Color Spaces and Evaluation Metrics

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Color Spectrum

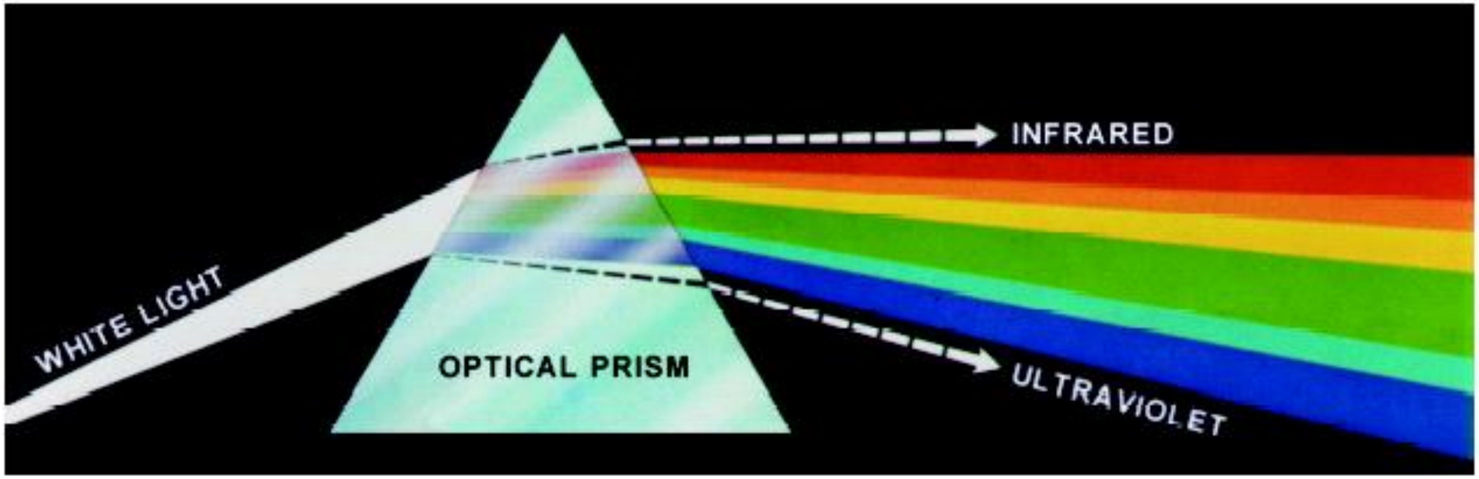


FIGURE 6.1 Color spectrum seen by passing white light through a prism. (Courtesy of the General Electric Co., Lamp Business Division.)

