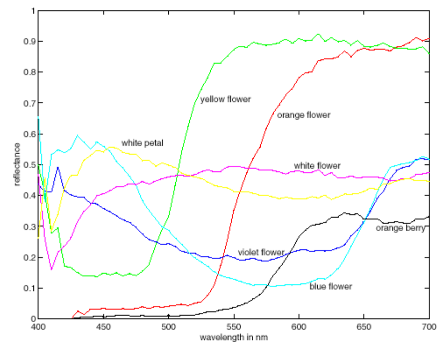
Illumination Color: Artificial light

Fig 3.4



Object Color: examples

- Fig. 3.6

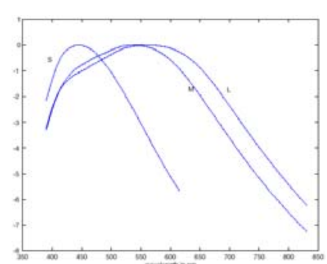


Sensors

- Cameras/eyes sensors rarely receive light of a single wavelength only (exception: laser light)
- Cameras/eyes do not have ability to measure intensity in narrow wavelength bands (they are not spectrometers found in a Physics lab)
- Instead, sensors integrate light in broad wavelength ranges
  - A monochromatic (grey level, b/w) camera has only one sensor type
  - Color images typically have 3 types of sensors

Typical Sensor Response

- Fig. 3.2



Trichromacy

- Human visual system has only three types of sensors
  - We do not compute *spectrogram* of the incoming light
  - Color cameras typically have sensors with similar responses
- Lack of spectral resolution can cause different spectral distributions to give the same color measurements
  - Yellow - Blue = Green, even though this G is not what we would get by adding/subtracting the Y, B light frequencies
- Visible colors can be synthesized by a linear combination of three *primary* colors
  - Additive for TV, subtractive for paint, print
  - Artifact of our sensory system
  - Two primaries work well for most colors, also some humans are bichromatic (limited color blindness)

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Representation of Color

- Measurements are in form of a 3-D vector; (R, G, B) values
  - Primaries are standardized, others could be used
- Many **linear** transformations used for different purposes
  - CMY (Cyan, Magenta, Yellow) is designed for *subtractive* applications, *e.g.* printers
  - YUV for digital video (DVD)
    - Y = .3 *R +.59*G + .11* B (luminance)
    - U = .4936 *(B - Y)
    - V= .877 *(R - Y)
    - Provides better compression results

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Human Color Perception

- Hue, Saturation Value (H, S, V)
  - V is *value* or brightness (same as Y value in YIQ system)
  - Hue: property that separates red from green, for example
  - Saturation: mixture of white light to colored light
  - (*hue, sat*) define the chromaticity space
- Fig. 3.13 shows transformation from R,G,B to H,S,V
  - Project an RGB point on plane perpendicular to cube diagonal to get *hue* and *saturation* values; define value such that all points in the same perpendicular plane have the same *value*
  - *Non-linear* transformation, formula not given but easily derived from the figure
  - Slightly different definitions of (*h,s,v*) exist in literature
    - http://en.wikipedia.org/wiki/HSV_color_space

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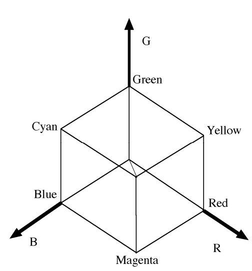
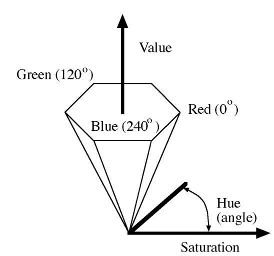
HSV hexcone





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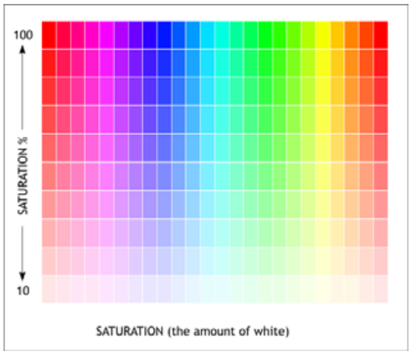
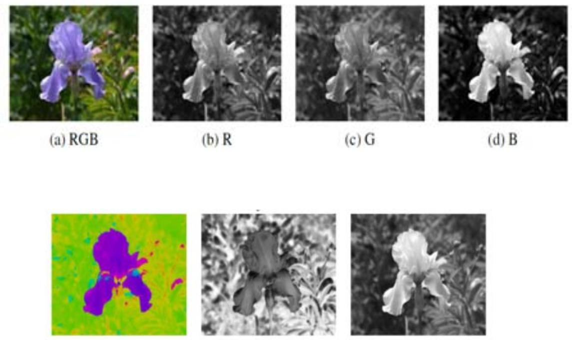
Hue and Saturation



From http://www.xaraxone.com/webxealot/workbook40/saturation_01.gif

HSV: Example Fig 2.32 RS Book



(a) RGB (b) R (c) G (d) B

(l) H (m) S (n) V

CIE LAB Space

- Desirable that same small distances in the color space correspond to the same (similar) perceptual differences, regardless of the absolute positions of the points in the space
- CIE (*Commission internationale de l'éclairage*,) L,a,b transformation, determined empirically, seems to be a good approximation
- First we apply a linear transformation to convert RGB to CIEXYZ
  - $$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950227 \end{bmatrix} * \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$
- From CIEXYZ to CIELAB

$$L^* = 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16$$

$$a^* = 500\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right]$$

$$b^* = 200\left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]$$

Here X_n, Y_n, and Z_n are the X, Y, and Z coordinates of a reference white patch.

Uses of Color

- Spectral albedo is characteristic of surface properties
  - Helps in segmentation as different surfaces are expected to have different “colors”
  - Helps distinguish material properties
    - Ripe *vs* raw fruit
    - Slippery *vs* dry ground conditions
    - …..
- To be effective for these tasks, we need to be able to infer surface spectral *albedo* even though the measurements combine color of illumination, surface and sensor responses (the last one could be calibrated).

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Estimating Illumination Color

- Gray world assumption
  - On the average, world is gray (no single color dominates)
  - Take average values in each channel (R,G,B) to represent illumination color (normalize to unit vector)
- White patch estimation
  - Assumes that brightest patch in image is “white” (achromatic)
  - Color is due to color of illumination
- Statistics of natural scenes
- …

Next Topics

- We are finished with image formation
- Next major topics of interest
  - Inference of 3-D
    - Single Images (difficult)
    - From multiple views
    - From direct range sensing
  - Detection and recognition of objects
- Image feature extraction and segmentation
  - Useful for both of the above topics
  - This is what we will study next

Next Class

- FP: Sections 4.1 and 9.3