Wavelengths of the Electromagnetic Spectrum

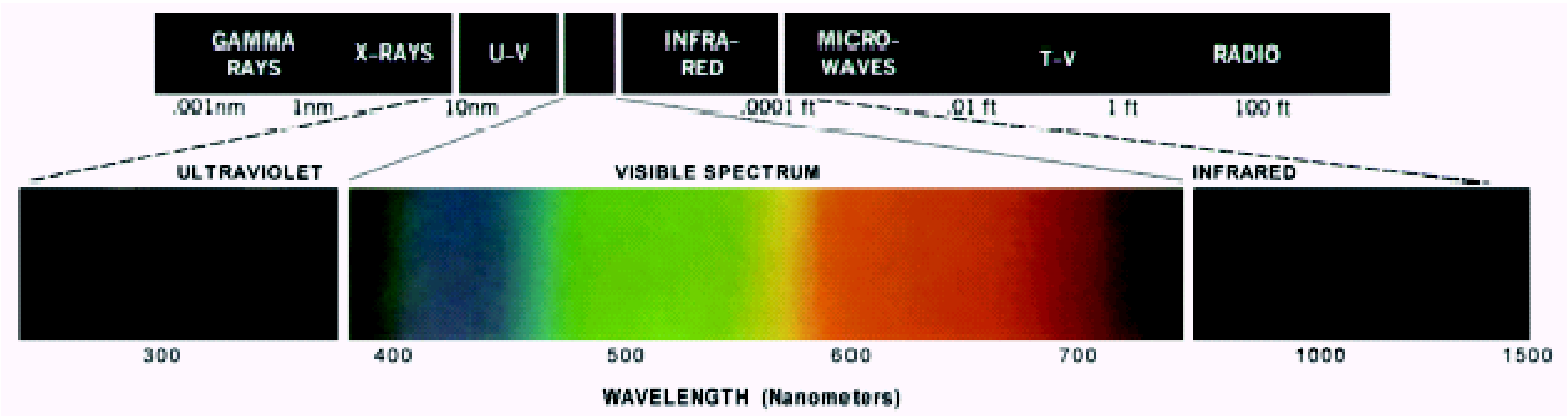


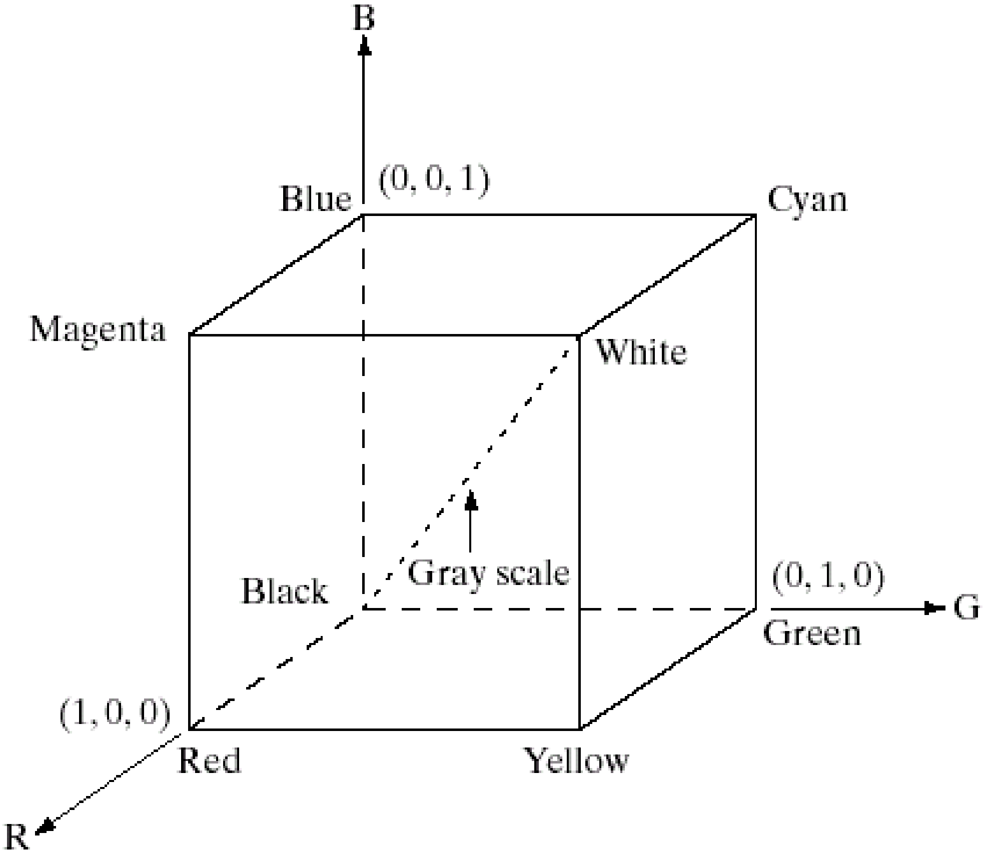
FIGURE 6.2 Wavelengths comprising the visible range of the electromagnetic spectrum. (Courtesy of the General Electric Co., Lamp Business Division.)

Grassman's First Law of Additive Color Mixture

- Any color can be matched by a linear combination of three other colors (primaries, e.g. RGB), provided that none of those three can be matched by a combination of the other two.
- $C = Rc(R) + Gc(G) + Bc(B)$

RGB Color Space

FIGURE 6.7
Schematic of the RGB color cube. Points along the main diagonal have gray values, from black at the origin to white at point (1, 1, 1).



CMY and CMYB Space

- [C M Y] = [1 1 1] – [R G B]
- Cyan, Magenta and Yellow
- But mixing these three colors can not produce black!

The Luminance of a Color

- The luminance of a color with coordinates (R,G,B) in the CIE-RGB system is given

  $L(C)=0.176R+0.81G+0.011B$

Problems with RGB

- Can only a small range of all the colors humans are capable of perceiving (particularly for monitor RGB)
  - Have you ever seen magenta on a monitor?
- It isn't easy for humans to say how much of RGB to use to make a given color
  - How much R, G and B is there in "brown"? (Answer: .64,.16, .16)
- Perceptually non-linear
  - Two points a certain distance apart in one part of the space may be perceptually different
  - Two other points, the same distance apart in another part of the space, may be perceptually the same

Image Fidelity Criteria

- Subjective measures
  - Examination by human subjects
  - Goodness scale: excellent, good, poor, unsatisfactory
  - Impairment scale: unnoticeable, just noticeable, …
  - Comparative measures
    - With another image or among a group of images
- Objective measures
  - Mean square error and variations
  - Advantage: simple, less dependent on human subjects, & easy to handle mathematically
  - Disadvantage: not always reflect human perception.

Mean-square Criterion

- Average (or sum) of squared difference of pixel luminance between two images

$$\varepsilon_1 = E\{|u - u'|^2\} \quad \text{(mean square error)}$$

$$\varepsilon_2 = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}|u(m,n) - u'(m,n)|^2 \quad \text{(average square error)}$$

$$\varepsilon_3 = \frac{1}{MN}\sum_{m=1}^{M}\sum_{n=1}^{N}E\{|u(m,n) - u'(m,n)|^2\} \quad \text{(average mean square error)}$$

- Signal-to-noise ratio (SNR)
  - SNR= $10\log_{10}(\sigma_s^2 / \sigma_e^2)$ in unit of decibel (dB)
  - σ_s^2 is image variance, σ_e^2 variance of error
  - PSNR= $10\log_{10}(A^2 / \sigma_e^2)$ with A being peak-to-peak value

Structure Similarity Index Measure (SSIM) [2]

- For image quality assessment, it is useful to apply the SSIM index *locally* rather than globally.
  - Image statistical features are usually highly spatially **non-stationary**.
  - Image distortions may also be **space-variant**.
  - Because of the fovea feature of the HVS, at typical viewing distances, only **a local area in the image can be perceived with high resolution** by the human observer at one time instance.
  - Localized quality measurement can provide a spatially varying quality map of the image, which delivers more information about the quality degradation of the image and may be useful in some applications.

Structure Similarity Index Measure (SSIM) [2]

- In this paper, the authors use an 11×11 circular-symmetric Gaussian weighting function **w** = {w_i| i = 1, 2, …, N}, with standard deviation of 1.5 samples, normalized to unit sum ($\sum_{i=1}^{N} w_i = 1$)

$$\mu_x = \sum_{i=1}^{N} w_i x_i$$

$$\sigma_x = \left(\sum_{i=1}^{N} w_i (x_i - \mu_x)^2\right)^{\frac{1}{2}}$$

$$\sigma_{xy} = \sum_{i=1}^{N} w_i (x_i - \mu_x)(y_i - \mu_y)$$

Structure Similarity Index Measure (SSIM) [2]

- The basic idea of SSIM is to separate the task of similarity measurement into three comparisons: ***luminance***, ***contrast*** and ***structure***
  - The luminance comparison function
    $$l(x, y) = \frac{2\mu_x \mu_y + k_1}{\mu_x^2 + \mu_y^2 + k_1}$$
  - The contrast comparison function
    $$c(x, y) = \frac{2\sigma_x \sigma_y + k_2}{\sigma_x^2 + \sigma_y^2 + k_2}$$
  - The structure similarity
    $$s(x, y) = \frac{\sigma_{xy} + k_3}{\sigma_x \sigma_y + k_3}$$

- The estimation is using a local weighted window, e.g., a Gaussian window, SSIM(x, y) = $l(x, y) \cdot c(x, y) \cdot \mathrm{s}(x, y)$

References

- [1] http://web.mit.edu/abyrne/www/ColorRealism.html
- [2] Z. Wang, A.C. Bovik, H.R. Sheikh, and E. P. Simoncelli, "Image quality assessment: from error visibility to structural similarity," IEEE Trans. On Image Processing, 13(4):600-612, 2004.

Thank You!

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